ICIC Express Letters
Part B: Applications
Volume **11**, Number **1**, January **2020**

ICIC International ©2020 ISSN 2185-2766
pp. 17–24

POWER EXTRACTION OPTIMIZATION OF PMSG WIND TURBINE SYSTEM BASED ON SIMPLE MODIFIED PERTURB & OBSERVE

Ratna Ika Putri, Ika Noer Syamsiana and Muhamad Rifa'i

Department of Electrical Engineering
State Polytechnic of Malang
Soekarno Hatta Street No. 9, Malang, East Java 65141, Indonesia
ratna.ika@polinema.ac.id

Received July 2019; accepted October 2019

Abstract. *The power generated by PMSG wind turbine is highly dependent on the wind speed that is very intermittent. The power extraction is needed to improve the efficiency of the wind turbine system. This paper presents a power extraction optimization using simple variable step perturb and observe algorithm to get high-efficiency optimal power on small scale stand-alone wind turbine system with permanent magnet synchronous generator (PMSG). The proposed method uses the output power and voltage of the converter to determine the duty cycle of a buck converter without the mechanical sensor. The step size of the duty cycle will be changed adaptively based on the rectifier output power and duty cycle. The effectiveness of the proposed method is validated by laboratory experiment and compared by the conventional P&O algorithm for some wind speed. Based on the experiment result, the proposed method can extract optimal power and has a higher average efficiency of 94.73% than P&O algorithm. The proposed power extraction optimization has a simple structure, low cost and high performance.*
Keywords: Wind turbine, Power extraction, Optimization, Converter, Simple modified perturb and observe

1. **Introduction.** The use of wind energy as a fossil energy substitute for electric power generation is growing rapidly because its advantages are an abundant resource, clean, and safe [1,2]. Wind energy conversion system (WECS) consists of a wind turbine, electric generator, and power electronics to generate electricity. The electric generator converts turbine mechanical energy into electrical energy. Currently, a PMSG is the most widely used electric generator in wind energy conversion systems because the PMSG has high efficiency, better reliability, light, low volume, high performance, and low cost [3-5]. The power generated by WECS is highly dependent on wind speed that is intermittent and unpredictable [6-9]. To improve the efficiency of wind energy conversion systems, wind turbines must work at the optimal power point that can be achieved at optimum rotor speed at any wind speed through controlling of duty cycle on the power converter.

Several algorithms have been developed to extract optimal power in WECS. Fathabadi [10] has compared between maximum electrical power tracker (MEPT) and maximum mechanical power tracker (MMPT) as optimal power extraction. MEPT efficiency is higher than MMPT and it has better performance and faster convergence than MMPT [11]. Zhao et al. [12] have developed output power smoothing with optimum power extraction that can be applied for double-fed induction generator (DFIG) and PMSG based wind turbine. This method duplicates MPPT control trajectory and output power smoothing is done based on this trajectory. Various techniques have been developed for MEPT to get optimal power without mechanical sensor and anemometer. Power signal feedback (PSF) uses DC current and voltage based on the relation between the parameter from

DOI: 10.24507/icicelb.11.01.17

the look-up table [2]. However, PSF method requires information about wind speed, generator torque, and turbine characteristics to determine optimal power, thus increasing equipment costs in implementation [7,13]. Bhattacharjee and Roy [14] have applied fuzzy logic controller (FLC) as optimal power extraction through controlling of duty cycle on boost converter. FLC produces marginal improvement as compared with classical control.

