Document details

Proceeding - ICSEEA 2017 International Conference on Sustainable Energy Engineering and Application: "Continuous Improvement of Sustainable Energy for Eco-Mobility"
Volume 2018-January, 2 July 2017, Pages 45-51
2017 International Conference on Sustainable Energy Engineering and Application, ICSEEA 2017; Balai KartiniJakarta; Indonesia; 23 October 2017 through 24 October 2017; Category numberCFP17AAF-ART; Code 134401

Implementation of maximum power point tracking algorithm on wind turbine generator using perturb and observe method (Conference Paper)

Nurzaman, I., Harini, B.W., Avianto, N., Yusivar, F.

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Abstract

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Energy from wind movement can be one of the alternatives of the renewable power source in fulfilling the need of electrical energy. This can be achieved by converting wind movement energy into electrical energy. The wind turbine is a device to convert energy from wind movement into electrical energy. The challenge in the usage of wind turbine generator is that the wind velocity is not always constant, hence the power generated by wind turbine generator is not always at its maximum point . That is why it is required a control so that the power generated by the wind turbine is always maximum . The control is conducted by applying the maximum power point tracking (MPPT) algorithm to the DC-DC boost converter so that the output power from the wind turbine generator can be controlled and always having a maximum value. © 2017 IEEE.

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Author keywords

Boost converter | MPPT algorithm | Wind turbine generator

Indexed keywords

Engineering controlled terms: Electric inverters | Energy conservation | Maximum power point trackers | Tracking (position) | Turbogenerators | Wind turbines

Engineering uncontrolled terms: BOOST converter | DC-DC boost converters | Electrical energy | Maximum Power Point Tracking | Maximum Power Point Tracking algorithms | Mppt algorithms | Perturb -and- observe method | Wind velocities

Engineering main heading: DC-DC converters

ISBN: 978-153861765-6
Source Type: Conference Proceeding
Original language: English

DOI: 10.1109/ICSEEA.2017.8267686
Document Type: Conference Paper
Volume Editors: Pramana R.I.,Atmaja T.D.,Darussalam R.,Rajani A.,Martides E.,Sya'bana Y.M.K.
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Implementation of Maximum Power Point Tracking Algorithm on Wind Turbine Generator using Perturb and Observe Method

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***Abstract*—Energy from wind movement can be one of the alternatives of the renewable power source in fulfilling the need of electrical energy. This can be achieved by converting wind movement energy into electrical energy. The wind turbine is a device to convert energy from wind movement into electrical energy. The challenge in the usage of wind turbine generator is that the wind velocity is not always constant, hence the power generated by wind turbine generator is not always at its maximum point. That is why it is required a control so that the power generated by the wind turbine is always maximum. The control is conducted by applying the maximum power point tracking (MPPT) algorithm to the dc-dc boost converter so that the output power from the wind turbine generator can be controlled and always having a maximum value.**

Keywords—Wind turbine generator; Boost converter; MPPT algorithm

I. INTRODUCTION

The need for renewable energy sources is growing rapidly. Various factors are identified as the main causes, such as limited availability of fossil natural resources and the increasing of public awareness of the negative effects of using fossil fuel on the environment. Therefore an alternative energy source is needed to reduce the use of fossil fuels [1-6]. Indonesia is one of the countries that has a big potential of natural resources. One of the resources that can be utilized and also has good potential to meet the energy needs is wind energy. However, the utilization of wind energy as one of the alternative sources of electrical energy today has not been well exploited due to various factors such as wind speed that is not constant in various places and has small efficiency in terms of energy conversion.

As an energy converter tool, wind turbine combined with a generator is required to convert wind energy into electric energy. The wind speed is not always constant, it can vary depending on the weather and conditions, and therefore the power generated is fluctuating. In this condition, a technique that can maximize the work of wind turbine required to make the output power always at a maximum value [7].

One of the common techniques is to implement the maximum power point tracking (MPPT) algorithm. The MPPT algorithm is the algorithm used to obtain maximum power under each condition. Implementation of MPPT algorithm used a dc-dc converter and microcontroller as its main controller. In this study, the author used a dc-dc boost converter to run the maximum power point tracking algorithm (MPPT) to control the output power of wind turbine generator.

