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Voltage Stabilizer for Wind Power Based on Fuzzy Logic

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Abstract:

The problem that occurs in Wind Power is the fluctuating output voltage due to unstable wind speed, so a stabilizer system is needed. In this paper, a stabilizer system based on fuzzy logic is proposed. The system is built with Matlab Simulink, and fuzzy logic is designed to determine the PWM duty cycle value of the buck-boost converter automatically, according to the desired output voltage at 18 V. The simulation results show that the voltage can be stabilized at 18 V, at fluctuation wind speeds between 4-7 m/s.

Keywords **—wind power, fuzzy logic, voltage stabilizer, buck-boost converter, pulse width modulation**

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I. INTRODUCTION

Until 2027, 54% of energy sources in Indonesia still depend on coal. Meanwhile, renewable energy such as wind, solar, and water is only about 22.6%. This is due to the low cost of producing electricity using coal compared to other materials [1]. The cost of producing electricity from coal is only around Rp. 600,-/KwH. Renewable energy, such as solar, reaches Rp. 2,900,-/KwH [2]. This has become a special spotlight for researchers to create ideas by utilizing the science of power electronics to reduce the cost of investing in renewable to become affordable and to be encouraged the government resolve the coal crisis.

One of the most common renewable energies is wind energy. Although many system/s have been proposed to convert wind energy into electrical energy, there are still many problem/s, including fluctuating wind energy and low wind speed. Like in Jember, which according to several previous studies, the average wind speed in Jember Regency only ranges from 3 m/s to 6 m/s at an altitude of 7.3 m. In this condition, it is still possible to develop a small-scale power generation system [3], although the power output produced by the wind turbine becomes distorted due to the influence of erratic wind speeds.

This article will discuss the design of a vertical type wind power generator voltage stabilizer system using a fuzzy logic-based control system to determine the right PWM value, so the output voltage becomes stable, even though the wind speed varies. The system will be simulated using Matlab Simulink software on a Personal Computer. The research method will be divided into two parts, without a control system and using a control system. The wind speed will be changed according to the parable of the conditions in the field with wind variations ranging from 4 m/s to 7 m/s.

II. LITERATURE STUDY

2.1 Wind Power

The Wind Power System has a main part in the form of a windmill which functions as a converter of kinetic energy in the form of wind into mechanical energy in the form of shaft rotation. The rotation of the shaft is then used for several things as needed. In this research, the rotation of the shaft is used to turn a generator, to generate electricity. The general configuration of wind turbines can be seen in Figure 1 [4-8].

Mechanical energy from the wind is used to rotate the blades which are then forwarded to the gear box. This is done so that the rotation of the propeller becomes lighter when paired with the generator. Not all types of wind turbines use the Gear-box system, because this system is an option to lighten the blade rotation when wind speeds are low. The mechanical output from the Gear-box will be forwarded to drive the generator and converted into electrical energy. The output from the generator is transmitted to the power converter with the aim that the system output frequency is controlled and synchronized with the turbine so that the distribution to the load is more efficient [4-9].

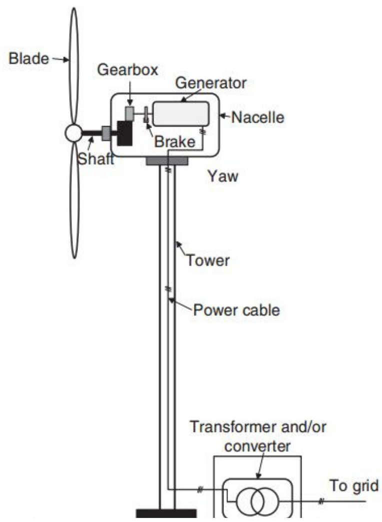

Fig. 1 Structure of a wind power system

2.2 Buck–Boost Converter

Buck-boost converter is a circuit that functions to increase or decrease the source voltage according to the controlling PWM [10-12]. This converter shown in Figure 2, and it is arranged using 1 FET type transistor for switching needs, an inductor to amplify the current, a diode as a current direction sign, a capacitor as a charge reservoir and a resistance resistor to the load.

