The Scientific Journal of University of Benghazi

http://journals.uob.edu.ly/sjuob

Simulation of MPPT with a PMSG-based wind energy conversion system considering variable wind speed

Elbahlul Abogrean [1] , Eddawi_Ali Elhatmi [2 *], Jamila Alnouri Saad [3]

1 Gharyan University- Faculty of Engineering- Gharyan, Libya.
2 Almarifa University For Humanities and Applied Sciences-Petroleum Engineering Tripoli-Libya.
3 College of Civil Aviation Technology and Meteorology-Asabi-Tripoli- Libya.

Received 30 / 11 / 2022; Accepted 19 / 01 / 2023

الملخص

لتعزيز كفاءة نظام تحويل طاقة الرياح (WECS)، عادةً ما يتم استخدام خوارزمية تتبع نقطة الطاقة القصوى (MPPT). يقدم هذا البحث خوارزمية مثالية لاستخراج الحد الأقصى من الطاقة المتاحة في ظل ظروف تغيير سرعة الرياح وجهاز تحكم زاوية الملعب، والذي يتم تطبيقه في مولد متزامن مغناطيسي دائم (PMSG) قائم على WECS.

توفر الطريقة المقترحة أداء تتبع جيدًا من خلال اكتشاف التباين في سرعة الرياح بسرعة. بالإضافة إلى ذلك، لا يتطلب التنفيذ معلومات مسبقة عن معلمات توربينات الرياح أو كثافة الهواء أو سرعة الرياح. من خلال التحقيق في اتجاهات التغيير لطاقة الخرج الميكانيكية لتوربينات الرياح وسرعة الدوار للمولد، يمكن لخوارزمية MPPT المقترحة تحديد السرعة المثلى لتحقيق أقصى نقطة طاقة (MPP).

بعد ذلك، يتم ضبط هذه السرعة المثلى على المرجع في حلقة التحكم في السرعة لإجبار النظام على العمل عند MPPT. تم استخدام محول التعزيز DC-DC لزيادة جهد التيار المتردد المنخفض الناتج عن PMSG المدفوع مباشرة بواسطة توربينات الرياح. يتم حساب طاقة الخرج الميكانيكية لتوربينات الرياح من عزم الدوران الميكانيكي الذي يتم قياسه مباشرة بواسطة جهاز الاستشعار.

تم تصميم المخطط المقترح ومحاكاته في إطار برنامج (MATLAB/ SIMULINK). وليحقق نتائج محاكاة دقيقة لنظام تحويل طاقة الرياح.

الكلمات المفتاحية: توربينات الرياح، تتبع أقصى نقطة للطاقة (MPPT)، مولد مغناطيسي دائم متزامن (PMSG)، نظام تحويل طاقة الرياح (WECS).

Abstract

The proposed method provides a good tracking performance through detecting the variation in the wind speed rapidly. In addition, the implementation does not require prior information on the wind turbine parameters, air density, or wind speed. By investigating the change directions of the mechanical output power of the wind turbine and the rotor speed of the generator, the proposed MPPT algorithm can determine an optimal speed to achieve the maximum power point (MPP).

Then, this optimal speed is set to the reference in the speed control loop to force the system to operate at the MPP. The DC-DC boost converter has been used to boost up the low AC voltage generated by the PMSG directly driven by the wind turbine. The mechanical output power of the wind turbine is calculated from the mechanical torque which is measured directly by sensor.

The proposed scheme is modeled and simulated under SIMULINK/MATLAB. The simulation results are accurate and validate the wind energy conversion system.

Keywords: Wind Turbine, maximum power point tracking (MPPT), permanent magnet synchronous generator (PMSG), wind energy conversion system (WECS).

1. INTRODUCTION

Wind energy sources, along with solar energy sources, are considered to be the most promising renewable energy sources. Wind turbines (WTS) and wind power plants do not produce pollution or emissions, so wind energy conversion is one of the cleanest and safest methods for generating electricity. In 2019, wind energy provided an estimated 6 % of the world's and 15 % of the EU's annual electricity generation (47 % in Denmark, the leading wind energy producer) [1]. Under the current rate of progress, wind energy will be able to meet about 29 % of the world's electricity consumption needs by 2030, with this figure reaching 34 % by 2050.