II. MPPT WIND TURBINE SYSTEM MODELING

A. Wind Turbine

A wind turbine is a tool used to convert kinetic energy due to wind movement into electrical energy. The energy of the wind movement is converted into mechanical rotation by the turbine blades and rotor, rotating the shaft connected to a PMSG generator. As a result, the electrical energy is generated from the generator's rotation [1,8]. The maximum power that can be converted from wind movement by a wind turbine can be formulated as [8] :

$$P \max = \frac{1}{2}\, \rho\, A\, v_1^3\, Cp \tag{1}$$

P_{max} is the maximum power value (watt) that can be generated from wind movement, ρ is the air density (kg/m^3), v_1 is wind velocity (m/s) and Cp is the power coefficient value (C_p).

The value of Cp determines how much power is generated by wind movement. The power coefficient value (Cp) can be formulated with the function with the value of tip speed ratio (λ) and the angle of the blade (δ), as the following:

$$C_p(\lambda, \delta) = C_1 \left(C_2 \frac{1}{\beta} - C_3\, \delta - C_4 \delta^x - C_5 \right) e^{-C_6 \frac{1}{\beta}} \tag{2}$$

The values of $C_1 - C_6$ and x depend on the type of rotor and the characteristics of the wind turbine. The parameter values of β and tip speed ratio (λ) are determined as follows:

$$\frac{1}{\beta} = \frac{1}{\lambda + 0.089} - \frac{0.035}{1 + \delta^3} \tag{3}$$

$$\lambda = \frac{\omega_m R}{v_{wind}} \tag{4}$$

where ω_m is the rotation speed of the turbine rotor and R is the radius of the turbine blades and v_{wind} is the wind speed.

B. Wind Turbine Shaft System

Shaft system modeling in wind turbines as shown in the Fig.1. Shaft system in a wind turbine can be modeled as follows:

$$\frac{d\omega_G}{dt} = \frac{T_e - \frac{T_t}{K} - B\omega_G}{J_t K^2 + J_p} \tag{5}$$

$$\frac{d\omega_t}{dt} = \frac{\frac{T_e - \frac{T_t}{K} - B\omega_G}{J_t K^2 + J_p}}{K} \tag{6}$$

$$\frac{d\theta_G}{dt} = \omega_G \tag{7}$$

$$\frac{d\theta_t}{dt} = \omega_t \tag{8}$$

ω_g (rad/s) is the speed of the axis generator, ω_t (rad/s) is the speed of the turbine shaft, θ_G (°) is the angle position of the generator shaft, θ_t (°) is the angle position of the turbine shaft, T_e (N-m) is the torsion of the generator PMSG, T_t (N-m) is the torsion of the turbine, K is gear ratio, B (Nms/rad) is damping coefficient, J_t(kg-m^2) is inertia of the turbine, J_p(kg-m^2) is inertia of PMSG.

C. Permanent Magnet Synchronous Generator

Permanent magnet synchronous generator (PMSG) is an AC machine that converts mechanical rotation energy into electrical energy. In modeling PMSG, a model is used in the d-q axis. Fig. 2 shows an equivalent PMSG circuit in the d-q axis.

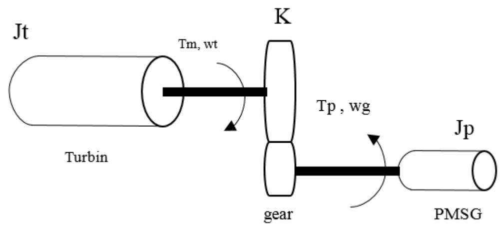

Fig. 1. Wind Turbine Shaft System

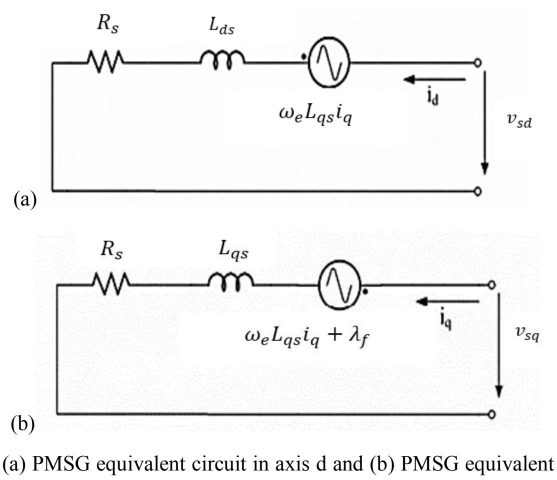

Fig. 2. (a) PMSG equivalent circuit in axis d and (b) PMSG equivalent circuit in axis q.

