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Speed controller of wind turbine emulator using variable speed drive based on PI method

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Abstract. The wind turbine system as a power plant is growing rapidly in line with the electrical energy needs and limitations of fossil energy as a source of electrical energy. Many research has been carried out to develop wind turbine systems and improve system efficiency. Research on wind turbine systems requires wind turbine emulators to simulate the behaviour of wind turbines against changes in wind speed. In this paper presents a design of speed controller based on PI controller for a Wind Turbine Emulator (WTE) using a Variable Speed Drive (VSD). WTE consists of VSD, microcontroller, 3 phase induction motor, Permanent Magnet Synchronous Generator (PMSG) and speed sensor. PMSG speed depends on wind speed. At certain wind speeds, PMSG will rotate at a certain value. WTE will adjust the speed of the induction motor according to a certain wind speed to drive PMSG. Motor and PMSG rotation speed are measured by rotary encoder sensor as speed sensor and feedback for WTE. Proportional-integral method is used to control the speed of a 3 phase induction motor through VSD analogue input. Based on experiment result, PI controller can adjust speed of induction motor so that PMSG will rotate according to a certain wind speed. WTE with PI controller controls the speed of induction motor at settling time 9s to simulate wind speed through PMSG speed controlling.

1. Introduction

Electrical energy derived from renewable energy has become an important issue in the last few decades. Especially in wind energy, this energy has become a very important issue to be developed. Many research has been carried out to develop wind turbine systems and improve system efficiency. Research on wind turbine systems requires wind turbine emulators to simulate the behavior of wind turbines against changes in wind speed. The wind turbine emulator (WTE) functions to simulate the behavior of the wind turbine against changes in wind speed. WTE are very important equipment to simulate wind turbines in hardware. Many researchers have been build WTE for theirs's research in laboratory scale.

Chen uses an AC drive inverter and permanent magnet synchronous motor (PMSM) as a wind turbine emulator to facilitate experiments in the laboratory [1]. Whereas Hui uses induction motors and motor drivers to simulate wind turbines in laboratory scale experiments [2]. Another study was conducted by L. Benaaouinate using an induction motor with field oriented control [3]. Also in earlier studies the use of electric drive wind turbine emulators for simulating the torque of a wind turbine is reported [4-12].

In this study, using a three-phase induction motor driven by variable speed drives (VSD) which will regulate the motor torque to drive the generator so that it will rotate according to the real speed at certain wind speed. Relationship between PMSG and wind speed was obtained by measurement in field. The higher wind speed will produce the bigger generator speed. The speed controlling of three-phase induction motor uses PI controller that is embedded on microcontroller to adjust variable speed drive (VSD) through analog input. Ziegler Nichols method is used to define PI controller parameter. Rotary encoder is used to measure induction motor speed and it gives feedback to PI controller.

2. Method

The wind turbine emulator must be able to move the generator at a certain speed to support certain wind speeds as well, so that the induction motor speed control is needed to drive the generator. Block diagram of the wind turbine emulator in this study as studied in the figure below.

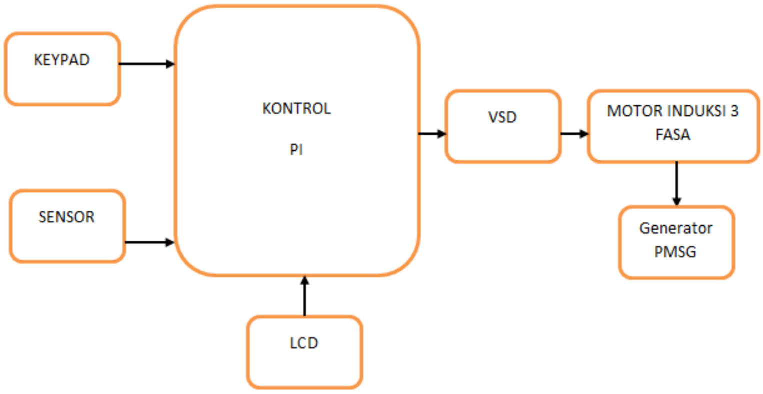

Figure 1. Wind turbine emulator block diagram.