***Correspondence**: Eddawi Ali Elhatmi
eddawi_elhatmi@yahoo.com

Falling costs per kilowatt-hour are making wind energy more competitive. However, due to the inherent variability of the wind, integration of wind power with the grid has brought various challenges, including power quality, system stability and planning. Contemporary wind energy conversion systems (WECS) for the commercial production of electric power most often use wind turbines with horizontal rotational axis (HAWTs) and a three-blade rotor. In this work, we consider a Type 4 WECS, in which an induction or synchronous generator is connected to the grid through a full power converter [2]. As the Permanent Magnet Synchronous Generator (PMSG) is the most preferred wind generator due to its reliability and size for stand-alone wind energy conversion, system MPPT control algorithms can be employed to capture the maximum power

 ISSN:Online 2790-1637, Print 2790-1629; National Library of Libya, Legal number : 154/2018

from available wind by maintaining the optimum steady voltage across the load.

2. LITERATURE REVIEW

In this paper, a model of a wind turbine using a permanent magnet synchronous generator (PMSG) is presented and the control schemes are proposed. The model presents the Maximum Power Point Tracking (MPPT) algorithm used to extract maximum power from a PMSG direct-driven wind turbine. The DC-DC boost converter has been used to boost up the low AC voltage generated by the PMSG directly driven by the wind turbine [3].

This work proposes a method for modeling and simulation of a wind turbine driving low-speed Permanent Magnet Synchronous Generator (PMSG) based on a DC-DC Boost converter using the MPPT Algorithm which consists of a wind turbine, PMSG, maximum power point tracking (MPPT) and a DC-DC Boost Converter. In the wind turbine model, the best performance coefficient has been determined according to the variable wind speed with MPPT control. The gearbox has been eliminated by the low-speed PMSG to achieve high efficiency. The AC power output from PMSG extracts maximum power through closed-loop regulation of generator speed. The current source PMSG is used to interface the system with the electrical utility which gives the torque, speed characters and efficiency of the system and output power and input power [4].

3. MODELING OF THE WIND ENERGY CONVERTER SYSTEM

The simulation models of wind turbines, PMSG and power electronics converters which comprise the whole WECS system are explained in this section. It will discuss the application of MPPT in a wind energy generation system. An A12.3 kW Wind turbine and a PMSG machine will be used, while drive train will not be used, so this will be a direct driven PMSG-based wind energy system with MPPT.

