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FUZZY MPPT CONTROLLER FOR SMALL SCALE STAND ALONE PMSG WIND TURBINE

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ABSTRACT

The use of wind energy, as a substitute for fossil energy, increase to generate electricity. The utilization of wind energy in rural areas that is not connected to the grid is very beneficial to the community. System stand-alone wind turbines small scale with a permanent magnet synchronous generator (PMSG) is very suitable for rural areas. To optimize the output power which is generated by wind turbine, controller is required to extract the maximum power. Fuzzy controller has been developed to produce a power output without using a mechanical sensor. Fuzzy controller controls the duty cycle of boost converter to obtain optimum generator speed and maximum power output of wind turbine system. To maintain the DC link voltage, bidirectional converter controllers have been used through the setting charging and discharging of the battery. Based on simulation results, the fuzzy controller has good performance to extract the optimum power. Fuzzy controller can maintain power coefficient on the optimal value despite a change in the wind.

Keywords: fuzzy controller, MPPT, wind turbine.

INTRODUCTION

Today the use of wind energy as electrical energy generation to replace conventional energy sources is increasing. The use of wind energy generation systems generate clean energy and pollution-free of CO2 emissions. The Indonesian archipelago has wind energy potential is quite large, but there are still some remote areas that have not received electricity from the grid so that the use of wind energy as electrical energy generation is necessary and appropriate. The utilization of wind energy in rural areas that have not been connected to the grid provides a huge benefit to the community. For rural areas, stand-alone wind turbine system on a small scale is one of the most suitable systems where efficiency and cost of maintenance is an important factor [1].

Currently the variable speed wind turbine (VSWT) is a type of wind turbine that is most widely used compared to fixed speed wind turbine (FSWT) because VSWT has a higher efficiency, lower maintenance costs, and can capture more power than FSWT [2]-[4]. Generator is required to convert the mechanical energy of the wind turbine into electricity. The permanent magnet synchronous generator (PMSG) is most widely used for small-scale wind turbines because it has the advantage with a high torque density, very low inertia, more efficient, and does not require an external excitation circuit [1]. One way to reduce the cost of wind energy is through the use of effective algorithms for track and extract the maximum power wind turbine that is called the maximum power point tracking (MPPT) so that the system can work at maximum power to the variation of the wind changes [3]-[11].

To improve the efficiency of variable wind turbine system using MPPT can be done through the use of power electronics. Some configurations as power electronic converters have been implemented on the wind turbine system. For systems with large scale, converters back to back most widely used. As for small-scale power, with power less than 10KW, the configuration of the converter the most widely used is a diode bridge rectifier and a dc/dc converter [12]. Boost converter is one of the dc / dc converter that is most widely used for small-scale wind turbines stand alone because it requires low cost and easily controlled than converters back to back [1].

Methods perturb & Observe (P & O) is the method most widely used to get the maximum power at wind turbine system because it is simple and easy to implement. The use of this method can reduce the use of mechanical sensors, does not require the measurement of wind speed and wind turbine characteristics data that can be replaced by current and voltage sensors. Determination of step size on the P&O method will determine the speed and performance tracking system. The larger the step size, time tracking will be faster but will cause great oscillations at steady state conditions while the step size small will improve accuracy in tracking the maximum power but requires a longer time so that efficiency will be reduced primarily on wind speeds fluctuate. The use of fuzzy logic has been studied to obtain maximum power at wind turbines. Fuzzy logic is used to get the maximum power based on the power and speed of the rotor PMSG [1]-[8]. However, the use of speed sensors increases the cost of the system so as not appropriate for small-scale wind turbine systems.

In this paper, fuzzy logic is designed to extract the maximum power at stand-alone small scale wind turbines by setting the duty cycle of the boost converter. Fuzzy logic determines the duty cycle based on the output power and voltage rectifier with current and voltage measurements. Bidirectional control serves to regulate the flow of power to the load through the bidirectional converter. If the wind turbine generated power exceeds the load requirements, bidirectional converter will charge the battery, otherwise battery will supply the load if the generated power wind turbines can not meet the load requirements.