The equations for PMSG can be arranged as follows:

$$\lambda_{sq} = L_{sq} i_{sq} \tag{9}$$

$$\lambda_{sd} = L_{sd} i_{sd} + \lambda_f \tag{10}$$

$$v_{sq} = R_s i_{sq} + \omega_e (L_{sd} i_{sd} + \lambda_f) + \frac{dL_{sq} i_{sq}}{dt} \tag{11}$$

$$v_{sd} = R_s\, i_{sd} - \omega_e (L_{sd} i_{sq}) + \frac{d(L_{sd} i_{sd} + \lambda_f)}{dt} \tag{12}$$

Assuming the flux on the rotor in the dx axis is represented in a constant current source which can be described as $\lambda_f = L_m i_f$. The stator current equation can be determined as follows:

$$\frac{d}{dt}\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = -\begin{bmatrix} \frac{R_s}{L_{sd}} & -\frac{L_{sq}}{L_{sd}}\omega_e \\ \frac{L_{sd}}{L_{sq}}\omega_e & \frac{R_s}{L_{sq}} \end{bmatrix} \begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_{sd}} & 0 \\ 0 & \frac{1}{L_{sq}} \end{bmatrix} \begin{bmatrix} v_{sd} \\ v_{sq} \end{bmatrix} \tag{13}$$

The electric angular velocity (rad/s) of the generator is $\omega_e = z_p \omega_m$. Therefore, electrical torque equation (Te) PMSG is determined as follows :

$$Te = \frac{3}{2} z_p (\lambda_m i_{sq} + i_{sd} i_{sq} (L_{sd} - L_{sq})) \tag{14}$$

where v_{sq} is stator voltage axis q, v_{sd} is stator voltage axis d, R_s is resistance per phase (Ohm), ω_e is electrical speed (rad/s), λ_{qs} is flux stator axis q (Wb), λ_{ds} is flux stator axis d (Wb), L_{sq} is q axis stator inductance (H), L_{sd} is d axis stator inductance (H), λ_f is flux rotor permanent magnet axis d (Wb), L_m is permanent magnet inductance (H), i_f is d-axis rotor current (A), i_{sq} is q-axis rotor current (A), i_{sd} is d -axis stator currents (A), Te is electric torsion (Nm), λ_m is flux permanent magnet (Wb), and z_p is number of pole pairs

D. Rectifier Boost Converter

Fig. 3 shows a converter boost rectifier model, where 3 phase voltages are connected to rectifier and boost converter.

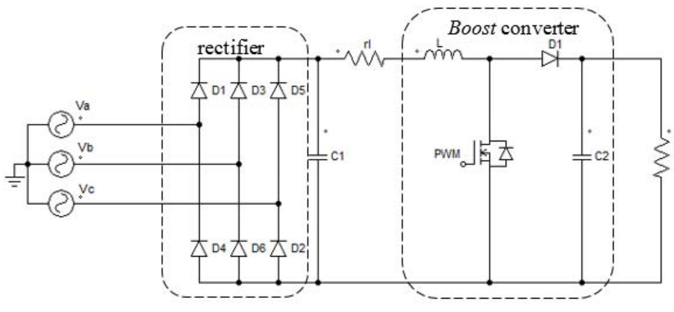

Fig. 3. Rectifier Boost converter.

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TABLE I. SWITCHING CONDITIONS OF RECTIFIER BOOST CONVERTER

No	Switch	Va	Vb	Vc
1	ON	1	1	0
2		0	1	0
3		0	1	1
4		0	0	1
5		1	0	1
6		1	0	0
7	OFF	1	1	0
8		0	1	0
9		0	1	1
10		0	0	1
11		1	0	1
12		1	0	0

Rectifier used in this study is a 6 pulse rectifier which has 6 switching conditions on the system. The diode condition is ON when the voltage v_a or v_b or v_c is greater than v_{DC} (C1 voltage). The MOSFET has two conditions, ON and OFF. Consequently, the rectifier boost converter will have 12 different switching conditions. Table I shows a condition of switching rectifier boost converter.

E. Low Pass Filter

Low pass filter is a filter that will weaken signals that have a frequency higher than cut-off frequency. This study used first order low pass filter. The function of the first order low pass filter is as follows:

$$\frac{V_o}{V_i} = \frac{1}{\tau s+1} \tag{15}$$

V_o is the output voltage, V_i is the input voltage and τ is the cut-off frequency of the filter.

F. MPPT Algorithm

One of the commonly used MPPT algorithms is P&O (perturb and observe). Flow diagram of the P&O algorithm is shown in Fig. 4.