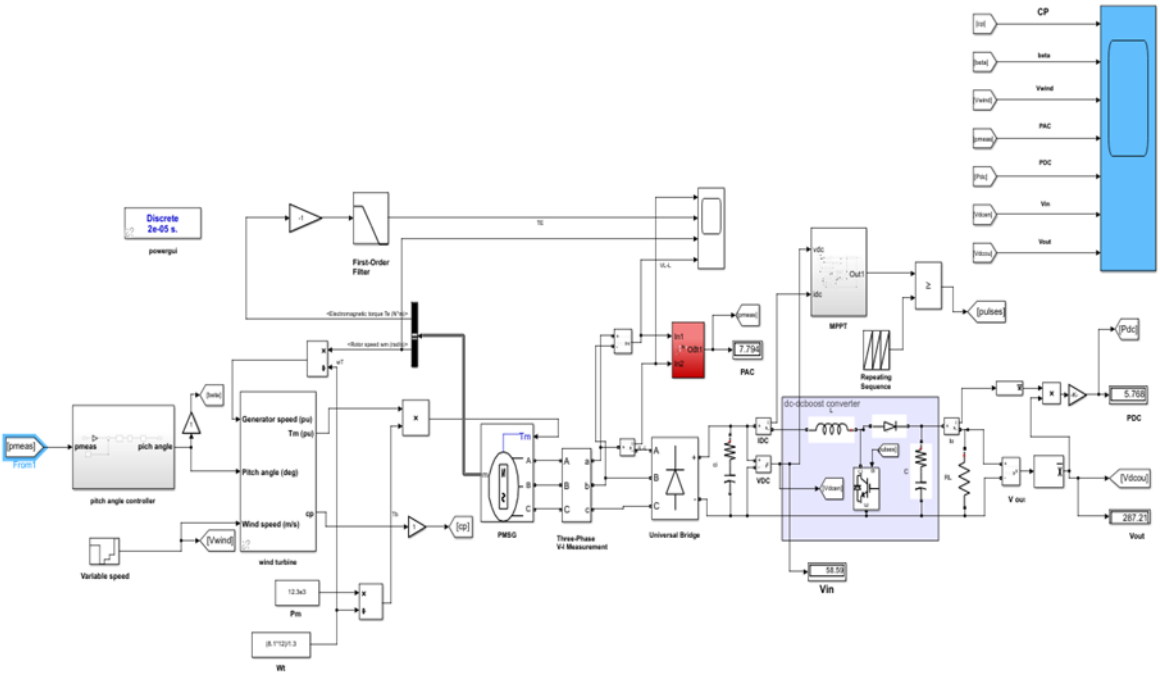

Figure.1. modeling of a wind energy conversion system considering variable wind speed.

3.1 Wind turbine system modeling

The modeling of the wind turbine is the greatest part of a wind energy conversion system. The modeling of the turbine must be made to collect the maximum kinetic energy of the wind with lower costs [5].

The equation gives the mechanical power, captured by the turbine:

$$P_m = \frac{1}{2} * \rho * A * V^3 * C_p(\lambda, \beta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where,

P = Power generated by the wind turbine

v = the wind speed

ρ =air density

λ = tip speed ratio

A =the area swept out by the turbine blades

β = pitch angle

Where, ρ, A and V stand for, respectively, air density, the area covered by the blades, and wind speed. In our situation, the variations are approximated by the following exponential function[5]:

$$C_p(\lambda, \beta) = (0.44 - 0.0167 * \beta) sin[\pi(\lambda - 2)/130.3\, \beta] - 0.0018(\lambda - 2) \ldots\ldots\ldots (2)$$

Where: offers the following expression for the relationship between the wind's speed and the linear velocity of the pale:

$$\lambda = \frac{R * \Omega}{V} \dots\dots\dots\dots (3)$$

Where: ωm is the rotor speed of a wind turbine. The input torque for the generator is obtained from the formula:

$$Tm = \frac{Pm}{\omega m} \dots\dots\dots\dots (4)$$

From the above equation, it can be determined that the performance of the wind turbine is highly dependent on wind speed.