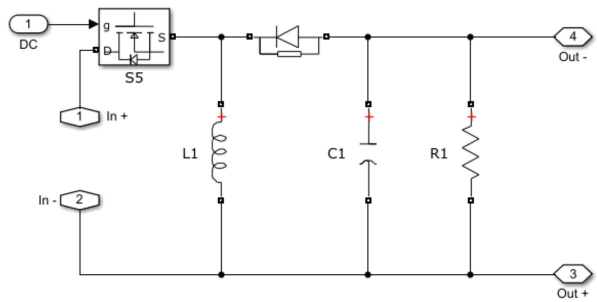

Fig. 2 Buck-Boost Converter Circuit on Simulink

Of the several parameters set, the design used for the design of the buck-boost converter if gate frequency = f, Lowest Input Voltage V, then the calculation of the Buck-Boost Converter component is:

1. *duty cycle*

$$\frac{Vo}{Vin} = \frac{D}{1-D}$$

2. R operation

$$R = \frac{Vo}{Io}$$

3. L_{min}

$$Lmin = \frac{(1-D)^2}{2f} R$$

4. Finding the capacitance value of the capacitor

$$\Delta Vo = \frac{Vo\ D}{R\ C\ f}$$

2.3 Fuzzy Logic System

Some of the basic Fuzzy theories that must be understood to be able to use this control model include the Membership function. Function membership is a curve that shows the membership function of the fuzzy [11-12]. Usually this curve is in the form of each connected point and then form a curve whose intervals start from 0 to 1. An example can be seen in Figure 3.

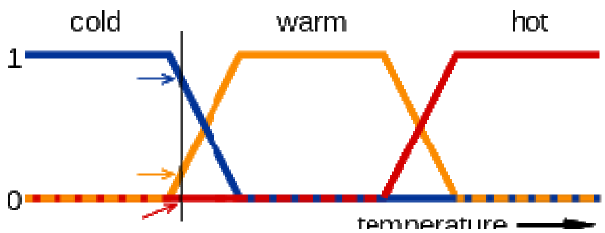

Fig. 3Example of Fuzzy Membership

Rules are rules that become the expert system of fuzzy. Rules are used to connect the input and output membership with the rules that have been made by the previous user. For example pictures can be seen in Table 1.

Table 1 Example of Rule Fuzzy Logic

D/DE	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	Z
NS	NB	NS	NS	Z	PS
Z	NS	NS	Z	PS	PS
PS	NS	Z	PS	PS	PB
PB	Z	PS	PS	PB	PB

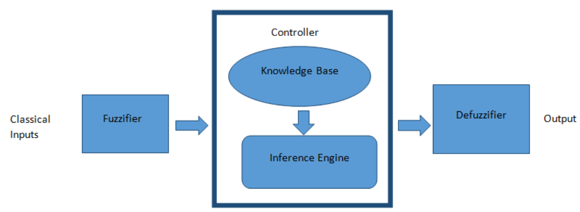

Fig. 4Fuzzy Inference System Flow

The working principle of fuzzy logic, the first input into the fuzzy logic block. Then the input will be changed according to the membership input that has been designed, this is what is called the fuzzifier process. The value which was originally in the form of a complete value, is now a fuzzy value which only has a range of values ranging from 0 to 1. Then each input that has been fuzzifier is connected by using the rules that have been found in fuzzy logic. From the results of the inference process, it then produces several conclusions which are then carried out by a defuzzifier process to obtain output that is in accordance with the conclusions. For more details can be seen in Figure 4.

III. RESEARCH METHODS

3.1 Diagram Block

This research is a voltage stabilizer system in a vertical wind power plant using fuzzy logic control. The research is focused on regulating the output voltage of the wind turbine which is constantly changing due to varying wind speeds. A fuzzy logic control is inserted in the buck-boost converter to overcome the unstable turbine output voltage. The research was conducted using a simulation on a PC Personal Computer with Matlab Simulink software. In simple term/s, the research description is presented in the Figure 5.