WTE uses a microcontroller board as its control center. The PI method algorithm is implemented on the microcontroller board. The controller input is a keypad to enter the set point from induction motor speed. The controller output is a 0-10 volt as analog signal reference which is used as a VSD input. Furthermore, VSD will drive a three-phase induction motor based on the input voltage of the controller. Three phase induction motor is coupled with PMSG on the shaft. The speed of a three-phase induction motor is measured with a speed sensor. The speed of this three-phase induction motor represents wind speed. Wind speed simulation can be changed by the changing of the VSD speed set point. Specification of three-phase induction motor as shown in Table 1.

Table 1. Three-phase induction motor specification.

Motor characteristics	**Data**
Rated voltage (V)	220
Rated frequency (Hz)	50
Rated power input (W)	1100
Rated current (A)	4,9
Degree of Protection (IP)	55

2.1. Speed sensor design

Rotary encoder sensor is used to sensing the speed of a 3-phase induction motor by producing a variable pulse voltage which is connected to the microcontroller input. The variable pulse voltage of the rotary encoder output is affected by the speed of the 3-phase induction motor, where the faster the motor rotates, the more pulse voltage released towards the microcontroller. This rotary encoder module is connected to the microcontroller on port D2 (INT 0).

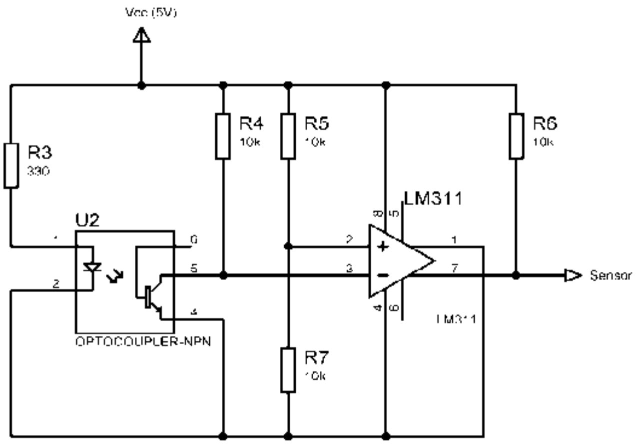

Figure 2. Rotary encoder circuit.

Rotary encoder sensor is a circuit-module in which there is an LED as a transmitter and a phototransistor as a light receiver. The two components are mounted face to face in one place and separated by a disc (rotary disc). Rotary disc is circular in shape and there are holes with no holes in the edges. The perforated part is intended to transmit the light emitted by the transmitter to be received by the receiver, and the non-hollow part is intended to block the light. Rotary encoder sensor requires a minimum voltage of 3.3V to a maximum voltage of 5.5V for activation.

2.2. VSD driver design

This VSD driver circuit is used for reading PWM signals coming out of the microcontroller board so that it can be read by VSD. VSD can read signals in the form of DC signals.