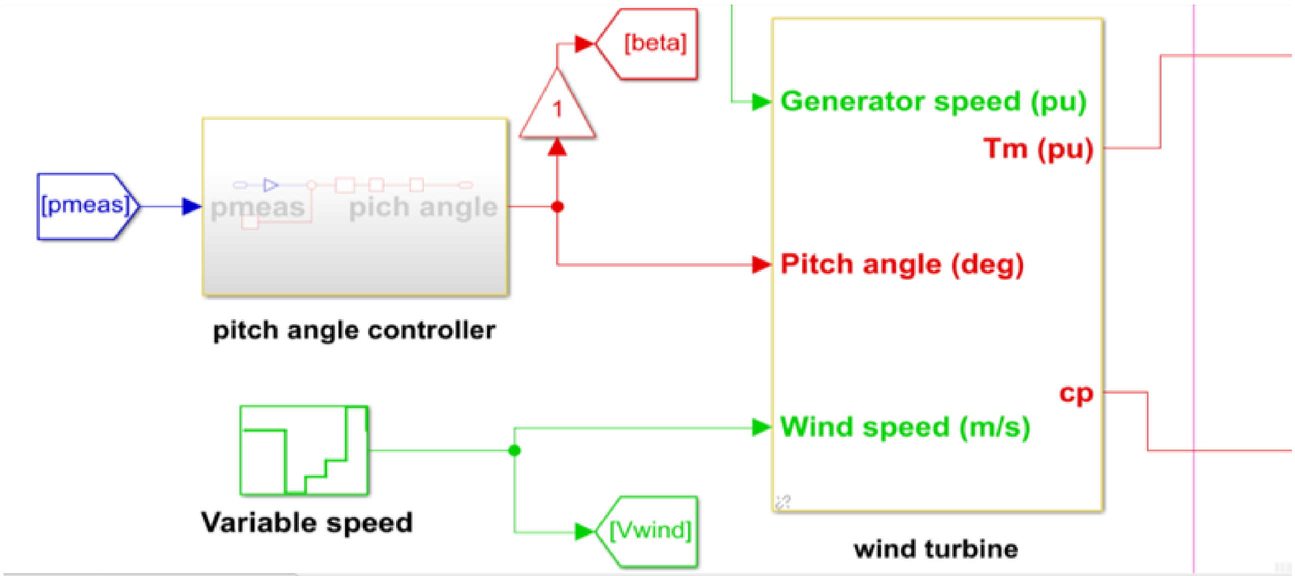

Figure. 2. wind turbine

3.2 Mathematical modeling of PMSG

PMSG is widely used for stand-alone small wind turbines because they have high efficiency and require less maintenance. The PMSG is modeled in the dq reference frame. Both the d and q axes contain a voltage induced by the armature. The generator is implemented with DC voltage and current. The current of the d-axis and the q-axis is determined by equations 5 and 6 respectively[6].

$$\frac{d}{dt} i_d = \frac{1}{Ld} v_d - \frac{R}{Ld} i_d + \frac{L_q}{Ld} \omega_r i_q \dots\dots\dots\dots (5)$$

$$\frac{d}{dt} i_{dq} = \frac{1}{Lq} v_q - \frac{R}{Lq} i_q + \frac{L_d}{Lq} \omega_r i_q - \frac{\lambda_p \omega_r}{L_q} \dots\dots\dots\dots (6)$$

The electromagnetic torque obtained from the rotor of PMSG is given by the equation

$$T_e = 1.5p[\lambda i_q + (L_d - L_q) i_d \dots\dots\dots\dots (7)$$

Where: L_q = q axis inductance, L_d = d axis inductance, R_s = resistance of the stator windings, i_q = q axis current, i_d = d axis current, v_q = q axis voltage, v_d = d axis voltage,

〖ω〗_r= angular velocity of the rotor, λ = amplitude of flux induced and p = the number of pole pairs.

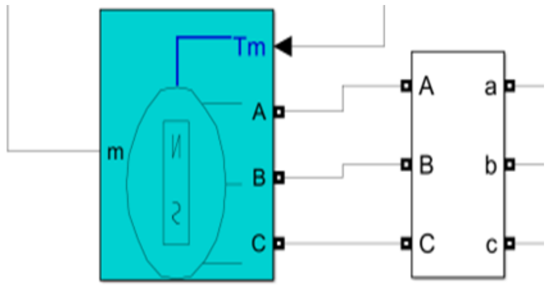

Figure. 3. permanent magnet system generator

Table 1. PMSG and wind turbine parameter

Parameter	Value
Rated Power	5KW
Stator Resistance	0.0485 ohms
Stator Inductor	0.395e-3 mh
No. of pole pairs	4
System Inertia	0.0027
Rated wind Speed	12m/s

3.3 Modeling of DC/DC Converter

The DC-DC converter employed here is a boost converter used to step up the input DC voltage. By varying the duty cycle the output voltage can be controlled. This converter regulates the input voltage through the switch to reach the reference voltage which consists of maximum power. The Boost converter operates in mainly two different modes [6]:

Mode I: Switch is ON, Diode is OFF

Mode II: Switch is OFF, Diode is ON

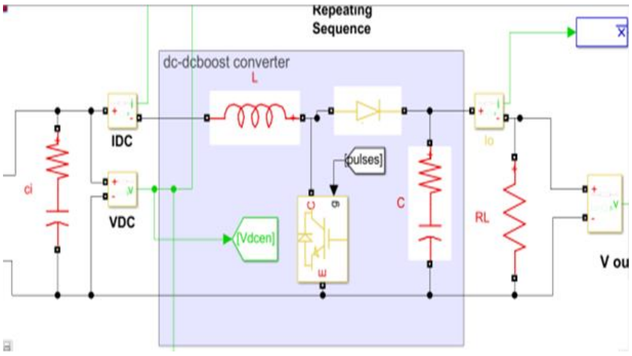

Figure.4. DC-DC boost converter.