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WIND TURBINE SYSTEM

Proposed wind turbine configuration

The proposed wind turbine system consists of PMSG 8.5kW, rectifier, boost converter, fuzzy MPPT, bidirectional converter, bidirectional control, and a resistive load, as shown in Figure-1. Configuration of the wind turbine system using a rectifier and boost converter is most suitable for small scale stand alone wind turbine because it is simple, easy and more efficient setting. Rectifier function to convert AC voltage into DC voltage of PMSG which will be increased to a larger DC voltage by a boost converter. The greater the wind speed, the greater the PMSG output voltage and will increase the DC voltage generated by the rectifier. To obtain optimum power, generator speed must be set at the optimal speed by setting the duty cycle by fuzzy MPPT. Fuzzy MPPT determine the duty cycle boost converter based on power and the output voltage rectifier, where power is determined by the measurement of voltage and current rectifier.

Fluctuating wind speed will produce fluctuated optimum power. Excess power generated by wind turbines can be stored in the battery through the bidirectional converter settings. Meanwhile, if the load requires power and wind turbines can not meet the needs of the load, the battery will supply the load based on signals from the PI controller.

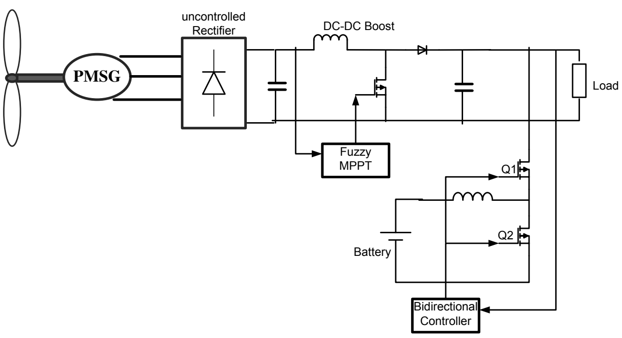

Figure-1. Small scale stand alone wind turbine system.

Wind turbine model

The wind turbine is important equipment in wind power generation system that will capture and convert wind energy into mechanical energy. The output power or torque of the wind turbine is determined by several factors such as the speed of the turbine, the rotor blade, pitch angle, the size and shape of the turbine, the turbine area and wind speed. Mechanical power generated can be expressed by

$$P_m = \frac{1}{2}\rho\pi R^5 \frac{\omega r^3}{\lambda^3} C_p \qquad (1)$$

Where Cp is a turbine power conversion coefficient, λ is the tip speed ratio, β is the pitch angle, R is the radius of the turbine and v is the wind speed. Turbine power conversion coefficient (Cp) can be expressed by the equation [11]

$$Cp = 0.5176\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\frac{21}{\lambda_i}} + 0.0068\lambda \qquad (2)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad (3)$$

Tip speed ratio (λ) is the ratio between the angular speed of the turbine (ω_r) and the wind speed that can be expressed by the equation

$$\lambda = \frac{\omega_r R}{v} \qquad (4)$$

Figure-2 shows the mechanical output power of the wind turbine to speed turbine with different speed winds and pitch angle 0^o. At every different wind speeds, the wind turbine will generate a different maximum power point.

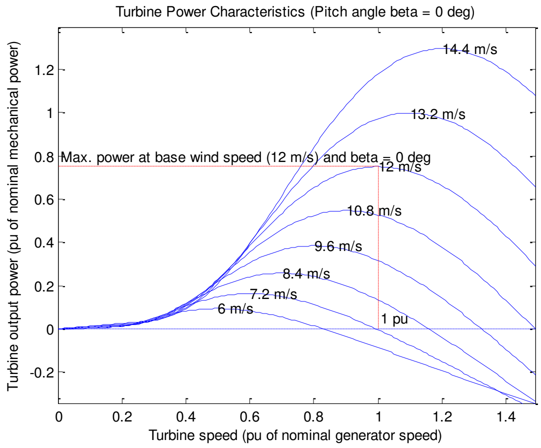

Figure-2. Wind Turbine Characteristic.