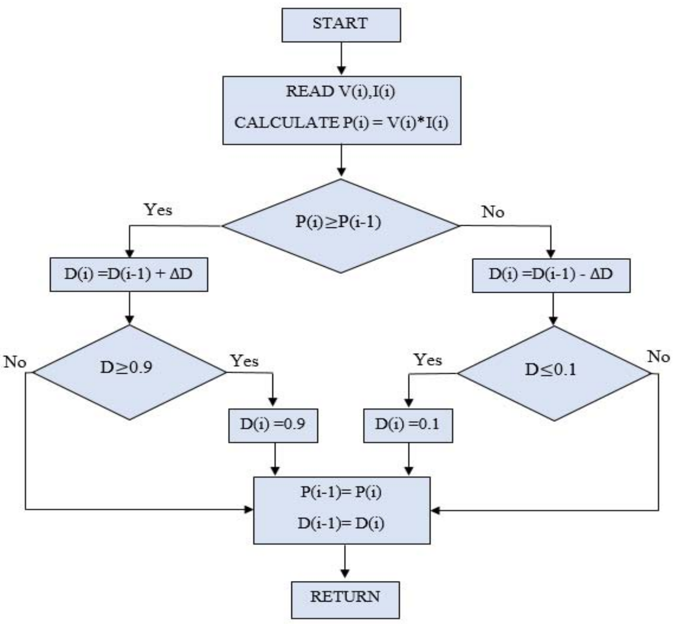


Fig. 4. Flow diagram of P&O algorithm.

In the MPPT P&O algorithm, the voltage (V) and current (I) output of the rectifier are read and the power value P(i) at that time is calculated. The power value P(i) is then compared with the power value in the previous calculation P(i-1). If the power P(i) is greater than the previous power P(i-1), then the duty cycle (D) value will be increased by ΔD. Conversely, if the power P (i) is less than the previous power P (i-1), then the duty cycle (D) value will be decreased by ΔD. If the duty cycle value of D (i) that has been obtained is greater or equal to 0.9, then the duty cycle D (i) will be set to 0.9. If the duty cycle value of D (i) that has been obtained is smaller or equal to 0.1, then the duty cycle D (i) will be set to 0.1. This is done to limit the resulting duty cycle value to remain in the range of values of 0.1 to 0.9. The power value P (i) is then stored in the memory and becomes the power value of P (i-1) at the next calculation. Likewise, the value of duty cycle D (i) will be stored also in the memory and becomes the duty cycle D (i-1) in the next calculation.

III. MPPT WIND TURBINE DESIGN SYSTEM

Fig. 5 shows the schematic of MPPT wind turbine system as a whole. The voltage and current of the three-phase AC wind turbine generator are rectified to the DC voltage and current by the rectifier. The output of the rectifier block (V_{dc} dan I_{dc}) will be the input of the MPPT controller block. The MPPT controller block will calculate the duty cycle value based on the MPPT algorithm that was built and will produce the duty cycle value corresponding to the maximum power of the wind turbine at that time. The duty cycle value is then used by the converter boost to determine how large the step-up input voltage (V_{dc}) is required to produce the maximum power.

In the wind turbine MPPT system design, modeling and simulation of the mathematical equation of each subsystem within CMEX on MATLAB/Simulink have been done. System modeling includes wind turbine modeling, shafts, PMSG, converter boost converters, and MPPT algorithms. Fig. 6 shows the whole model simulation performed on MATLAB/Simulink.

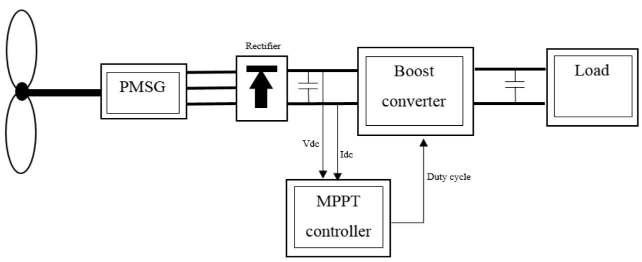


Fig. 5. Schematic of MPPT wind turbine system.