3.4 Control strategy of a wind energy converter system

The MPPT-based control strategy is used here to obtain the maximum power. Even though wind energy is available in abundance, wind speed varies rapidly. The efficiency of the WECS depends upon the accuracy with which the maximum power is extracted by the MPPT controller. The PMSG-based MPPT control mainly focuses on converting variable voltage and frequency to fixed voltage and frequency. The most commonly used power electronics converter configuration is analyzed in this project. Three MPPT techniques such as the conventional PI controller, the P&O method and the FLC MPPT method are utilized. A comparative study is conducted to choose the efficient and appropriate MPPT technique so that the maximum power is extracted from the available wind. In this project, the P&O MPPT method is used to extract maximum power from the available wind [7].

- **Perturb and Observe Control**

The P&O method is used to search for the maximum optimal point for the given wind speed. The P&O method does not require any prior wind turbine knowledge. It is an independent, flexible and simple technique. Here the P&O method uses the perturbed output voltage across the load to determine the optimal operating point that will extract the maximum power. If the power of the current cycle is greater than the previous one, then the voltage is modified in the same technique as the previous one. Whereas, if the power is lesser than the previous technique the voltage must be varied in the opposite direction. The only disadvantage of the P&O technique in wind energy conversion is that the rapid variation of the wind speed cannot be tracked thus affecting the efficiency of the overall system and the speed of convergence [7]

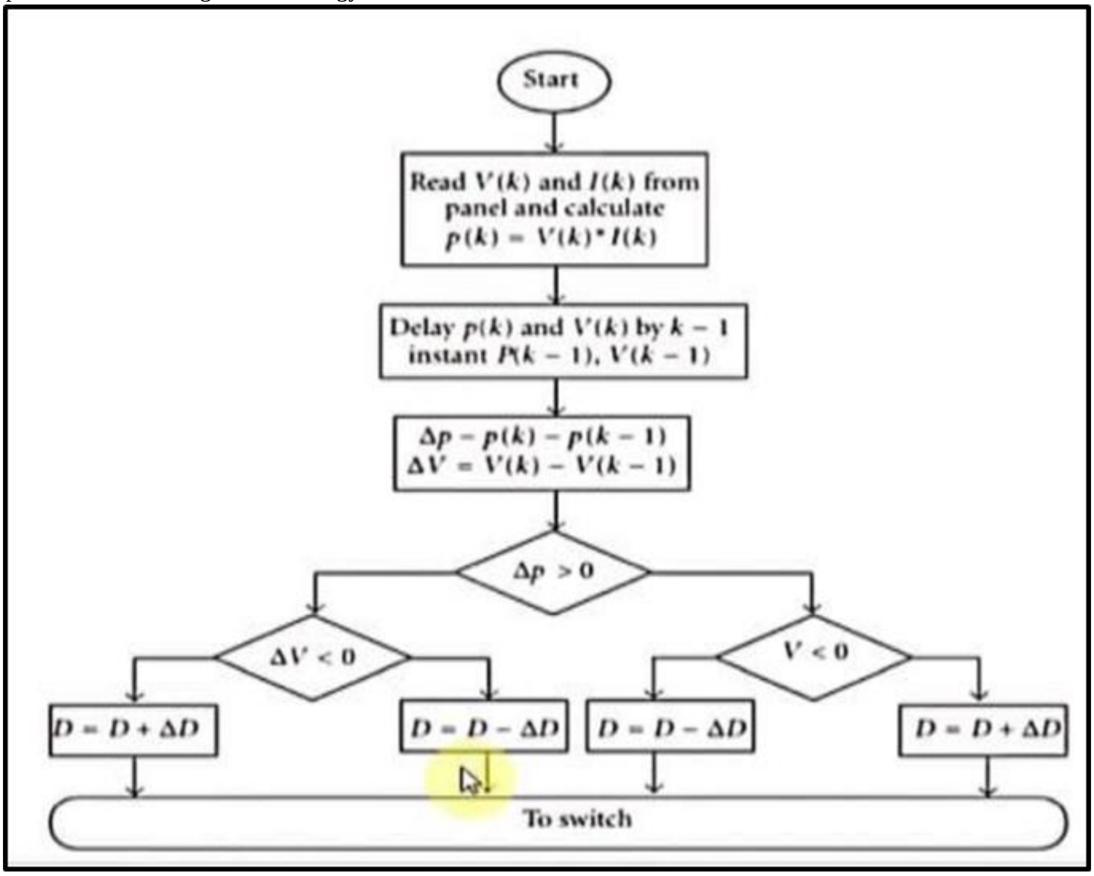

Figure. 5. Flowchart of MPPT algorithm wind turbine for the boost converter [8]