The P&O method is the simplest and easiest method to implement. However, the performance of this method is determined by step size. The greater the value of step size the accuracy decreases and enlarges the oscillation around the maximum power point. However, the small step value will increase the search accuracy but the computation time will be longer [7,13,18]. To overcome the weakness of the P&O method, the variable step size has been developed. Mahdi et al. [8] modified the P&O algorithm by tuning automatically at the step size and observation period. Based on the experimental results, the algorithm can maximize the captured maximum power with varying wind speed conditions. However, this algorithm needs information about the rotor speed so it requires a mechanical sensor. This will certainly increase system costs and reduce system accuracy. Harrag and Messalti [15] modified the P&O method using a genetic algorithm to determine the step size of the P&O algorithm for a photovoltaic system. The use of GA and PID controllers adds to the complexity of the system, requiring larger memory and increasing system costs. Chen et al. [16] modified the P&O algorithm by using a PI controller to obtain a duty cycle value. The P&O algorithm uses dc link voltage and power as input variables, without using mechanical sensors. However, the use of PI controllers requires the determination of the appropriate controller parameters and is not easy in determining them. Shahi and Bhattacharjee [17] have modified P&O method using fuzzy logic to determine step size duty cycle on P&O method. Based on simulation result, fuzzy based MPPT has better performance than classical P&O method. Youssef et al. [18] have developed variable step perturb and observe based on multi sector operation region by comparing the power-speed curve. Compared by conventional P&O method, variable step size method has higher efficiency and faster system response.

This paper presents simple modified perturb & observe (SMPO) method to overcome drawback of conventional P&O method. Step-size of duty cycle will be changed adaptively based on the rectifier output power and the duty cycle to get optimal power faster and reduce oscillation on maximum power point. The proposed method introduces simple power extraction that is applied on PMSG wind turbine. The simple modified P&O algorithm is based on the output voltage and current of a converter to set the duty cycle of the buck converter. SMPO algorithm is implemented on the microcontroller and tested on a prototype of small scale standalone wind turbine. Performance of SMPO will be compared by conventional P&O method. Experiments have been done at several wind speeds using the stand-alone WECS prototype. The SMPO algorithm can extract optimal power and has higher efficiency than P&O method. The organization of paper is as follows. PMSG wind turbine system is shown in Section 2, simple modified P&O for optimal power extraction design is given in Section 3, and experiment result and conclusion are given in Section 4 and Section 5.

2. **PMSG Wind Turbine System.** The wind turbine system with the optimal power extractor using the SMPO algorithm consists of wind turbine emulator with variable speed drive and induction motor, PMSG, full-bridge 3 phase rectifier, buck converter, and a microcontroller to implement the SMPO algorithm. The buck converter is controlled by the SMPO algorithm so that the output power of the converter produces maximum power. Figure 1 describes the proposed system. Wind turbine emulator will drive PMSG according to desired wind speed.

Microcontroller has function to generate duty cycle for MOSFET switching in buck converter circuit based on SMPO algorithm used. The output of the buck converter