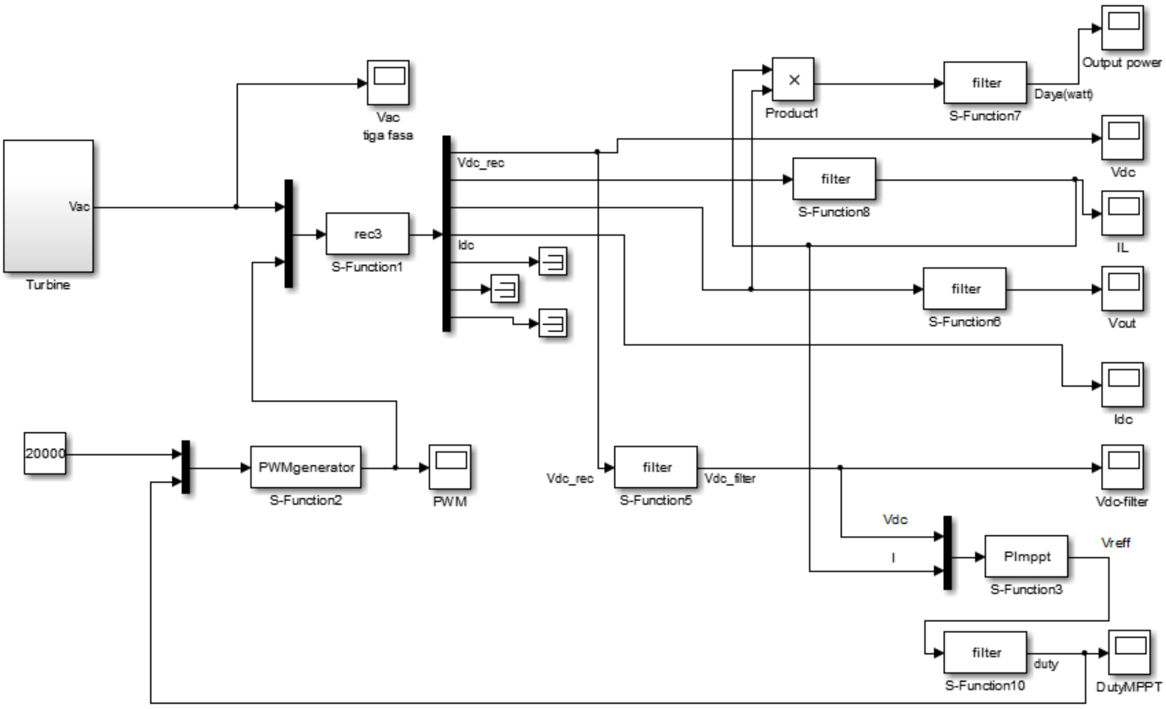


Fig. 6. The whole MPPT wind turbine system on MATLAB/Simulink.

Fig. 7. Wind turbine MPPT in real system.

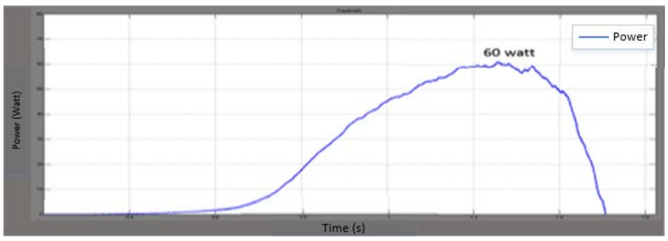


Fig. 8. Characteristics of the wind turbine generator output power at 2 m/s.

TABLE II. OUTPUT POWER CHARACTERISTICS OF WIND TURBINES ON VARIOUS THE WIND SPEED

No	Wind speed (m/s)	Max Power (Watt)
1	2	60
2	2.5	80
3	3	120
4	4.5	230

After modeling and simulation, then the author designed a wind turbine MPPT in the real system. The design of MPPT wind turbine in the real system includes wind turbine system design, converter boost converter system and wind tunnel manufacture. Fig. 7 shows the whole MPPT wind turbine system that has been built.

IV. TESTING AND ANALYSIS

A. MPPT algorithm on MATLAB / Simulink Testing

This test is carried out by providing varying wind velocity inputs on the turbine simulation block with values of 2m/s, 2.5m/s, 3m/s and 4.5m/s. The first step is to get a graph of the wind turbine generator power output characteristics at each given wind speed. Then test the MPPT algorithm on the wind turbine generator system. Fig. 8 shows the characteristics of the wind turbine generator output power at 2m/s. The test results of simulation output power characteristics of wind turbines at various wind speed can then be seen in Table II.

The testing of MPPT algorithm to the variation of the wind speed is performed after obtaining the output power characteristic graph. Fig. 9 shows changes in wind speed variation. Power MPPT algorithm calculation results are shown

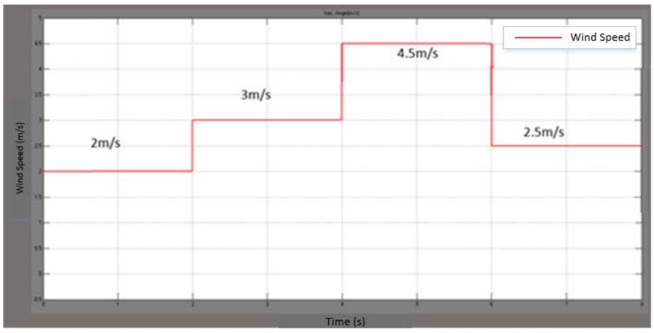


Fig. 9. Changes in wind speed variation graph.