4. SIMULATION RESULT AND DISCUSSION

According to the simulation results of the wind power conversion system on PMSG, the PMSG is connected to the network via an uncontrolled three-phase diode rectifier that converts the output voltage of a permanent magnet synchronous generator to a DC voltage, which is then followed by a DC-DC boost converter to maintain the output voltage. Constant DC with output power by MPPT control technique is dependent on the output and input voltage on the operating ratio with a constant value of D, as shown by the curves in the scope.

For the calculation of the DC-DC boost converter following, the Live Editor program is used:-

Table 2. boost converter Parameter

Set Parameters	
Input Voltage (DC Link Voltage) *Vdc*	50-339V
Output Voltage (DC Grid Voltage) *Vdcgrid*	400V
Switching Frequency *fs*	20kHz
Converter Power *P*	5kW
Output voltage peak percentage ripple Δvo	0.5%
Inductor Resistance *RL*	13.333Ω
ESR of Capacitor *Rc*	0.005Ω
Calculated Values	
Duty Cycle *D*	0.8813
Inductor *L*	4.5573e-5H
Capacitor *C*	6.6094e-4F

Table 3. An illustration of the effect of variable load on the (voltage–power)

S. No.	R load	Vin	Vout	Pac	Pdc
1	13.33	58.32	279.84	7.324	5.875
2	13.5	56.82	281.29	8.131	5.861
3	14	58.33	284.86	7.367	5.796
4	14.5	0.11	0	$5.17e^{-21}$	0.3014

Figure (6) shows the outcomes of the simulation: (A) the power coefficient is displayed, and we can see that it rises until it reaches its maximum value of 0. 45. When the pitch angle is zero and the velocity rate ratio is 8.1, it decreases as the wind speed increases(c): displays the changeable wind speed, and we can see that it rises gradually from 8 m/s to as high as 13. (b): Pitch angle control displays the presence of (PI), which modifies the rate of change of velocity pitch angle and modifies the value of the angle that stops the turbine from turning, and (f), which displays the DC input voltage. We observe that it fluctuates initially, reaching its maximum value in less than a nanosecond and that it rises with wind speed. (g) Displays the output voltage of the DC, which drops until it reaches a minimum of 57.59 volts. (d) Displays the strength of the alternating current in PMSG. We come to the conclusion that the PMSG's alternating current power swings initially, increasing and decreasing along with the wind speed until it stabilizes at 7.794 kw. (e) Displays the DC output power. It can be observed that the power rises and falls according to the wind speed before stabilizing at 5.768 kw.