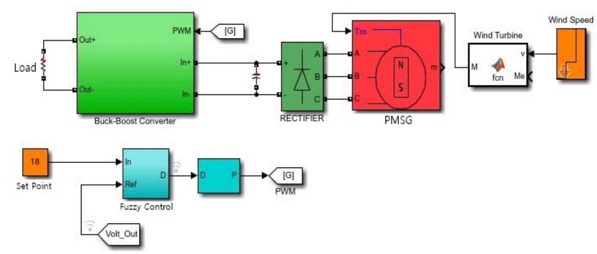

Fig. 5 Diagram Block

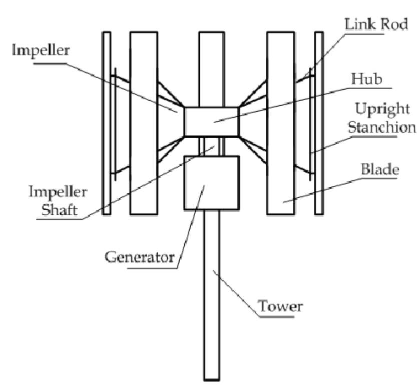

Fig. 6 Vertical Wind Power

3.2 Wind Power

The type of generator used in this study is a Permanent Magnetic Synchronous Generator (PM/SG) which is driven by a vertical axis wind turbine with a capacity of 2 kW at 500 rpm rotation with a 3-phase AC output voltage. The voltage will be converted into direct current (DC) using a rectifier. The buck boost type DC – DC converter was chosen in order to overcome the turbine output voltage which tends to be unstable which will be controlled first using fuzzy logic control. In simple term/s, the simple design form of the PLTB is show in Figure 6.

3.3 Parameter of Buck-Boost Converter

1. *duty cycle*

$$\frac{Vo}{Vin} = \frac{D}{1-D}$$

$$\frac{18}{4} = \frac{D}{1-D}$$

$$18(1-D) = 4D$$

$$18 - 18D = 4D$$

$$18 = 4D + 18D$$

$$18 = 22D$$

$$0{,}8 = D$$

2. R operation

$$R = \frac{Vo}{Io}$$

$$R = \frac{18}{0{,}2}$$

$$R = 90\ \Omega$$

3. Lmin

$$Lmin\ = \frac{(1-D)^2}{2f}\ R$$

$$Lmin\ = \frac{(1-0{,}8)^2}{2\ .\ 25000}\ 90$$

$$Lmin\ \leq 72\ u\text{H}$$

4. Finding the capacitance value of the capacitor

$$\Delta Vo\ = \frac{Vo\ D}{R\ C\ f}$$

$$2{,}5\ = \frac{18\ .\ 0{,}411}{90\ .\ C\ .\ 25000}$$

Then it becomes :

$$C\ = \frac{18.\ 0{,}8}{90\ .\ 2{,}5\ .\ 25000}$$

$$C\ = 6{,}56\ u\text{F}$$

Then the components used in the buck boost simulation are: L1 = 72 uH, C1 = 6,56 uF, R1 = 100 Ω, Fs = 25000 Hz.

3.4 Fuzzy Control Design

Fuzzy is set in Matlab to determine the ideal PWM Pulse Width Modulation value according to the specified voltage set point, then inputted to the gate transistor buck-boost converter. Fuzzy will be used as a control that will be connected to the gate on the transistor for switching which is used as an increase or decrease in voltage on the buck-boost converter. The fuzzy control scheme is shown in Figure 7.

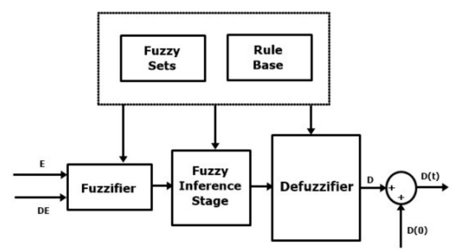

Fig.7 Fuzzy control scheme

The control scheme shown in Figure 7 shows that in this study there are two fuzzy controller inputs consisting of an error value and a delta error, where the error is the difference between the wind turbine output voltage and the desired setpoint voltage, while the delta error is the difference between the current error. this with the previous error.

The output of the fuzzy control is the duty cycle value which is used to control the buck-boost converter. Figure 8 is the membership function of the Gaussian type of error, while Figure 9 is the membership function of the Gaussian type of delta. For the fuzzy output membership function, it is shown in Figure 10 in the form of a duty cycle value where the actual duty cycle that will be used to control the buck-boost converter is the sum of the previous duty cycle or D (0) with the duty cycle of the fuzzy output or D.

