Design and analysis of maximum power point tracking algorithms for PV/Wind hybrid system

Oumlkheir BOUCHIBA, Tahar MERIZGUI*, Bachir GAOUI, Saliha CHETTIH, Ali CHEKNANE
LMSF Laboratory, Electrical Engineering Department, Laghouat 03000, Algeria
*Corresponding author:
Tahar MERIZGUI
t.merizgui@lagh-univ.dz

Abstract: This work proposes the hybrid renewable sources, for instance, the wind generator and the photovoltaic modules used to produce energy to recharge the solar battery storage system automatically. In addition, the proposed hybrid system could operate in a grid-attached or autonomous mode. The coordination control algorithms are compared with regard to fine power transfer between maximum power point tracking P&O (Perturbe and Observe) and IncCond (Incremeted Conductance). The performance of the wind turbine was analysed for different wind speed values. The efficiency of the solar photovoltaic system was tested for various irradiance levels. Hybrid renewable resources have been modeled and simulated using the Simulink in the MATLAB software. The simulation result indicates that the performance of the P & O algorithm is more satisfactory than that of the IncCond algorithm as regards the recharging of batteries in a hybrid system with guaranteed continuous product power. Therefore the authors strongly believe that the P&O method decreases the complete time for battery recharge compared to IncCond MPPT (Maximum Power Point Tracking) algorithm control.

Keywords: Perturb and Observe (P&O), Incremental Inductance (IncCond), Wind, Photovoltaic, Maximum power point tracker (MPPT).

1. Introduction

The wind and solar power industry is growing extremely fast, demonstrating itself to be an inexhaustible, environment-friendly, sustainable resource for generating electricity. Electrical energy systems are being extra stressed due to the raise in the power request, limitations on energy delivery ability of the grid, and to the difficulty to building novel transmission distribution infrastructures [Bhandari, B. et al., 2014: Kumar, K., Babu, N. Ramesh, & Prabhu, K. R., 2017]. The choices based on renewable energy become economically viable when environmental costs and lower operating costs are taken into consideration. The main focus of the governments` renewable power policy is to produce energy by utilizing renewable power in order to guarantee environmentally sound sustainable energy development that would cause minimum harm to the environment [KARABACAK, Kerim et CETIN, Numan, 2014: BADWAWI, Rashid Al, ABUSARA, Mohammad, et MALLICK, Tapas, 2015]. A hybrid renewable energy system could be standalone or grid-linked. Standalone systems require sufficient storage capacity to hold the load. In a grid-linked framework condition, the volume of storage capacity could be comparatively lower because minus energy can be gained from the grid. PV solar and wind power conversion systems have been widely utilized for electricity feeding in isolated sites far from the distribution network [Abdullah, M. A., Yatim, A. H. M., Tan, C. W., & Saidur, R, 2012]. Its availability is intermittent and must be accomplished by other energy sources such as batteries in most conditions. These systems supply a credible service, and could operate unattended for prolonged periods of time if they are duly designed [Indragandhi.V, Subramaniyaswamy.V, Logesh R. 2017: LIU, Chunhua, CHAU, K. T., et ZHANG, Xiaodong, 2009: KRISHNA, K. Shivarama et KUMAR, K. Sathish, 2015].

This study focuses on a comparison regarding the achievement of various MPPT control algorithms based on different solar irradiation/wind velocity responses and values to implement the highest power yield. This paper epitomizes the mathematical modeling of renewable energy systems, in particular PV, wind, storage devices, and different controls. PV and wind order private mechanisms to extract highest energy. Hybrid energy has complicated monitoring configuration due to the combination of two different energy sources. The intricacy of regulation arises from the use of the MPPT mechanism in their subsystems. The main objective of this work is to design a suitable PV/Wind hybrid system to cover the electricity consumption based on different control

algorithms like as P&O and IncCond MPPT algorithm. Correlations between the solar/wind energy data were made on a daily basis. It is shown that the hybrid system could be used for the efficient and economic exploitation of these resources. Energy utilities must provide a careful balance between power consumption and power generation to cover the accuracy of the electricity distribution and transmission networks.

Energy produced by a PV array depends on solar irradiance and temperature. The energy output in this model is expressed as [KRISHNA, K. Shivarama et KUMAR, K. Sathish, 2015: BHANDARI, Binayak, POUDEL, Shiva Raj, LEE, Kyung-Tae, et al., 2014: JANEVSKA, Gordana, 2017].

$$P_{pv} = \eta_{pvg} A_{pvg} G_t \tag{1}$$

With

H_{pvg} : PV generation efficiency.

A_{pvg} : PV generator space (m^2).ââ

G_t : solar irradiation in tilted module plane (W/m^2).