Based on Eq (1)-(4), it can be determined mechanical torque

$$T_m = 0.5\rho A \frac{C_p(\lambda,\beta)}{\lambda} v^2 \qquad (5)$$

Dynamic equations for wind turbines can be expressed by

$$\frac{d\omega_r}{dt} = (1/J)[T_m - T_L - F\omega_r] \qquad (6)$$

Where J is the moment of inertia, F is the friction coefficient, T_m is the torque produced by the turbine and T_L is generator torque connected to the turbine. Optimum power from wind turbines can be expressed by the equation

$$P_{m\text{-}opt} = K_{opt}\, \omega_{ropt}^3 \qquad (7)$$

$$K_{opt} = \frac{0{,}5\pi\rho C_{Pmax}\ R^5}{\lambda_{opt}^3} \qquad (8)$$

The relationship between power and torque of the turbine can be expressed by

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$$P_m = T_m\omega_r \quad (9)$$

Based on the equation (7) - (9) can be determined the optimal torque

$$T_{m\text{-}opt} = \frac{1}{2}\rho\pi R^5 \frac{\omega r^2}{\lambda opt^3} C_p \quad (10)$$

SPEED SENSORLESS FUZZY MPPT CONTROLLER

Fuzzy logic has been applied to several applications to control nonlinear systems because the use of fuzzy logic is based on human experience of the operator, thus reducing the use of mathematics. In the fuzzy logic control consists of three stages, namely fuzzification, inference engine and defuzzification. Fuzzification will change the real values of the fuzzy inputs into fuzzy membership value while the inference engine is the decision-making process which is based on fuzzy rule base containing expert knowledge or heuristics. This rule base contains a collection of fuzzy conditional statements expressed with If ... Then rule. Decisions of the inference engine of fuzzy value will be converted into real values / crisp on defuzzification process.

In this paper, fuzzy logic is used to extract the maximum power on a small scale wind turbine systems stand alone based on current and output voltage rectifier. Fuzzy logic has two inputs namely dP and dV. dP is the difference between the current power and the previous power where power is the multiplication of voltage and current output rectifier. While dV represents the difference between the current output voltage of the rectifier and previous, which can be expressed by

$$dV = V(n) - V(n-1) \quad (11)$$

$$dP = P(n) - P(n-1) \quad (12)$$

Input of fuzzy logic has five membership function in the form of triangular and trapezoidal having a value fuzzy is Negative small (NK), Negative (K), Zero (Z), Positive (P), Positive Big (PB), as shown in Figure-3.

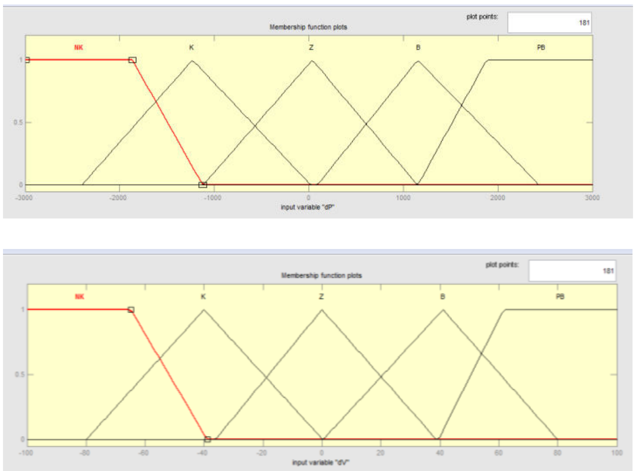


Figure-3. Input of fuzzy MPPT controller.

To extract the maximum power, PMSG must rotate at the optimum speed that can be achieved through the setting duty cycle in boost converter. If the value of dP is positive then the wind turbine operating point is to the left of the maximum power point so the duty cycle must be increased as well as vice versa. The output of the fuzzy logic is the duty cycle for the boost converter, which has a 5 membership function of triangular and trapezoidal with a value of fuzzy Negative small (NK), Negative (K), Zero (Z), Positive (P), Positive Big (PB), such as shown in Figure-4. In the proposed system, a fuzzy implication method uses max-min method and defuzzification uses the center of gravity method. Table-1 shows the fuzzy rule that states the relationship between the fuzzy inputs with the resulting decision in which the duty cycle should be adjusted up or down to find the maximum power point.