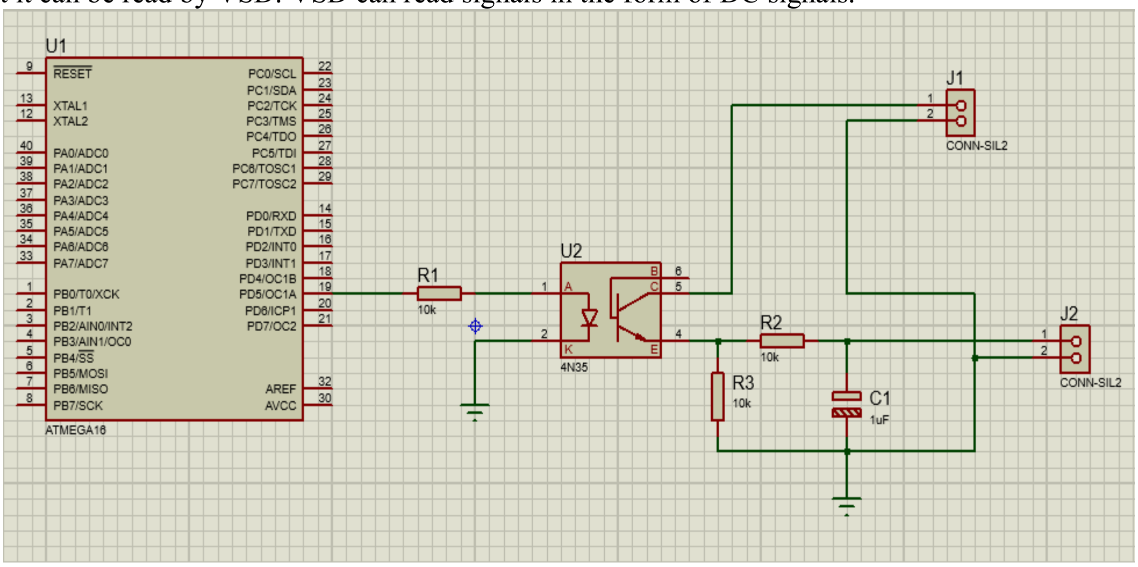

Figure 3. VSD driver circuit.

VSD input is a voltage with a range of 0-10 V to set the output frequency to the three-phase induction motor. Therefore, a driver circuit is needed as communication from the microcontroller to VSD. This circuit consists of an opt coupler that functions as a PWM signal separator between microcontroller board and VSD. Then the PWM output is converted to voltage with the addition of resistors and capacitors installed as shown in Figure 3.

2.3. Speed controller based on PI method

PI controller is used to adjust the rotation of a three-phase induction motor so that the motor rotational speed remains stable at a certain speed. After getting the speed reading of the sensor readings, the PI controller will calculate the error between the reading of the speed sensor and the set point. After the error is processed, the PI controller will generate a control signal in the form of the ignition time of the VSD. The VSD will adjust the motor speed.

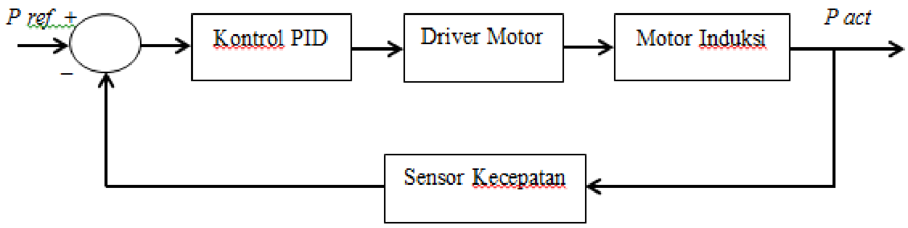

Figure 4. PI controller diagram block.

PI design start by the determine the Kp and Ki values of the controlled plan in this case is three-phase induction motor speed. The design is done by providing input in the form of unit steps in the plan so that a response is obtained. From these responses it can be seen the response curve in the form of an S curve or oscillation. If the response is in the form of an S curve then the Ziegler Nichlos 1 method is used. After getting a response, the next calculation for Ziegler Nichlos 1 uses the calculation as shown in Table 2:

Table 2. Ziegler Nichols method for S curve.

Control Type	Kp	Td	Ti
P	T/L	~	0
PI	0,9 T/L	L/0,3	0
PID	1,2 T/L	2L	0,5L

L is the delay time and T is the time delay constant. The values are then entered in the formula below to get the values of Kp, Ki and Kd:

$$K_p = \frac{T}{L} \qquad (1)$$

$$K_i = \frac{K_p}{T_I} \qquad (2)$$

$$K_d = K_p \, x \, T_D \qquad (3)$$

Where Kp is promotional constantan, Ki is integral constantan and Kd is derivative constantan. First the design is done by giving input unit step on the motor. The response speed reading used is the rotary encoder sensor, because the rotary encoder is feedback from the system. The unit step input response is shown in Figure 4.

