Controlling of PMSG-Assisted Wind Energy Conversion System with Maximum Power Tracking Technique

Diwaker Pathak, Rupendra Pachauri and Yogesh K. Chauhan

Abstract This paper develops a dynamic model of small-scale wind energy conversion system (WECS) based on diode bridge rectifier and permanent magnet synchronous generator (PMSG). The simple and effective perturb and observe (P&O) algorithm has been proposed for extracting maximum power point tracking (MPPT) of wind turbine (WT) in the moderate-to-cutout wind speed region by sensing input parameters of DC–DC buck–boost converter. The MPPT algorithm in addition to the DC–DC converter is being simulated in MATLAB/Simulink software. The obtained characteristics show the effectiveness of P&O MPPT technique for extracting maximum power from the wind and delivering it appropriately to the resistive load.

Keywords DC–DC buck–boost converter · Wind turbine · P&O controller
Permanent magnet synchronous generator (PMSG) · Renewable energy

1 Introduction

The energy composed from the sources which are replenished by nature such as sunlight, wind is defined as renewable energy (RE) [1]. RE sources exist on large geographical areas on earth in the form of various energies such as wind, solar, biofuel. The depletion of energy resources like fossil fuels is due to rapid and high

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R. Singh et al. (eds.), *Intelligent Communication, Control and Devices*,
Advances in Intelligent Systems and Computing 624,
https://doi.org/10.1007/978-981-10-5903-2_109

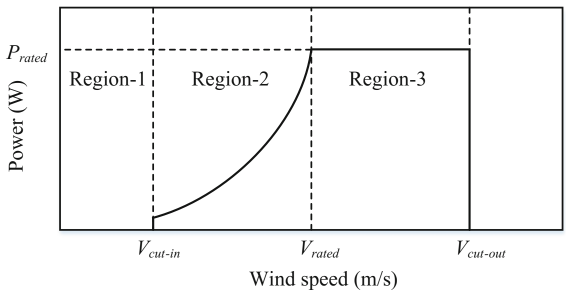


Fig. 1 Ideal power characteristics of wind turbine

utilization. So exploring more energy sources is must. Therefore, a concept of power feedback based on the WECS is proposed in this paper.

The wind potential and direction can be used to generate electricity. But the characteristics of wind speed are highly variable in nature [2]. In this work, a WECS is integrated with P&O algorithm as maximum power extraction technique to investigate the connected resistive load under variable state of wind speed [3, 4].

Control techniques are implied to a wind turbines (WTs) to operate them in a specific range of wind velocity within cut-in ($V_{\text{cut-in}}$) and cutout ($V_{\text{cut-out}}$) velocities. Figure 1 shows the generalized power characteristics of a WT having three different operating regions, namely low-speed region (speed less than or equal to $V_{\text{cut-in}}$), moderate-speed region (speed between $V_{\text{cut-in}}$ and V_{rated}), and high-speed region (speed between V_{rated} and $V_{\text{cut-out}}$). The center of attention of this paper is to analyze the WECS in moderate- and high-wind speed [5].

In [5], authors have concluded that P&O method is flexible and simple in implementation. However, they found P&O method as inefficient having some problems during the determination of optimal value of variable wind speed conditions. In [6], authors have proposed a control scheme for output power extraction from grid-integrated dynamic WECS. They analyzed the proposed MPPT algorithm in MATLAB/Simulink and found an effective technique. In [7], the authors have compared two MPPT algorithms and their implementation in small WECS, namely incremental conductance method (INC) and P&O to prove the effectiveness and reliability of the designed algorithms. In [8], the authors used the P&O algorithm to initialize the command for searching online a maximum power point (MPP) to operate an ideal relation-based technique. The authors in [9] derived a relation for the optimal current in terms of voltage to reach MPP.

This research work presents an effective algorithm, namely P&O for extracting the maximum power in the moderate and above wind speed regions. The WT has been modeled with the dynamic equations in MATLAB/Simulink comprising of PMSG, diode bridge rectifier, and a DC–DC buck–boost converter. The method used in this paper is focused on the concept of identifying the peak value and calculating the voltage and current at that value for the approximation of the duty cycle of buck–boost converter. Once the duty cycle is estimated, then this method can be implemented to determine the optimum output voltage and current for MPPT.