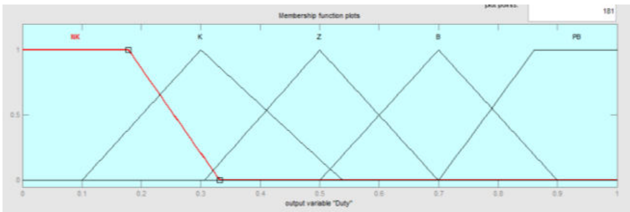


Figure-4. Output of fuzzy MPPT controller.

Table-1. Fuzzy rule for maximum power extraction.

Output		dV				
		NK	K	Z	P	PB
dP	NK	NK	K	K	B	PB
	K	K	K	K	B	PB
	Z	Z	Z	Z	B	B
	P	B	B	K	K	NK
	PB	PB	B	K	K	NK

Fuzzy control will extract maximum power based on wind speed captured by wind turbines. Fluctuating wind speeds will produce maximum power fluctuates so that it's needed control to obtain constant power to the load through the control of the bidirectional buck boost converter and a battery as energy storage. If the maximum power generated exceeds the power load, bidirectional control will be charging the battery via the setting duty cycle MOSFET Q1 and Q2 in the buck boost converters, and vice versa. The difference between the load voltage with a reference voltage is processed by the PID controller to produce a duty cycle that will turn the MOSFET Q1 and Q2, as shown in Figure 5. MOSFET Q1 and Q2 work interchangeably based on charging or discharging of the battery. As the battery is charging, MOSFET Q1 will be active and Q2 will be off so that the converter serves as a buck converter and the current flowing into the battery. While when the battery is discharging, the MOSFET Q1 will be off and Q2 will be active so that the converter serves as a boost converter and a current flows from the battery to the load.

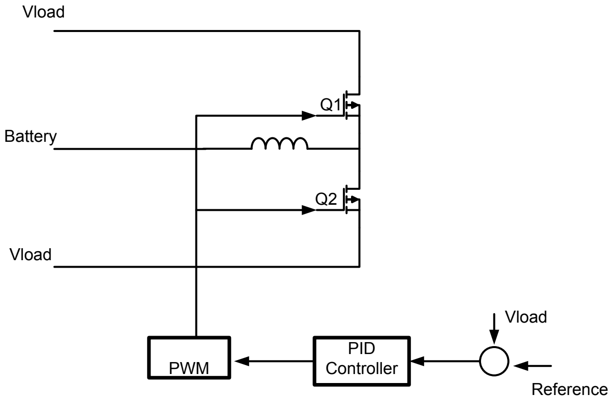


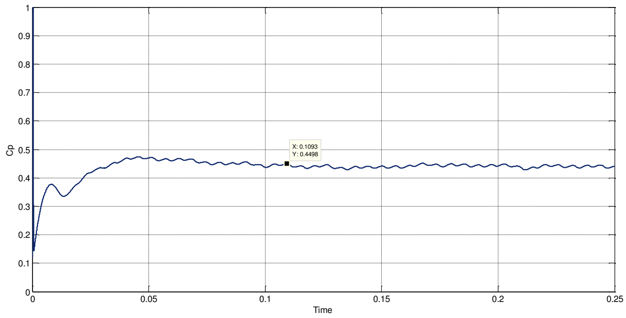
Figure-5. Control of bidirectional converter.

SIMULATION RESULT

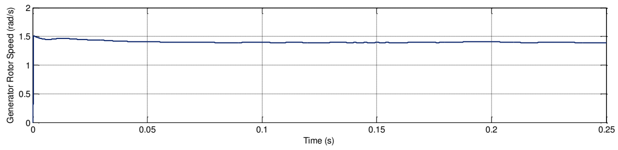
Figure-6. Wind speed measurement.

Fuzzy logic to extract the maximum power on a small scale stand alone wind turbine using PMSG has been modelled and simulated using MATLAB Simulink. In this paper, the wind turbine parameters used are the rated output power of 8.5 Kw, pole number by 10, stator winding resistance of 0.425Ω, stator winding inductance of 8.2mH, inertia of 0.01197 Kg.m2 and friction factor of 0.001189N.m.s. Fuzzy logic as maximum power point tracking is tested in two conditions, the constant wind speed and random wind speed.Simulated wind speed was based on wind speed measurement in Ciheras, Indonesia as shown on Figure-6.