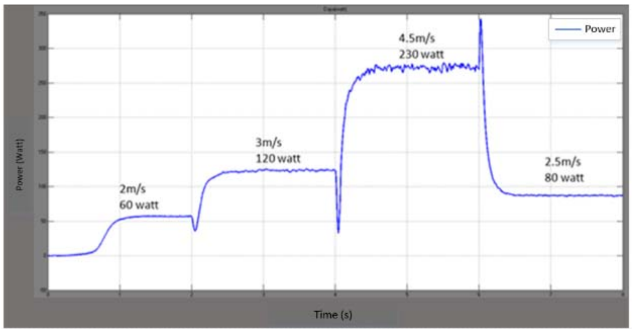


Fig. 10. Power MPPT algorithm calculation results.

in Fig. 10. Based on the test results in Fig. 10, the MPPT algorithm that has been built in the simulation is able to make the wind turbine produces maximum power at any given wind speed variation.

B. Turbine Output Power Characteristics Based on Load Variations Testing

In this test, variations of the load in MPPT system of the wind turbine generator are used. The loads used are 1000 ohm 100 watts resistor, 200 watts 1500 Ohm resistor, 2500 Ohm 300 watts resistor, 1 incandescent lamp, and 2 incandescent lamps. In each load variation, two tests were conducted, first, testing the output power of wind turbine generator without a controller and the second is testing to determine the maximum output power of the wind turbine generator. Testing the output power of an unmanned wind turbine generator is performed to find out how much output power can be generated when no power control is performed by the MPPT algorithm on each load. Whereas the maximum output power of wind turbine generator testing is performed to find out the maximum power that can be generated by wind turbine generator at each load.

The method used to test the maximum output power of wind turbine generator is the duty cycle set at zero, then the duty cycle value is incremented with the added factor of 10^{-6}. From the increase of duty cycle, the author will be able to examine the response of wind turbine output power at certain load condition. Testing is performed by connecting dc-dc boost converter with a certain variation of load to obtain the response of different power output of each load. The characteristics test of wind turbine power with load variation carried out at a constant wind speed of 8.5 m/s. Fig. 11 shows graphic of wind turbine power characteristics to the load variation along with the given duty cycle.

C. MPPT algorithm without filter testing

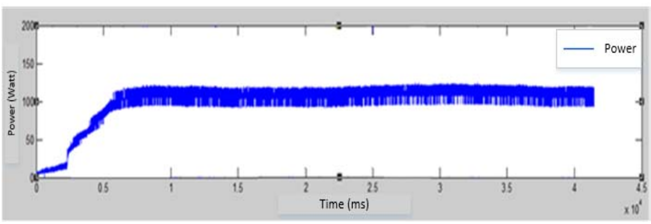
Testing the MPPT algorithm on the system is projected to validate the algorithm that has been built previously. The system used the same load variations and system configuration as characteristic testing. The MPPT algorithm test is performed by connecting the three-phase wind turbine generator output to the converted dc-dc boost converter. The three-phase output will then pass through a three-phase rectifier present in the dc-dc boost converter system. The output voltage and current from the rectifier will then be sampled for later processing in the MPPT algorithm. The test is carried out at a constant wind speed of 8.5 m/s. Fig. 12 shows one of the results of the MPPT algorithm without filter (1000 Ohm 100 watts load).

D. MPPT algorithm with filter testing

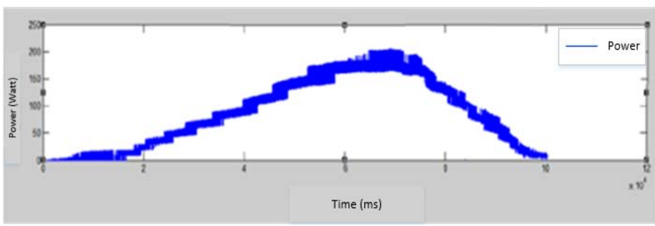
The MPPT algorithm with low pass filter testing is performed by applying filter algorithm at input voltage (V_{dc}) and input current (I_{dc}). It is to minimize the noise that occurs in both variables and to obtain a better duty cycle calculation on the MPPT algorithm that has been built. The cut-off frequency of the filter used is 100 Hz. The same system configuration as MPPT algorithm without filter testing for each load variation. The test is carried out at a constant wind speed of 8.5 m/s. Fig. 13 shows one of the results of MPPT algorithm with filter testing (1000 Ohm 100 watts load):