2 Wind Energy Conversion System Layout

The proposed WECS comprises a fixed blade pitch and fixed tip-speed ratio (TSR) WT, a PMSG, a diode bridge rectifier, a DC–DC buck–boost converter, and a resistive load as shown in Fig. 2.

2.1 Wind Turbine System Architecture

The wind power (P_{wind}), power (P_m), and torque (τ_{WT}) equation of a WT are expressed [2] as

$$P_{\text{wind}} = \frac{1}{2}A\rho V_w^3, \quad P_m = 0.5\rho A C_p V_w^3, \quad \tau_{\text{WT}} = 0.5\rho A C_p V_w^2 \frac{R}{G\lambda} \tag{1}$$

where A is the probe area of WT blades. ρ, $V_{w,}$ and C_p are air density, wind velocity, and performance coefficient, respectively. R, G, and λ are rotor radius, gear ratio, and tip-speed ratio (TSR), respectively. C_p is expressed [1] as

$$C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{-C_5}{\lambda_i}} + C_6\lambda, \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3+1} \tag{2}$$

where $C_1, C_2, \ldots C_6$ are coefficients. β and λ_i are pitch angle and initial TSR, respectively. λ is the ratio of the speed of blade tips of a WT and wind velocity [3].

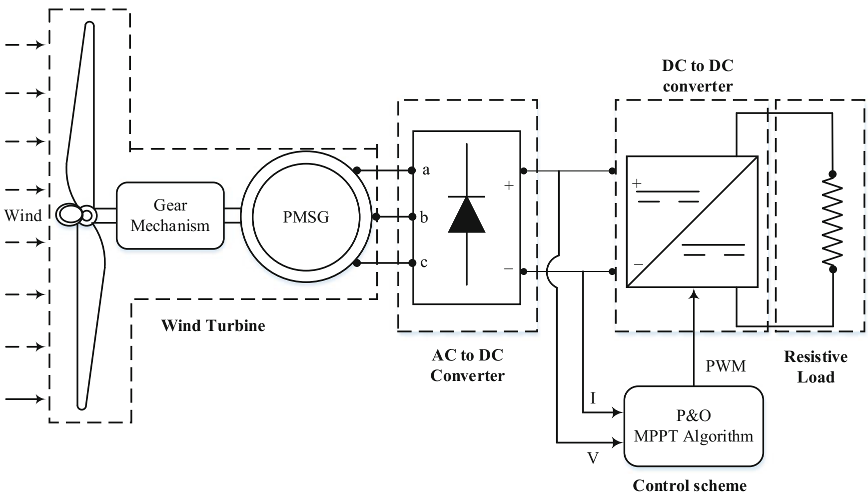
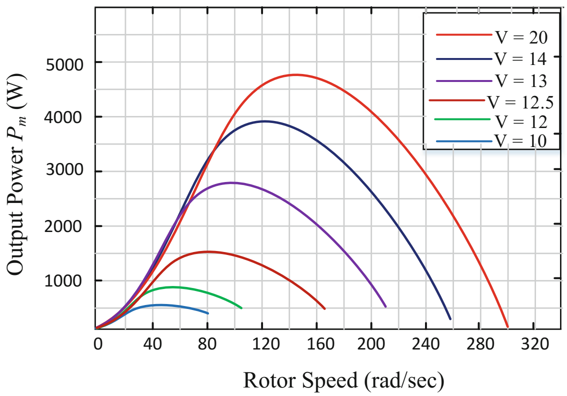


Fig. 2 Proposed system layout

Fig. 3 Power characteristics



$$\lambda = \frac{V_{\text{TIP}}}{V_W} = \omega_r \cdot R/V_w \tag{3}$$

where V_{TIP} is speed of tips of blades, and ω_r is rotor angular velocity. Figure 3 shows the power characteristic curves in various wind speed conditions.

