Controllable and observable control design of wind generator system using PID algorithm

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Abstract. This paper describes a design process of the wind generator control system. Controlling a wind generator, fan, is important to study the design of the wind turbine. A complex wind generator model was approximated with 5th order polynomial function. The paper describes a procedure for identifying system, especially for finding the transfer function of a plant, that based on input and output. The plant’s input is an electric motor fan voltage and output is wind speed produced. It’s important to simplify control’s design of the wind generator for configuring transfer functions of the plant. The identification method that is used is Linear Regression, applying Excel program, which produces a polynomial function. And then, the Matlab’s System Identification Toolbox (SIT), which produces a transfer function. From this study, applying SIT, a model of wind generator, shows the fit estimation data is 90.78% and MSE is 0.078%. A closed-loop control system using PID controller is proposed. Controllable and Observable of the state space model were verified. The best performance of the close-loop system was achieved using $K_p=0.2247$, $K_i=6.05\times10^{-5}$, and $K_d=208.75$ applying Ziegler-Nichols. The results showed that the closed loop stability by applying PID can stabilize the wind generator.

1. Introduction

The rapid increasing of the global population can be increasing the energy consumption in various sectors. In addition, it produces energy production made from fossil fuels that can increase air, soil and air pollution [1,2]. The discovery of new energy sources must be found soon, one of which is the use of wind energy for the development of pollution-free renewable energy [3]. While in terms of the high potential wind speed in Indonesia; especially, in Java, it has range from 2 m/s to 13 m/s [4]. Based on these wind speed characteristics, Indonesia is suitable for using small (10kW) and medium (10-100kW) wind power plants [5]. Furthermore, to find the best performance, the best efficiency of the wind turbine, and the lowest cost of making process an empirical wind turbine simulation for the prototype, before implementing the real size technology.

Simulation on wind tunnel has been used for obtaining required data for making the wind turbine. The wind tunnel is as a research supporting tool to log data and analyze the effect of wind flow toward a specific vertical axis wind turbine. In designing wind tunnel, the performance of wind generator, fan, is crucial. Related to wind speed, where wind speed has fluctuating properties, so that, the wind power produced also fluctuating. Therefore, it is necessary to control the wind speed produced by wind
generators using the PID method. The PID algorithm is flexibility of the controller make it possible in many situations and the controller can be used in other controller configurations [6].

Figure 1. Block diagram control system [6].

This paper describes the method to estimate the parameter identification of the wind generator model based on input and output of the system by using System Identification Toolbox (SIT) from Matlab package. The obtained parameters represent the model of the wind generator, therefore, the performance of the proposed PID algorithm can be verified. The block diagram of the closed-loop system is shown in figure 1.

2. Wind generator modelling
Model of the system is obtained by means of input and output process signals. First, the voltage data of the wind generator as an input data and the wind speed as an output data using anemometer are collected. And then, measure wind speed in the various voltage of the wind generator, in this step wait the output until steady state. In process analysis, there is a lack of possibility to access certain parts of the examined system, because the structure of the system is not known or the knowledge of mathematical model. In this research wind generator, fan, has specification that is induction motor 1 phase with 1.500 power consumption.

2.1. Parameter identification based on excel program
Linear regression was used to find the parameters of the wind generator representation. The wind generator representation was estimated to be in the polynomial form as expressed 5th order (n=5) as follows [7]:

\[ y = m_nx^n + m_{n-1}x^{n-1} + \cdots + m_1x + b \]  \hspace{1cm} (1)

The obtained 5th order polynomial equation parameters is shown in figure 2.

Figure 2. Result from linear regression process.
2.2. Parameter identification based on Matlab
Parameter identification can be calculated by using System identification toolbox (SIT). SIT is a tool for creating mathematical models, and is based on collecting input/output data of the system. By using SIT to obtain the model of wind generator is faster and simpler than using conventional methods [8].

![](image1.png)

**Figure 3.** (a) Import data on SIT; (b) Plant identification process.

In the Figure 3 (a), shows a graphical interface of the SIT. On the left set of graphical interface is a space for entering imported data and in the right side is result of the model; Figure 3 (b) shows the process of calculating input and output to find the best transfer function. The resulted transfer function of the Wind Generator is described as:

\[ G(s) = \frac{6.4 \, e^{-5} \, s^2 + 1.727 \, e^{-6} \, s + 7.865 \, e^{-7}}{s^5 + 0.2347 \, s^4 + 0.07546 \, s^3 + 0.009064 \, s^2 + 0.0001093 \, s + 1.288 \, e^{-5}} \]

The accuracy of the resulted transfer function was measured to be 90.78% and the MSE was obtained to be 0.078%.