E. Test Results of Power Characteristics and MPPT Algorithm on Load Variations

Based on the testing of wind turbine generator power output characteristics and MPPT algorithm on load variation, the data obtained are shown in Table III. Table III shows the comparison of the output power without MPPT controller and output power using MPPT algorithm. It can be seen that by implementing the MPPT algorithm on the wind turbine

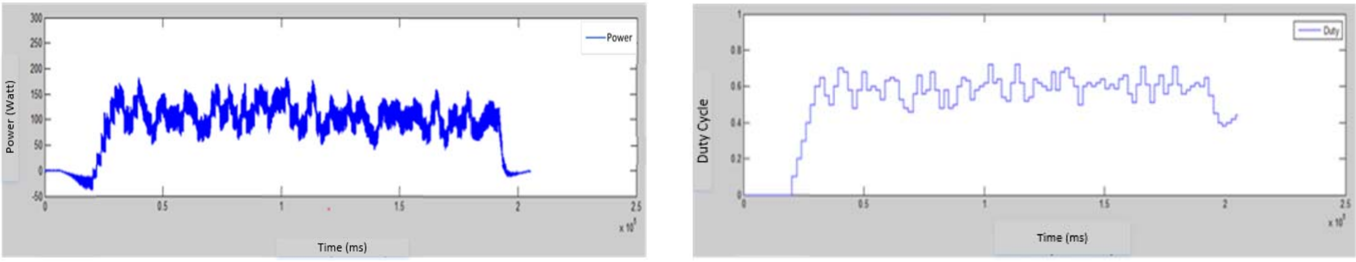


(a)



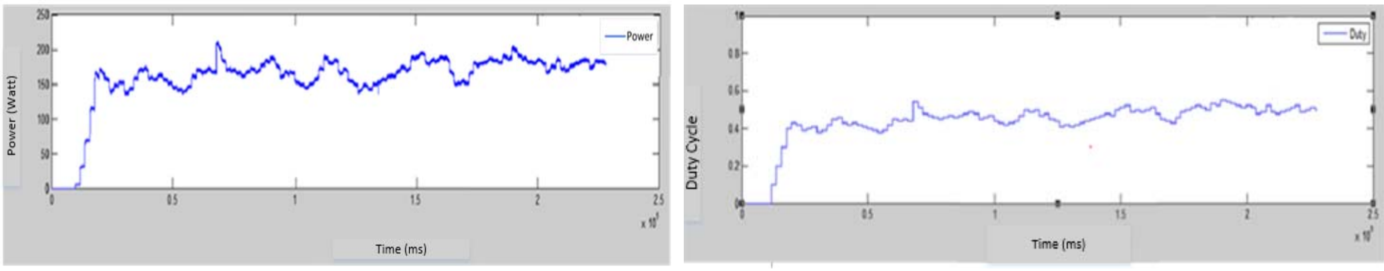
(b)

Fig. 11. (a) The output power of the generator without the controller at 1000 ohm 100 watt resistor load, (b) Graph of power characteristics at 1000 Ohm 100 Watt resistor load.



(a) (b)

Fig. 12. (a) Power resulted without MPPT filter 1000 Ohm 100 watts load. (b) Duty Cycle.



(a) (b)

Fig. 13 (a) shows one of the results of MPPT algorithm with filter testing (1000 Ohm 100 watt load). (b) Duty Cycle.

TABLE III. TURBINE GENERATOR OUTPUT POWER ON LOAD VARIATIONS

Load	Power (watt)			
	W/O controller MPPT	Max. Power Obtained	Power MPPT W/O filter	Power MPPT With filter
Resistor 1000 Ohm 100 watt	100	150-160	120	150
Resistor 1500 Ohm 200 watt	100	170-190	150	170
Resistor 2500 Ohm 300 watt	120	250	200	250
1 Incandescent Lamp 60 watt	40	130-150	120	130
2 Incandescent Lamp 120 watt	50	80-100	80	80

generator, the power generated by the wind turbine generator at each load variation became higher. It can also be seen that by applying the filter algorithm, the output power value generated is higher and closer to its maximum power value. This proves that the filter algorithm can produce a better calculation of MPPT algorithm. Figure 14 shows the outputs power of wind turbine generator to the variation of loads. From Fig. 14, it can be concluded that the power generated by the MPPT algorithm always has higher values than the wind turbine generator without the MPPT controller. The power generated by the MPPT algorithm using filter has higher values than the power generated by the unfiltered MPPT algorithm.