2.2 DC–DC Buck–Boost Converter Architecture

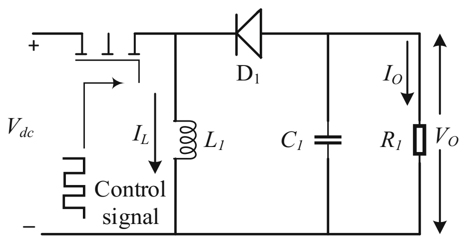
The buck–boost converter is one of the DC to DC PWM converters having output voltage level that must be larger or less than the input voltage level. Relation of the voltage and current is given by Eq. (4) as

$$V_{\text{in}} = L\frac{I_2 - I_1}{T_1} = L\frac{\Delta I}{T_1}, V_o = -L\frac{\Delta I}{T_2} \tag{4}$$

where V_{in} is input voltage, I_1 and I_2 are the minimum and maximum inductor currents, respectively. T_1 and T_2 are switching periods.

The equivalent circuit diagram of buck–boost converter is presented by Fig. 4.

Fig. 4 Equivalent circuit of buck–boost converter



The relation between the on time and off time of the switch and the total time duration is given in terms of duty ratio (D) [10] as

$$T_1 = DT, T_2 = (1 - D)T \tag{5}$$

where T is total switching period ($t_{\text{on}} + t_{\text{off}}$).

Combining both relations of Eqs. (5, 6) is derived as

$$V_o = -\left(\frac{D}{1 - D}\right)V_{\text{in}} \tag{6}$$

3 Maximum Power Point Tracking System

In this paper, analysis of P&O method is presented. The P&O is one of the most extensively used methods in recent years. The output voltage and power of WT are changed by varying the D, and whether the new output power increases constantly or not is being observed. The operating power point on the left or right of the curve is perceived allowing the input voltage. Finally, whether the duty cycle D keeps changing in the same direction or not is determined. The MPP can be achieved by such repeated perturbation, observation, and comparison. The algorithm is presented by flowchart in Fig. 5.

The actual output DC voltage and current developed by MPPT method is applied as a source signal for comparison with the input parameters of buck–boost converter. Finally, the variation between outputs has been fed to duty cycle [8].

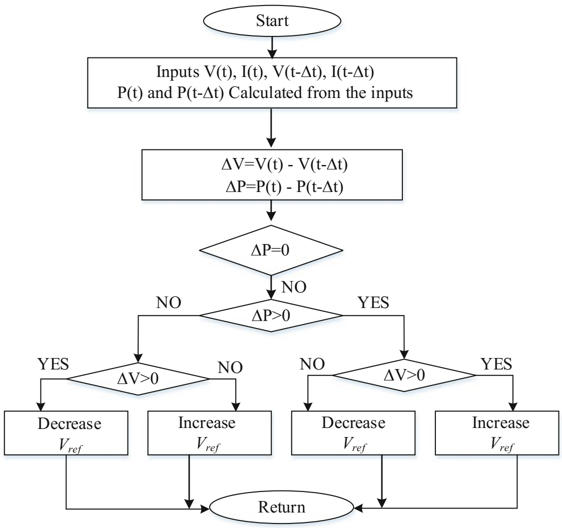


Fig. 5 Flowchart of P&O algorithm

4 Simulation Analysis Results

The proposed MPPT technique is analyzed and investigated under the dynamic wind speed as shown in Fig. 6. The WECS response is analyzed under the proposed strategy.

Figure 7a–b shows the WT generator performance. Figure 7a shows the response of electromagnetic torque of the WT, and Fig. 7b shows rotor speed of the PMSG. Initially, the wind speed is 20 m/s. At this moment, electromagnetic torque starts increasing and gets stable on 18 Nm. Negative sign shows the generating mode. At the same time, rotor speed also starts increasing from its standstill position and gets settled at 152 rad/s. After 0.5 s, wind velocity is step-decreased as shown in Fig. 3.

At t = 1.5 s, wind velocity is step-increased to 14 m/s. Both parameters of the WT generator start increasing. At this time, electromagnetic torque is again 16 Nm and rotor speed is 130 rad/s.