2.3. Plotting Pole and Zeros
The poles and zeros of the wind generator model is shown in Figure 4, where the poles of the system are indicated in the plot by ‘X’ while the zeros are indicated by ‘O’. It can be seen that the generator model is a stable system. The requirements of system are stable, if the pole and zeros are on the left side of the centre line of the stability curve [9].

![](image2.png)

**Figure 4.** Pole and Zeros of model parameters.
2.4. Check controllable and observable

By knowing a system has controllable and observable properties, it can be ascertained that the system can be controlled and further observed. To find out these properties, the thing that needs to be done is to change the model of the wind generator to the state space model. This can be done by using the following command [10,11]:

\[
[A B C D] = tf2ss(num, den)
\]

\[
A =
\begin{bmatrix}
-0.2347 & -0.0755 & -0.0091 & -0.0001 & -0.0000 \\
1.0000 & 0 & 0 & 0 & 0 \\
0 & 1.0000 & 0 & 0 & 0 \\
0 & 0 & 1.0000 & 0 & 0 \\
0 & 0 & 0 & 1.0000 & 0
\end{bmatrix}
\]

\[
MatA = A
\]

\[
B =
\begin{bmatrix}
1 \\
0 \\
0 \\
0 \\
0
\end{bmatrix}
\]

\[
MatB = B
\]

\[
C =
\begin{bmatrix}
1.0 e^{-4} \\
0 \\
0.64 \\
0.0173 \\
0.0079
\end{bmatrix}
\]

\[
MatC = C
\]

\[
D =
\begin{bmatrix}
0 \\
0 \\
0 \\
0 \\
0
\end{bmatrix}
\]

\[
MatD = D
\]

For finding controllable matrix, can be done by following command: \( Qc = ctrb(MatA, MatB) \).

The wind generator model is controllable if \( Qc \) has same rank \( MatA \) [12].

\[
Qc =
\begin{bmatrix}
1.0000 & -0.2347 & -0.0204 & 0.0134 & 0.0004 \\
0 & 1.0000 & -0.2347 & -0.0204 & 0.0134 \\
0 & 0 & 1.0000 & -0.2347 & -0.0204 \\
0 & 0 & 0 & 1.0000 & -0.2347 \\
0 & 0 & 0 & 0 & 1.0000
\end{bmatrix}
\]

For finding observable matrix, can be done by following command: \( Qb = obsv(MatA, MatC) \).

The wind generator model is observable if \( Qb \) has same rank \( MatA \).

\[
Qb =
\begin{bmatrix}
0 & 0 & 0.64 & 0.0173 & 0.0079 \\
0 & 0.64 & 0.0173 & 0.0079 & 0 \\
0.64 & 0.0173 & 0.0079 & 0 & 0 \\
-0.1329 & -0.0404 & -0.0058 & -0.0001 & -0.0000 \\
-0.0092 & 0.0042 & 0.0011 & 0.0000 & 0.0000
\end{bmatrix}
\]

3. Design PID algorithm

In order to improve performance of control system, so this paper focuses to implementing a PID algorithm to control speed of wind generator. The following is the transfer function that will be used to making controller:
\[ u = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{de(t)}{dt} \] (2)

The proportional-integral-derivative (PID) controller, where \( K_p, K_i, \) and \( K_d \) are controller parameters to be selected, often by trial and error or by the use of a lookup table in industry practice. The goal, as in the cruise control example, is to drive the error to zero in a desirable manner. All three terms Eq. (2) have explicit physical meanings in that \( e \) is the current error, \( \int e \) is the accumulated error, and represents the trend. This, together with the basic understanding of the causal relationship between the control signal \( (u) \) and the output \( (y) \), forms the basis for engineers to “tune,” or adjust, the controller parameters to meet the design specifications [13].

4. Simulation of the PID algorithm
Simulation PID algorithm for control speed of the wind generator using SIMULINK on Matlab as shown in figure 6, where the input as unit step.

![Figure 5. PID algorithm in SIMULINK.](image)

5. Results and discussion
To evaluate the performance of the system, a series of the simulation of the plant has been accomplished. Figure 6(a), as shown respond of the plant without controller and Figure 6(b), as shown the respond of the system with PID controller based on reference input step response.

![Figure 6. Simulation result for PID algorithm.](image)

Result from this simulation shown that \( K_p \) is 0.2247, \( K_i \) is 6.05*10^{-5}, and \( K_d \) is 208.75. And the overshoot is 1.873\%, and rise time is 10.726 s.

6. Conclusion
This paper presents the method to approach parameter identification wind generator model based on input and output of the system by using System Identification Toolbox (SIT) from Matlab package. And
then presents simulation results of PID control algorithm for control speed of wind generator. The value of fit estimation from SIT is 90.78% and MSE is 0.078%. the system has been proven to be observable and controlled. The best performance was achieved using PID algorithm.

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