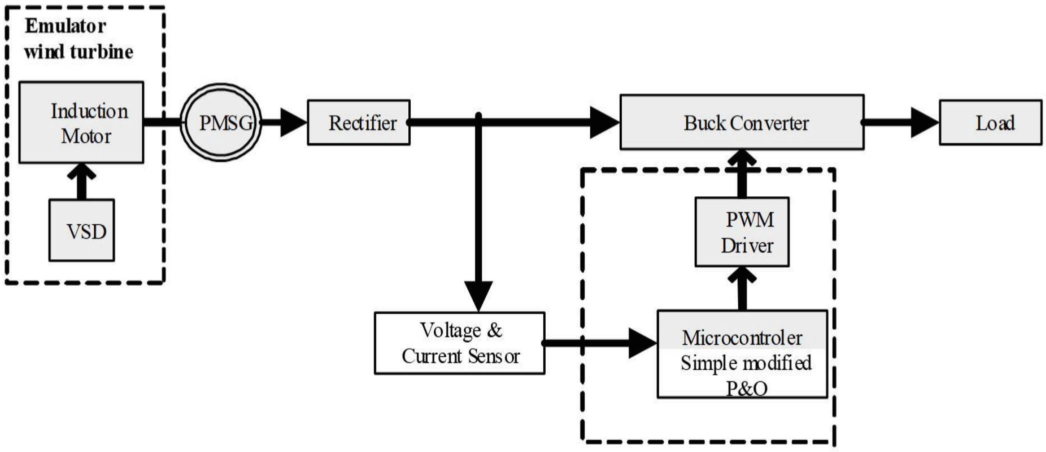


Figure 1. Block diagram of wind turbine system

is connected to the load. Microcontroller used Atmega 16 to implement simple modified perturb & observe that extracts optimum power in wind power system through controlling of the duty cycle of buck converter. Microcontroller Atmega 16 is equipment that is cheap and easy to implement in the proposed system. The SMPO algorithm will adjust duty cycle of pulse width modulation (PWM) signal to get optimal power. PWM signal will be sent to drive MOSFET switching at buck converter. Current and voltage of converter is read by microcontroller through sensor. Current sensor used ACS741 20 Ampere.

3. Simple Modified P&O for Optimal Power Extraction.

To achieve the optimum power, rotor speed of PMSG must be adjusted by duty cycle controlling of converter. PMSG is connected to 3 phase rectifier so that the rectifier output voltage depends on rotor speed. To simplify the control design, the relationship between rotor speed and the rectifier output voltage can use straight line approach and can be expressed by [19]

$$V_{rec} = Kr \cdot \omega \tag{1}$$

where V_{rec} is the rectifier output voltage, Kr is the approximation constant and ω is rotor speed of PMSG. The relationship between the rectifier output power and rotor speed is shown in Figure 2. At a certain wind speed, the optimum output power will be achieved at the optimum rotor speed.

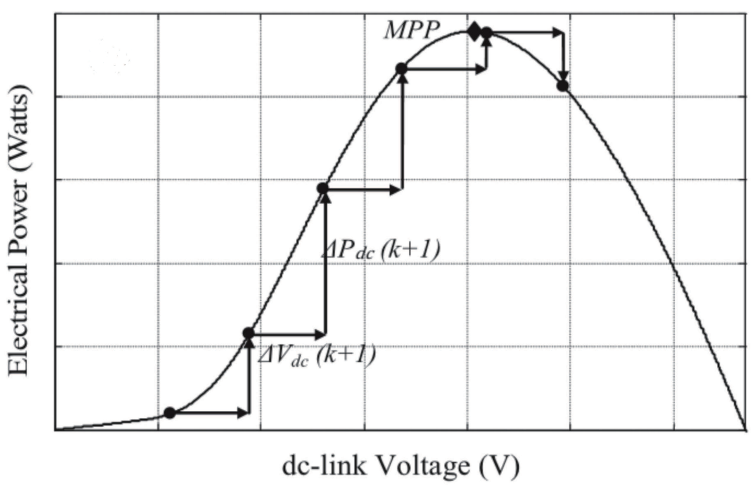


Figure 2. Characteristic curve in perturb and observe algorithm

The P&O method can be used to determine the optimum point. Using the P&O method, the maximum power value can be obtained without having to know the characteristics of the wind turbine system. The maximum power value is obtained by adjusting the dc voltage in the converter. The P&O method is the simplest and easiest method to apply among other methods. However, this method has limitations because the efficiency of this method depends on the variable size of ΔD. ΔD value also defines computation time to get the optimum value and resulted oscillation of system so that determining the appropriate ΔD value will influence algorithm performance. Drawback of perturb and observe (P&O) methods can be solved by changing the value of ΔD used to find the generated maximum power point value.

In this paper, the SMPO algorithm was developed based on the P&O algorithm without rotor speed measurement and wind speed. The algorithm will determine the duty cycle based on the voltage and output current of the rectifier. This method regulates and observes any such changes that are determined at a certain step-size (ΔD) and a certain time. The value of electric power generated compared to previous electrical power. The rectifier output power was calculated by microcontroller through measurement of voltage and current that are sampled and recorded by it. Microcontroller calculates the output power difference and the output voltage difference that can be expressed by

$$\Delta P_{dc} = V_{rec}(k)I_{rec}(k) - V_{rec}(k-1)I_{rec}(k-1) \tag{2}$$

$$\Delta V_{rec} = V_{rec}(k) - V_{rec}(k-1) \tag{3}$$

where $V_{rec}(k)$ is the k-th sample of the rectifier output voltage and $I_{rec}(k)$ is the k-th sample of the rectifier output current. Based on flowchart of algorithm, there are three cases.