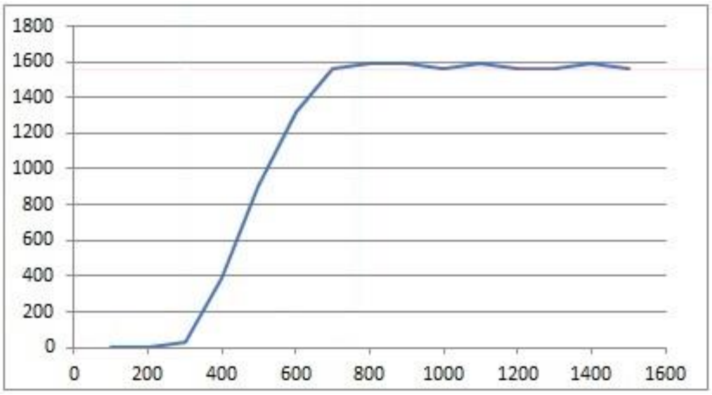

Figure 5. Step response of three-phase induction motor.

From the response graph in Figure 4 it is known that the response plan is in the form of an S curve, so in this design the Ziegler Nichlos 1 method is used. The next step is to find the L and T values from the response graph, then the value of L = 0.3 s and T = 0.4 s are obtained. Based on table 2and step response, parameter of PI controller is defined and gets value.

Kp = 0.9 x T/L
= 0.9 x (0.4/0.3) = 1.2
Ti = L/0.3
= 0.3/0.3 = 1

After obtaining the values of Kp, Ti and Td, the values of Kp and Ki can be calculated with the equation (1) and (2) so that it's gotten value Kp and Ki of 1.2.

3. Result and discussion

The speed sensor is used to provide feedback for the controller. Speed sensor testing is needed to ensure feedback to the controller is functioning properly. Speed sensor testing is done by comparing the speed sensor readings with a tachometer. The sensor test results are shown in Figure 6.

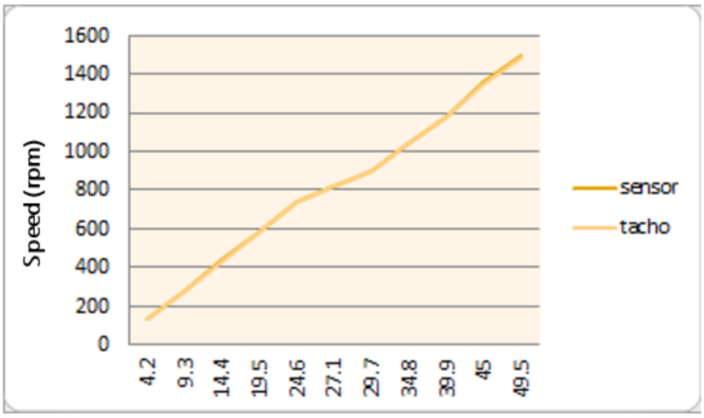

Figure 6. RPM sensor result test

After calculating the error in each speed sensor test, the average error calculation is performed using equation 4.

$$E_r = \frac{E_T}{P_D} \qquad (4)$$

Er = Average Error (%)
ET = Total Error (%)
Pd = Amount of data retrieval

Based on the data and graphics obtained from the speed sensor test, it can be concluded that the value of the rotary encoder sensor is 0.283%, meaning this speed sensor can be used as feedback from this system.

The next step is to test the system response test is conducted which aims to test the overall system. The system is tested by providing a set of speed points. The system response at the set point of 300 rpm and 500 rpm is shown in Figure 7 and Figure 8.

