Optimization of controller frequency in wind-turbine based on hybrid PSO-ANFIS

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Abstract. The variable speed wind turbine field has grown rapidly in recent years. If the low wind speed was below the average value, the speed controller must be able to adjust the rotor speed to maintain the speed in order to provide maximum power coefficient, turbine efficiency will increase. The Pitch angle control was one way to adjust the aerodynamic torque in the wind turbine so that the wind turbine power output is constant. In this paper, methods without control, PID, PID-PSO, and PID-PSO-ANFIS controls are compared for pitch angle control. The research results showed that the lowest average active power and unstable active power in the uncontrolled model was 0.3305 Watt with a frequency of 10 m$^{-1}$ s$^{-1}$, and the largest was the PID-PSO-ANFIS model with an active power of 2.282 Watt with a frequency of 180 m$^{-1}$ s$^{-1}$. PID-PSO-ANFIS model is the best model in this study and can be proposed to be applied to higher systems.

Keywords: ANFIS, PSO, PID, wind turbine

1. Introduction
As technology advances and increases in population, the need for electricity will also increase. As a result, the electricity load will increase too. With the increase in electricity load, electricity supply to consumers is also affected. As a result, if the electricity supply increases, it will cause the output power released by the generator to also increase. An increase in generator output power can be done by adding renewable energy. Some renewable energy that can be used was a wind turbine and photovoltaic [1,2]. Permanent Magnet Synchronous Generator (PMSG) was a synchronous generator that had a permanent magnet [3]. PMSG be coupled with the wind turbine to produce electrical energy so that the PMSG can reduce expensive expenses. PMSG has a less efficient efficiency to generate electric power because is affected by wind speed and pitch angle [4]. Therefore, the PMSG needs to be controlled to produce optimal electric power. PMSG was a synchronous generator that has a permanent magnet. PMSG will be coupled with the turbine to
produce electrical energy [5]. PMSG has a suboptimal efficiency for producing electric power [6,7].

Artificial Intelligence (AI) is often used in the development of various sciences including vehicle steering control [8,9], wind turbine blade control [5], micro-hydro control [10], and DC motor speed control [11]. Among them also use the method of particle swarm optimization (PSO) [12,13], and ant colony optimization (ACO) [14,15]. So in this study, the intelligence method for PSO and ANFIS was used.

Figure 1. Characteristics of wind turbine [5]

Aerodynamic wind turbine can convert wind energy into kinetic energy which will be used to operate an electric generator (equation 1).

\[ U = \frac{1}{2}(\rho Ax)V^2 \]  

where:

\begin{align*}
U & = \text{kinetic energy (joule)} \\
\rho & = \text{air intensity (kg m}^{-3}\text{)} \\
A & = \text{cross-sectional area (m}^2\text{)} \\
x & = \text{cross-sectional thickness (m)} \\
V & = \text{wind speed (m/s)}
\end{align*}

A strength of the wind \( P_w \) is a derivative of kinetic energy (equation 2).

\[ P_w = \frac{1}{2}\rho AV^3 \]  

The mechanical power and torque are then transformed (equation 3 and 4).

\begin{align*}
P_r &= P_wC_p = \frac{1}{2}C_p(\beta , \gamma )\rho \pi R^2V^3 \\
T_r &= \frac{1}{2}C_T(\beta , \lambda )\rho \pi R^3V^2
\end{align*}
Value of $C_p$ value is nonlinear and varies, influenced by wind speed, turbine rotation speed, turbine blade parameters and pitch angle. This is limited by the Betz limit (59%).

$$\lambda = \frac{\omega R}{V}$$  \hspace{1cm} (5)

Where:

- $\lambda$ = speed ratio
- $\omega R$ = ratio between the square speed of the turbine end
- $V$ = wind speed
- $C_p(\lambda, \beta) = \lambda C_t(\lambda, \beta)$  \hspace{1cm} (6)

The coefficient $C_t$ is a nonlinear function of the ratio of tip velocity, and blade pitch angle $\beta$ [7]. The operating characteristics of the variable-pitch wind turbine speed can be illustrated from the power curve, which gives an estimate of the power output in a function of wind speed (Figure 1).

A wind turbine operating area consists of three different points, namely the cut-out wind speed, the cut-in wind speed, and the rated wind speed, and. The cut-in wind speed is the lowest wind speed at which the wind turbine starts generating electricity. The rated wind speed is the wind speed at which the wind turbine produces maximum electric power. The cut-out wind speed is the speed of the wind that can stop and shut down a wind turbine to protect it from mechanical damage.

2. Method

2.1. PID controller

In the PID method, tuning is performed on the parameters $K_p$, $K_d$, and $K_i$ in a closed loop where the reference is the step function [16-18]. In this paper, the tuning of $K_p$, $K_d$, and $K_i$ was performed using the PSO-ANFIS hybrid method.