- dP_{dc}/dV_{rec} with the negative sign, there are two cases: $dP_{dc} > 0 - dV_{rec} < 0$ and $dP_{dc} < 0 - dV_{rec} > 0$. In this case, generator speed must be increased and duty cycle will be decreased that can be expressed by

$$D(k+1) = D(k) - \Delta D \tag{4}$$

- dP_{dc}/dV_{rec} with the positive sign, there are two cases: $dP_{dc} > 0 - dV_{rec} > 0$ and $dP_{dc} < 0 - dV_{rec} < 0$. In this case, generator speed must be decreased and duty cycle will be increased that can be expressed by

$$D(k+1) = D(k) + \Delta D \tag{5}$$

- dP_{dc}/dV_{rec} equals zero, the optimum power is achieved and duty cycle change does not require, so that

$$D(k+1) = D(k) \tag{6}$$

ΔD is duty cycle change that is updated continuously by,

$$\Delta D(k+1) = \Delta D(k) * C \tag{7}$$

C is a constant, a modification factor, with value between 0-1. If the value of ΔP_{dc} is above the minimum value, the maximum power value has not been achieved, then the step size of the duty cycle will be updated through multiplication with modification factor (C) that has a value between 0-1. The larger the iteration, the closer to optimal power so that the step size value will be getting smaller.

4. **Result and Discussion.** The effectiveness of the simple modified perturb & observe algorithm to obtain the optimum power is tested at several wind speeds and compared with conventional P&O methods. Figure 3 shows experimental equipment of the proposed system that consists of variable speed drive (VSD), induction motor, PMSG, converter and control circuit. Converter and control circuits include a voltage sensor, the current sensor, microcontroller, 3 phase rectifier, and buck converter. Wind speed is simulated