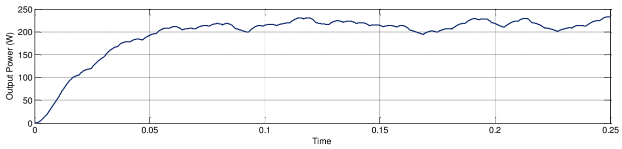
Figure-7 shows the simulation results with a constant wind speed of 11m / s. Fuzzy logic controller as to extract the maximum power can achieve optimal power coefficient at 0.45. This shows that the fuzzy logic can work well with rectifier output voltage of 250V and achieve optimal generator speed at 1.48rad / s.



(a) Cp



(b) Generator speed.



(c) Rectifier output voltage.

Figure-7. Simulation result with constant wind speed.

To evaluate the performance of MPPT controller at varying wind conditions has been simulated by providing a change of wind speed of 7m / s to 11m / s, as shown in Figure-8. Based on the simulation results indicate changing winds resulted in a change of generator speed and the rectifier output voltage. Fuzzy logic can work well to obtain optimum power at certain wind speed. Fuzzy logic can maintain WECS works on optimum power by maintaining a constant Cp values at the optimum value of 0.45 despite a change in the wind. Figure-9 shows the DC link voltage response to changes in wind speed. Although a change in wind speed, the dc link voltage can be maintained constant by bidirectional converter controller through charging and discharging battery. PID controller as a bidirectional converter dc link voltage controller generates a response that has a 10% overshoot, 1% error steady state and settling time of 0.04s.

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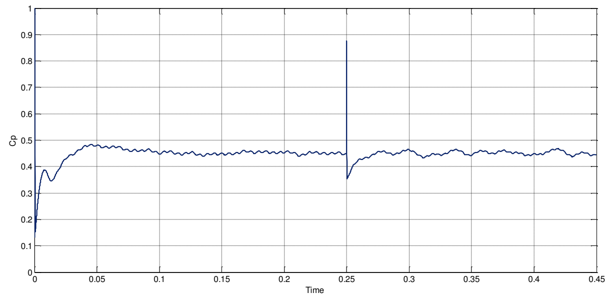
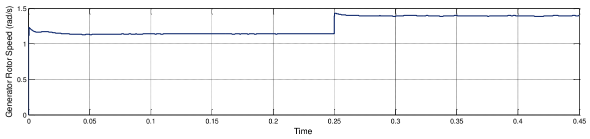
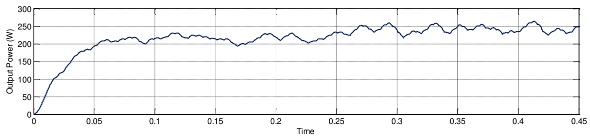


(a) Cp



(b) Generator speed.



(c) Rectifier output voltage.

Figure-8. Simulation result with wind speed variation.

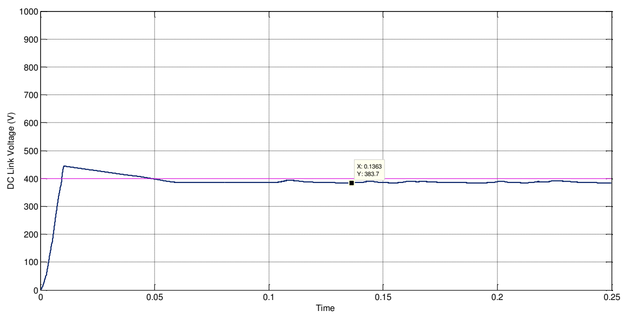


Figure-9. DC-Link voltage response.

CONCLUSIONS

Fuzzy logic as MPPT controller to obtain optimum power has been presented in this paper. The use of fuzzy logic does not require the data characteristics of wind turbines and wind speeds, reducing the use of mathematics and without the use of mechanical sensors. To obtain optimum power, its required generator speed setting that can be done through the controlling of duty cycle boost converter. Fuzzy controller based on measuring rectifier power and voltage produced, whereas a fuzzy output is duty cycle for boost converter. Based on simulation results, fuzzy logic has a good performance to get optimum power by maintained power coefficient at optimal value despite a change in the wind. While the DC link voltage controller can maintain the DC link voltage of 400V although a change in wind speed.

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