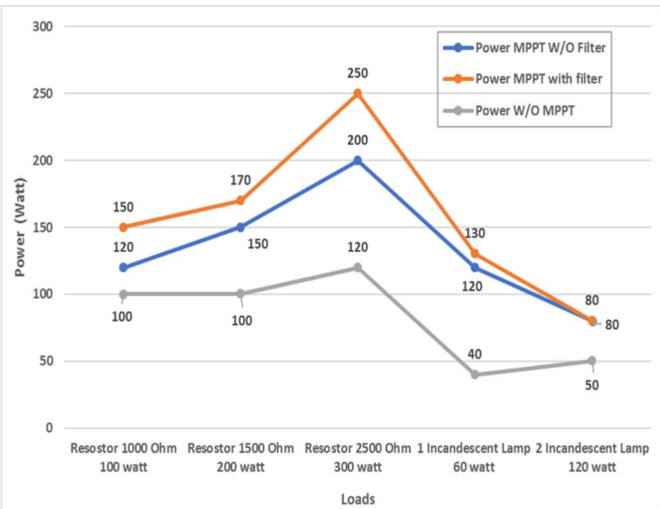


Fig. 14. Graphic of turbine generator output power to load variation.

F. Characteristic Testing of Wind Turbine Output Power to Wind Speed Variations

This test is performed by adjusting the wind speed with certain variations; 8.5 m/s, 6m/s, and 4.5 m/s. Wind speed was measured by using an anemometer to obtain proper wind speed. The same method on testing turbine characteristic to load variation was performed, duty cycle value incremented with addition factor 10^{-6}. The data resulted in this testing as shown in Table IV. Fig. 15 shows the output based on the test result in Fig. 14.

TABLE IV. CHARACTERISTICS OF WIND TURBINE POWER TO WIND SPEED VARIATIONS

No	Wind Speed (m/s)	Max. Power (Watt)
1	4.5	30
2	6	90
3	8.5	190

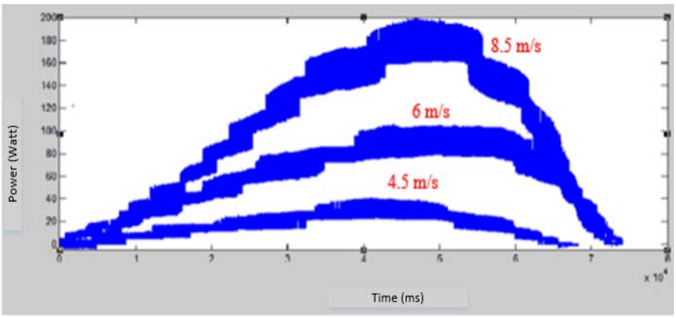


Fig. 15 Power characteristics to wind speed variations.

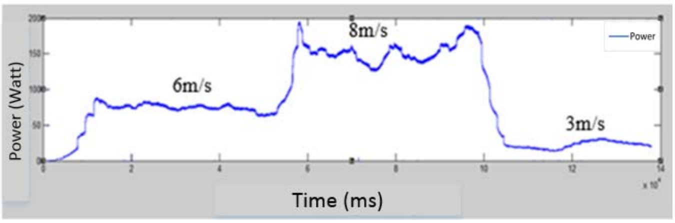


Fig. 16. The output power of MPPT algorithm to variations of wind speed.

G. MPPT algorithm Testing to Wind Speed Variation

This test is performed to determine the dynamic response of the MPPT algorithm that has been built by applying a low pass filter algorithm to the system. The load used on the system is a 100 watts 1000 Ohm resistor and the variations of wind speed were given on the system. First wind speed was set at 6 m/s, raised to 8 m/s then lowered to 3 m/s. The output power obtained from the test as shown in Fig. 16.

Fig. 16 shows that the turbine output power changed as the wind speed changed. It can be seen that the output power generated when the wind variations occur is always at the maximum power, compared with MPPT results with the filter on the test with 100 Ohm 100 watts resistor load in the previous section. The turbine output power is around 20 watts for the wind speed 3 m/s, about 80 watt for the wind speed 6 m/s, and 150 watts for the wind speed of 8 m/s.

V. CONCLUSIONS

The design of maximum power point tracking system in wind turbine has been successfully built and executed in controlling the maximum output power of wind turbine. Applying filter algorithm to the input voltage (Vdc) and input current (IDC) produces better MPPT calculation. The results show that the duty cycle calculation is more stable using MPPT algorithm with the filter. Therefore, the output of power calculation becomes higher.

ACKNOWLEDGMENT

Thanks to the Universitas Indonesia, which has funded this research.

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