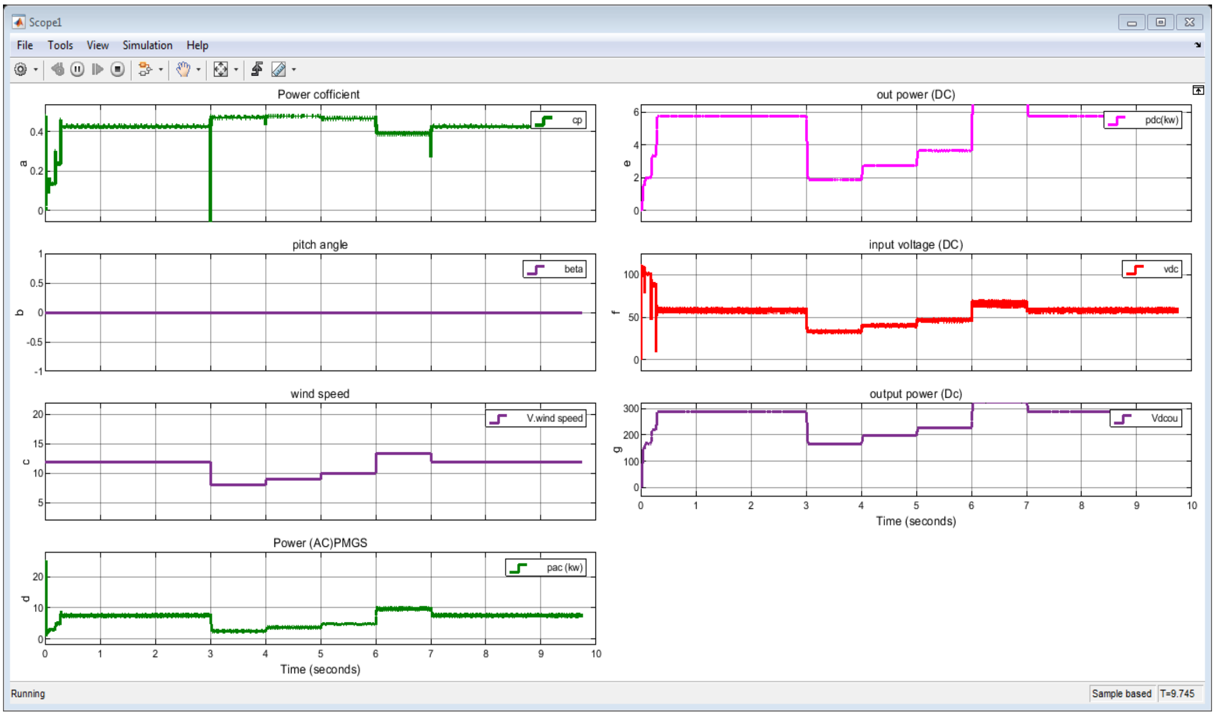

Figure. 6. Simulation results: (a) shows the power coefficient,(b) The pitch angle control (c) shows the variable wind speed,(d) shows the power of the alternating current in PMSG,(e) shows the output power,(f) shows the input voltage of the Dk8C,(g) shows the output voltage of the DC.

5. CONCLUSIONS

1-In this paper, the MPPT controller P&O controller is modeled and the output is compared for wind energy under varying speed conditions. The performance of the controller is analyzed, and it is verified that the controller is more efficient and reliable; the P&O-based technique is suitable for the condition where the system is stable with minimum variance. Wind speed being high non-linear, the P&O algorithm oscillates around the optimal point thus making it difficult to track the next point. It is concluded that the P&O-based MPPT method is the best option for stand-alone WECS.

2-When the wind speed increases, the output voltage and input and output power increase and the power factor decreases if the wind speed is changed.

3-The MPPT algorithm controls the current of the boost converter according to the differences ink8 the DC correlation power to obtain the maximum power output.

6. REFERENCES

1. Cheng, Q., Liu, X., Ji, H., Kim, K.C., Yang, B. Aerodynamic Analysis of a Helical Vertical Axis Wind Turbine. Energies 2017, 10, 575.
2. Luo, Z.; Sun, Z.; Ma, F.; Qin, Y.; Ma, S. Power Optimization for Wind Turbines Based on Stacking Model and Pitch Angle Adjustment. Energies 2020, 13, 4158.
3. Nitin Patel, Simulation of PMSG-based wind energy conversion system using MPPT, Vol. 9, Issue 5, May 2021:249-255
4. Sai Kumar, U. Simulation of a Wind Turbine Based on Permanent Magnet Synchronous By Using MPPT Algorithm on DC-DC Boost Converter Volume 8, Issue 1, August 2021.
5. Baroudi, J.A., Dinavahi, V., and Knight, A.M. (2007). A review of power converter topologies for wind generators. Renewable Energy, volume (32), 2369 - 2385.
6. Dalala, Z.M., Zahid, Z.U., Yu, W., Cho, Y., and Lai, J. (2013). Design and analysis of an MPPT technique for small-scale wind energy conversion systems. IEEE Transaction on Energy Conversion, volume (28),756 - 766.
7. Babu, N.R. and Arulmozhivarman, P. (2013). Wind Energy Conversion System- A Technical Review. Journal of Engineering Science and Technology, volume (8), 493 - 507.
8. Chen, W.L. and Jiang, B.Y. (2015). Harmonic Suppression and Performance Improvement for a Small-scale Gridtied Wind Turbine using Proportional-Resonant Controllers. Electric Power Components and Systems, volume (43), 970 - 981.