2.2. Particle swarm optimization (PSO)

![Figure 2. PSO algorithm [10]](image-url)
PSO is an algorithm of the behavior of birds and fish to find food [19]. In the PSO algorithm, the best food position represents the optimal value sought. While the bird / fish population and individual bird / fish are swarms and particles, respectively. When a particle finds its best position, other particles will move closer to the particle [6]. The PSO control flow chart is shown in Figure 4.

2.3. **Adaptive neuro fuzzy inference system (ANFIS)**
Adaptive neuro fuzzy inference system (ANFIS) is a combination of the Fuzzy Inference System (FIS) mechanism described in the neural network architecture. The FIS used was the first order Tagaki-Sugeno-Kang (TSK). To explain the ANFIS architecture, it is assumed that the FIS has two inputs, x and y, and one output z. In the first-order Sugeno model, the rule set uses a linear combination of existing inputs, can be expressed as follows: If x is B1 and y is A1 then f1 = p1x + q1y + r1, If x is B2 and y is A2 then f2 = q2x + p2y + r2. The structure is depicted in a block circle or called neural network architecture as can be seen in Figure 3.

![Figure 3. ANFIS structure](image)

3. **Result and discussion**

3.1 **Wind turbine model**
Wind power plant converts wind energy into electricity using wind turbines. Wind energy that rotates the wind turbine, continues to rotate the rotor on the generator so that it will produce electrical energy. This electrical energy will be stored in the battery before it can be used as a wind power plant (Wind-Turbine). Technically, Wind Turbine has three main components namely wind, turbine, and generator. Torque and wind turbine rotation settings can be modelled (Figure 4 and Figure 5).
Figure 4. Modeling PID controller on wind turbine

Figure 5. ANFIS modeling on wind turbine
3.2 PID parameters on wind turbine
By entering the parameters and running program in the wind-diesel hybrid generator plant, the PID parameters value obtained for each model. Kp, Ki, and Kd parameters on PID can be shown in Table 1.

| PID   | PID-PSO |
|-------|---------|
| Kp    | 1       | 0       |
| Ki    | 1       | 6.654   |
| Kd    | 0       | 0       |

3.3 Wind turbine response
Figure 6 shows the average active power at the smallest and unstable uncontrolled, which is 0.3305 Watt with 10 m^{-1}s^{-1}, for PID shows 1.4984 Watt with 20 m^{-1}s^{-1}, for the PID-PSO model shows 2.16 Watt with 180 m^{-1}s^{-1}, for the PID-PSO-ANFIS model shows 2.282 Watt with 180 m^{-1}s^{-1}.

Figure 7 shows the average reactive power of the uncontrolled model is the largest and unstable, that is -14.31 Var with 10 m^{-1}s^{-1}, for PID it shows -1.5798 Var with 20 m^{-1}s^{-1}, for the PID-PSO model that is -0.1821 Var with 180 m^{-1}s^{-1}, for the PID-PSO-ANFIS model that is -0.1931 Var with 180 m^{-1}s^{-1}.

![Figure 6. The active power](image-url)
Figure 7. The reactive power (Var) in wind turbine

Figure 8. The output voltage

Figure 8 shows that the maximum current of the uncontrolled model is the smallest and unstable i.e. 0.1807 A with 10 m$^{-1}$ s$^{-1}$, PID shows the current 0.7155 A with 20 m$^{-1}$ s$^{-1}$, the PID-PSO model is 3.184 A with 180 m$^{-1}$ s$^{-1}$, the model PID-PSO-ANFIS is 3.362 A with 180 m$^{-1}$ s$^{-1}$. The output current can be seen in Figure 9. It shows that the maximum current uncontrolled model is the smallest and unstable, i.e. 0.1807 A with 10 m$^{-1}$ s$^{-1}$, PID shows the current 0.7155 A with 20 m$^{-1}$ s$^{-1}$,
The PID-PSO model is 3.172 A with 180 m/s, the model PID-PSO-ANFIS is 3.263A with 180 m/s. The output of the generator consists of; Rotor speed “wm” (rad/s) and stator current (A, B, C) can be seen in Figure 10. Figure 10 shows that generated power in the uncontrolled model is the smallest and unstable, and the PID-PSO-ANFIS model is the best.

![Figure 9. The output current](image9)

![Figure 10. Generator output results](image10)
4. Conclusion
The comparison of the four (4) control models shows that the PID-PSO-ANFIS is the best model with an active power of 2.282 Watts with an active power of 180 m\(^2\)s\(^{-1}\), reactive power of -0.1391 Var with a frequency of 180 m\(^{-1}\)s\(^{-1}\), and the generator output is the most stable compared to other controls.

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