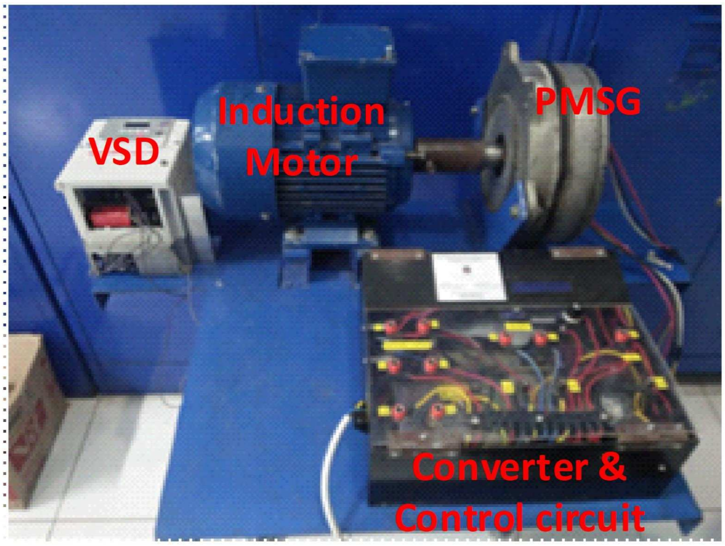


FIGURE 3. Wind turbine system prototype

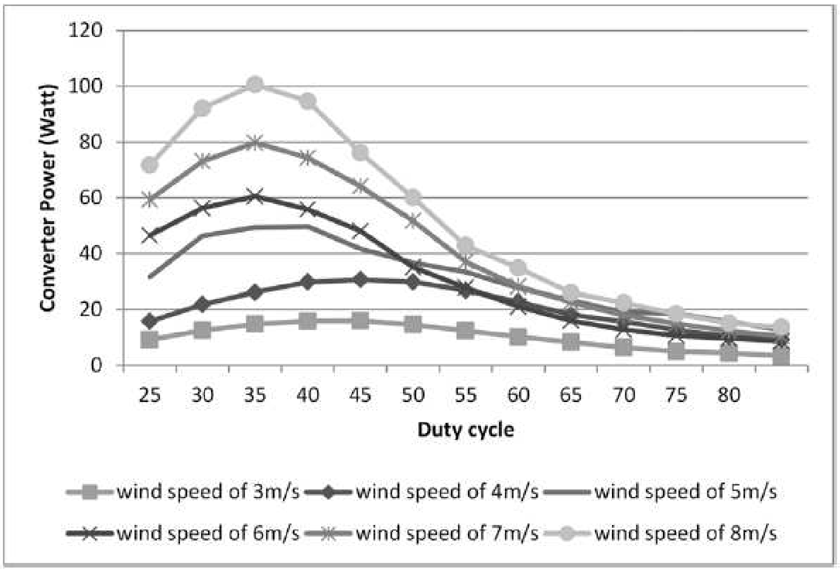
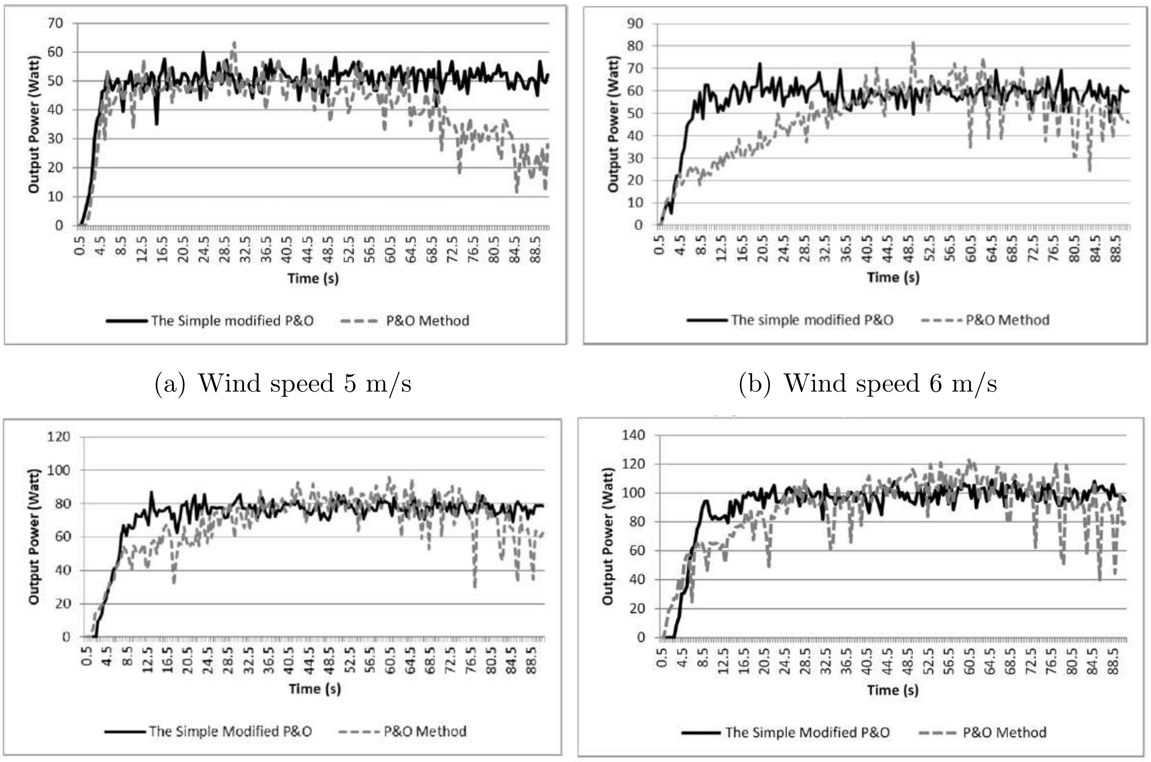


FIGURE 4. The real characteristic curve of output power and duty cycle

using a wind turbine emulator through motor induction controlling to adjust generator speed that is suitable with the desired wind speed.