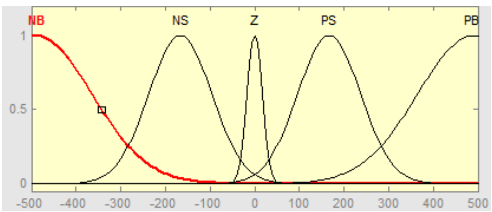

Fig. 8 Membership function of error

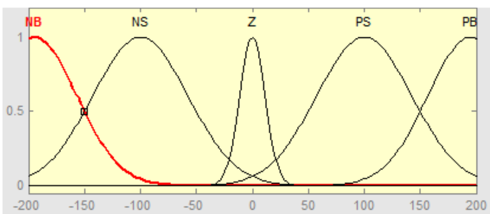

Fig. 9 Membership function of delta error

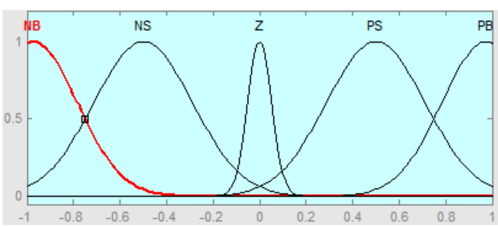

Fig. 10 Membership function of duty cycle

The input and output membership functions use 5 variables, including NB (negative big), NS (negative small), Z (zero), PS (positive small) and PB (positive big). same. Therefore, the total rules that will be designed in this study are 25 rule bases which can be seen in table 2.

Table 2 Rule fuzzy logic controller for converter

D/DE	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	**Z**
NS	NB	NS	NS	Z	**PS**
Z	NS	NS	Z	PS	**PS**
PS	NS	Z	PS	PS	**PB**
PB	Z	PS	PS	PB	**PB**

3.5 Set up System

The overall system simulation is presented in Figure 11. In simple term/s, this research system is divided into 3 core blocks, namely PM/SG wind turbine, buck-boost converter, and fuzzy control. The author uses a generator type Permanent Magnetic Synchronous Generator (PM/SG) which is driven by a vertical axis wind turbine with a capacity of 1 kW at 500 rpm rotation with an output voltage of 48 Volt AC which will later be converted into direct current (DC) using a rectifier.

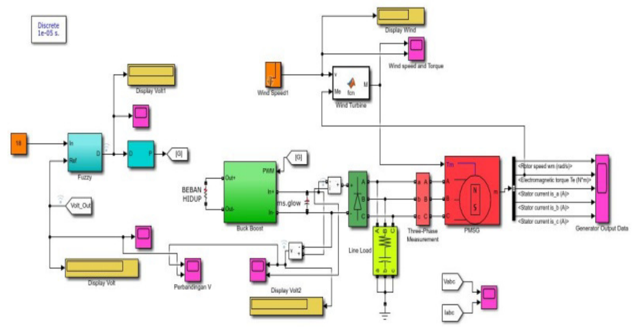
Fig.11 Set up system

The author uses a DC-DC converter with a buck boost type which will be controlled first using fuzzy logic. Fuzzy is set to control the voltage from the turbine which tends to go up and down by processing the value of the duty cycle on the converter. If it is felt that the voltage is good enough, it will be forwarded to the load. The selected load is battery. The research was carried out by performing simulations on Matlab Simulink.

IV. RESULTS AND DISCUSSION

4.1 Wind Speed and Voltage Correlation

The simulation results of the wind power in the variation of wind speed shown in Table 5. In this table, for example when the wind speed is 7 m/s, the voltage generator of input voltage (uncontrolled) is 61.4 V. This voltage is too high for the load, so that the converter changes it to the set point 18V. In this condition, the input current is recorded at 0.011 and at the output is 0.189 this happens a fairly small current because according to converter theory, if the voltage is prioritized, the current will usually succumb a little or be small.

Table 3 Correlation of wind speed, voltage and current

Wind Speed (m/s)	**Vin** (without fuzzy)	**Vout** (using fuzzy)	I **in**put	I **out**put
3	14,5	18,4	0,001	0.126
4	19,6	18,5	0,002	0,173
5	39	18,5	0,006	0,185
6	56,8	18,3	0,007	0,183
7	61,4	18,9	0,011	0,189
8	62,2	18,5	0,016	0,189

4.2 Voltage Stability

The test scenario is adjusted to the real conditions in nature that the wind speed changes ramdomly every time. Changes in wind speed are shown in Figure 12.