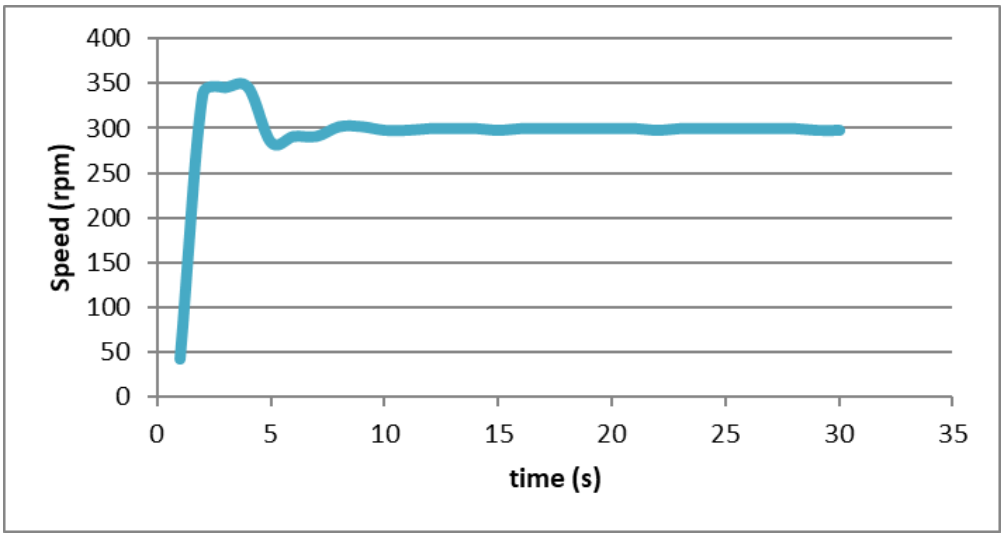

Figure 7. Speed Response with 300 RPM set point

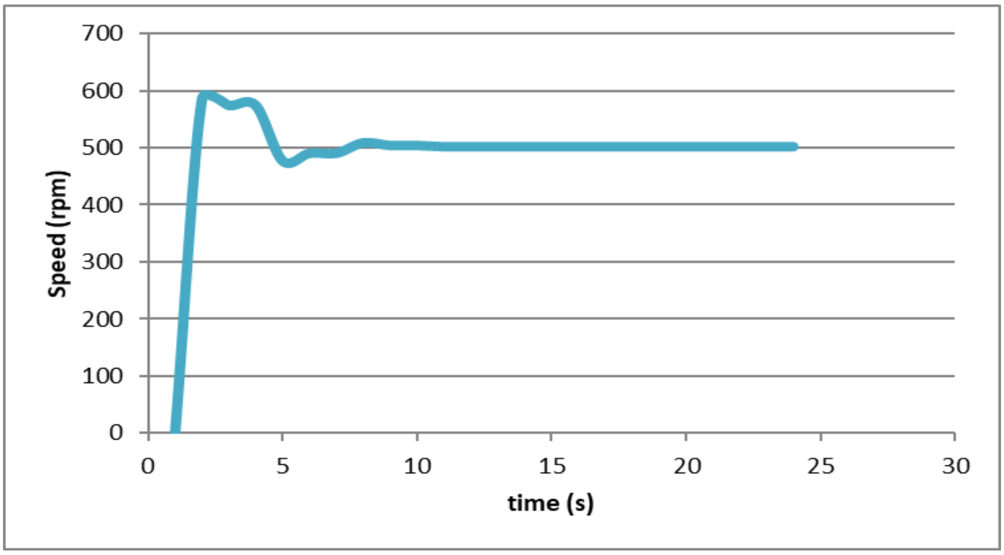

Figure 8. Speed Response with 500 RPM set point

4. Conclusion

Design WTE with PI controller using three phase induction motor to drive PMSG wind turbine has been presented in this paper. WTE has function to simulate wind speed to drive PMSG at certain speed value based on relationship between PMSG speed and wind speed that is obtained by measurement in field. PI controller is embedded on microcontroller to drive VSD that is connected to induction motor. The speed controller of WTE based on PI method shows that the speed of the WTE can follow the specified set point of induction motor speed. WTE has been build can be used to simulate the behaviour of wind turbines against changes in wind speed.

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