The relationship between wind speed and generator speed was gotten through measurement in Tasikmalaya Indonesia. Based on the measurement results, the change in wind speed is proportional to the change in the speed of the generator. The system characteristic curve to obtain optimum power is needed to evaluate the performance of the SMPO algorithm. The characteristic curve is obtained based on the measurement results of the buck converter output power produced for several different wind speeds. The measurement of buck converter output power is done on the system through changing the duty cycle without using a controller. The real characteristic curve of the proposed system based on output power is shown in Figure 4. At certain wind speeds, the optimum power will be achieved at a certain duty cycle. Testing the optimum power value without MPPT is done by adjusting wind speed 3 m/s up to 8 m/s and the duty cycle of the buck converter is changed manually from 20% to 80%.



(a) Wind speed 5 m/s (b) Wind speed 6 m/s

(c) Wind speed 7 m/s (d) Wind speed 8 m/s

Figure 5. Comparison of experiment result between proposed algorithm and P&O algorithm

The SMPO algorithm as the optimum power extraction controller has been tested for some wind speed. To evaluate its performance, the experiment result of the SMPO algorithm will be compared with the conventional P&O method and the real characteristic curve. The wind turbine emulator generates wind speed changes at 5 m/s, 6 m/s, 7 m/s and 8 m/s. At each wind speed, the output voltage and current of buck converter is measured by sensor and recorded through microcontroller to get the converter output power. The experiment result of implementation of the SMPO algorithm which is compared by the P&O algorithm is shown in Figure 5. At wind speeds of 5, 6, 7, and 8 m/s, the converter average output power produced by the proposed system with SMPO algorithm are 49, 55.79, 72.13, and 91.68 Watt respectively. At same condition, the system with the conventional P&O algorithm produces 24.76, 40.75, 47.67, 67.51, and 88.41 Watt. Based on experiment result, implementation of the SMPO algorithm produces a bigger optimum power and smaller oscillation compared by the P&O algorithm so that the SMPO output power more optimal than P&O algorithm and the time required to reach the optimum power is shorter.

The efficiency of used SMPO is determined based on a ratio between a real characteristic curve based on measurement result, as shown in Figure 4, and the optimal power converter that is obtained by the optimal power extractor. The efficiency comparison between the P&O and SMPO algorithms is summarized in Table 1. The average of efficiency for SMPO algorithm achieves 94.73% and the conventional P&O algorithm is only 82.64%.

5. **Conclusion.** The SMPO algorithm, as power extraction optimization, for a stand-alone 500-Watt wind turbine with PMSG has been presented in this paper. To achieve optimal power, SMPO algorithm controls the duty cycle of the buck converter through the output voltage and current of the converter. The proposed method is appropriate for small scale wind turbine system because it does not need the mechanical sensor and

Table 1. Comparison of efficiency between P&O and SMPO method

Wind Speed	Optimum Power (Watt)			Efficiency (%)	
	Real Characteristic Curve	SMPO	P&O	SMPO	P&O
3 m/s	16.02	15.88	13.06	99.11	81.58
4 m/s	30.65	29.64	24.76	96.70	80.81
5 m/s	49.63	49	40.75	98.73	82.12
6 m/s	60.48	55.79	47.67	92.26	78.83
7 m/s	79.75	72.13	67.51	90.45	84.65
8 m/s	100.61	91.68	88.41	91.13	87.87
Average Efficiency				94.73	82.64

wind turbine information, low cost and simple. Based on experiment result, the SMPO algorithm has better performance than P&O method and has the average efficiency of 94.73%. The future research will develop SMPO algorithm for wind turbine system that is connected to grid.

Acknowledgment. The authors gratefully acknowledge the full financial support received from ministry of research, technology and higher education, Indonesia through university basic research grant.

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