Figure 8a–c presents the performance characteristics of DC–DC buck–boost converter under the P&O technique when wind speed is varied stepwise. Initially, when wind speed is taken 20 m/s, output voltage of the DC–DC buck–boost

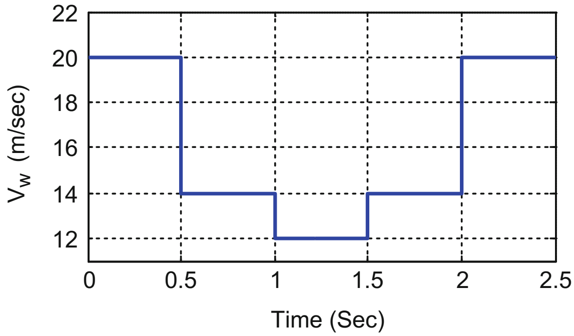


Fig. 6 Considered wind speed pattern

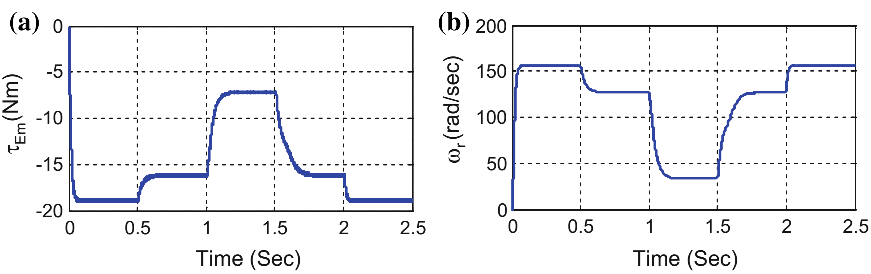


Fig. 7 **a**, **b** WT generator performance

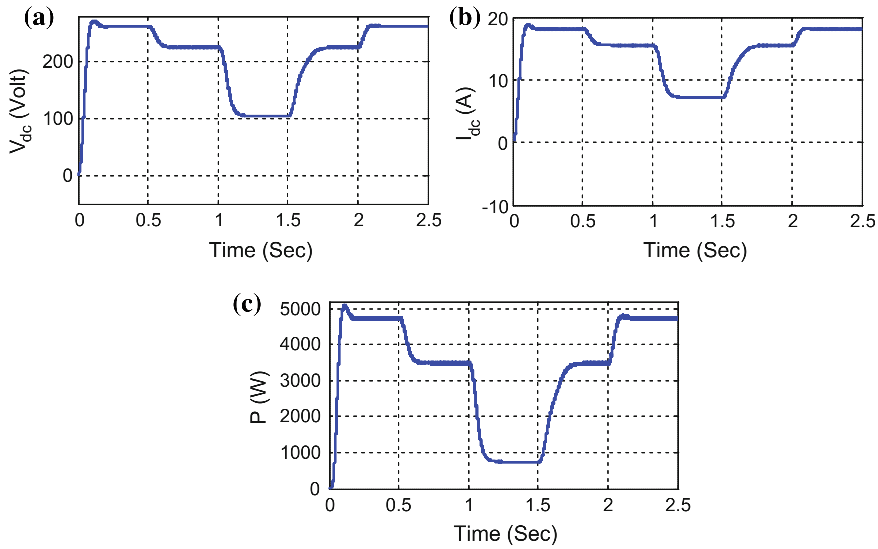


Fig. 8 **a–c** Output parameters at resistive load

converter is 263.88 V and current is 18 A. Therefore, power obtained by the MPPT technique is 4750 W.

Hence, it is investigated that maximum power tracked by the MPPT is 4750 W at rotor speed of the 152 rad/s when wind speed is 20 m/s. Above or below this wind speed and rotor speed, power gets reduced and efficiency of the WECS experienced very poor.

5 Conclusion

Investigations of WECS have been carried out by developing the Simulink model of complete system under consideration. The results have been discussed in detail to assess the performance of P&O MPPT-assisted WECS. The P&O controller operated in this paper used voltage and current generated by the WECS to generate the duty cycle by adjusting the parameter for different systems. The obtained results show a significant performance for WECS system with P&O algorithm. The study can be used to increase the system's stability by constant power generation in dynamic wind speed condition. Due to fewer controller parameters, the considered system is less complex, which is having good speed and stability. When this control is employed with small wind power system, it can be a cost-effective solution.

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