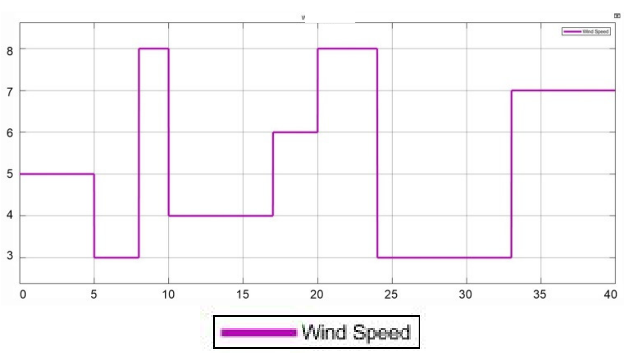

Figure 12 Variation of wind speed on test

The variation of changes of wind speed at the starting from 3 m/s to 8 m/s and using sample time of 40 minutes. The x-axis on the scope displays the simulation running time, while the y-axis displays the value or magnitude of the wind speed.

Result simulation of wind fluctuation shown in Figure 13. The input voltage of the buck-boost converter on the scope is green, while the output voltage of the fuzzy-controlled buck-boost converter is red.

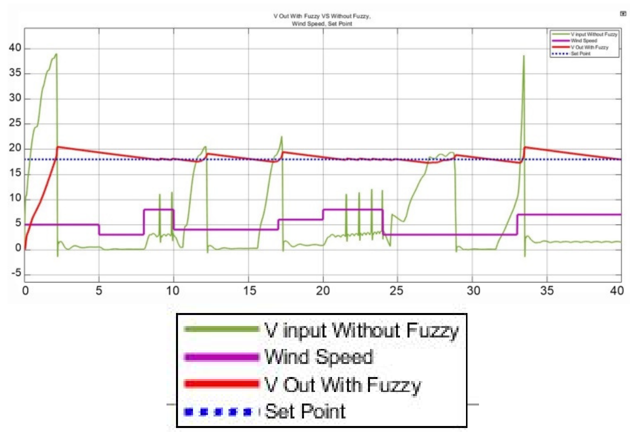

Fig. 13 Result of voltage

A fairly significant difference is seen between the input voltage and the fuzzy controlled output voltage. For example, when the wind blows 4 mS up to a time of 10 to 17 minutes, the input voltage reads 19.6 V. While the set point or the desired output voltage in this study is 18 V, so that in this condition the buck-boost converter is assigned to reduce or buck the voltage by adjusting the duty cycle in the PWM. With fuzzy control, the buck-boost converter will automatically select the appropriate duty cycle value to provide a PWM trigger so that the voltage can be controlled/reduced from 19.6 V to 18 V according to the set point up to 17 minutes. If the duty cycle value is more than 0.5 then the converter will work as a voltage increaser or boost converter, and if the duty cycle value is less than 0.5 then the converter will work as a voltage reducer or buck converter.

The graph results from the input voltage do look less stable or tend to be distorted. This is due to the impact of switching on the dc converter used. According to several research journals, the standard value of MAE (Mean Absolute Error), the average difference between the setpoint and the output in a test series must be close to the value 0. The function of this parameter is to determine the amount of difference between the average setpoint and the response value obtained. The smaller the value of this parameter (close to zero) the better the level of system stability. By using the menu in Matlab, the MAE value in this test series can be automatically obtained. The following is the MAE value obtained from the matlab.

V. CONCLUSION

From the results of the tests and analyzes carried out, a vertical type wind power generator voltage stabilizer system based on fuzzy logic control has been produced by adding a buck-boost converter to increase and decrease the voltage according to the 18 V set point with the input voltage changing according to the wind speed.

The performance of the system is quite efficient where the input voltage which is initially very unstable and distorted can be stabilized with a control system designed so that the output voltage is in accordance with the 18 V set point.

The system test results have a pretty good Mean Absolute Error (MAE) value of -0.624 which is considered to have met the MAE testing standard, which is close to zero.

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