η_{pvg} is further defined as

$$\eta_{pvg} = \eta_r \eta_{pc} \left[1 - \beta (T_c - T_{cref}) \right] \tag{2}$$

With

η_{pc} : energy conditioning efficiency whose value is similar to the one when MPPT is utilized.

β : temperature coefficient ((0.004-0.006) per 0C).

η_r : the reference module efficiency.

T_{cref} : reference cell temperature in ºC.

The reference temperature (Tcref) could be acquired via relation

$$T_c = T_a + \left(\frac{NOCT - 20}{800} \right) G_t \tag{3}$$

Where

T_a : ambient temperature in °C.

NOCT : nominal operating cell temperature in ºC.

G_t : solar irradiation in tilted module plane (W/m^2).

The total radiation in the solar cell considering normal and diffuse solar radiation could be expressed as

$$I_r = I_b R_b + I_d R_d + (I_b + I_d) R_r \tag{4}$$

Solar cells are mostly modeled as double diode circuit models (see Figure 1).
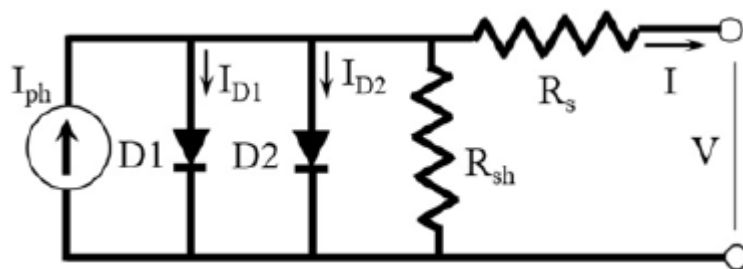

Figure 1. Double diode PV model

Output current of the PV cell using two diode model could be described as

$$I = I_{PV} - I_{D1} - I_{D2} - \left(\frac{V + IR_s}{Rsh} \right) \tag{5}$$

With

$$I_{D1} = I_{01}\left[\exp\left(\frac{V+IR_s}{a_1 V_{T2}}\right)-1\right] \tag{6}$$

$$I_{D2} = I_{02}\left[\exp\left(\frac{V+IR_s}{a_2 V_{T2}}\right)-1\right] \tag{7}$$

I_{01} and I_{02} are reverse saturation currents of diode 1 and diode 2.

V_{T1} and V_{T2} are thermal voltages of respective diode.

a_1 and a_2 represent the diode ideality constants.

Simplified model for PV system modeling is given below:

$$V_{oc} = \frac{V_{oc}}{cK\dfrac{T}{q}} \tag{8}$$

$$P_{max} = \frac{\dfrac{V_{oc}}{cK\dfrac{T}{q}} - \ln\left(\dfrac{V_{oc}}{cK\dfrac{T}{q}}+0.72\right)}{\left(1+\dfrac{V_{oc}}{nK\dfrac{T}{q}}\right)}\left(1-\dfrac{R_s}{\frac{V_{oc}}{I_{sc}}}\right)\left(\dfrac{V_{oc}0}{1+\beta\ln\dfrac{G_0}{G}}\right)\left(\dfrac{T_0}{T}\right)^{\gamma} I_{sc0}\left(\dfrac{G}{G_0}\right)^{\alpha} \tag{9}$$

Where v_{oc} is the normalized value of the open-circuit voltage Voc with respect to the thermal voltage Vt = nkT/q, n is the ideality factor (1 < n < 2), K is the Boltzmann constant, T is the PV module temperature in kelvin, q is the electron charge. α is the factor responsible for all the non linear impacts that the photocurrent depends on, β is a PV module technology particular-related dimensionless coefficient, and γ is the factor related all the non-linear temperature-voltage effects.

The essential equation predominant the mechanical energy of the wind turbine is specified by [KRISHNA, K. Shivarama et KUMAR, K. Sathish, 2015: BHANDARI, Binayak, POUDEL, Shiva Raj, LEE, Kyung-Tae, et al., 2014: JANEVSKA, Gordana, 2017: REKIOUA, Djamila, 2020: EID, Ahmad, 2014: Khan, M. W., Wang, J., Ma, M., Xiong, L., Li, P., & Wu, F, 2019].

$$P_w = \frac{1}{2}C_p\left(\lambda,\beta\right)\rho A V^3 \tag{10}$$

Where

ρ : air density (kg/m^3).

C_p : power coefficient.

A : intercepting area of the rotor blades (m^2).

V : average wind speed (m/s).

λ : tip speed ratio.

The theoretical maximum value of the power coefficient C_p is 0.593, also known as Betz's coefficient.

The Tip Speed Ratio (TSR) for wind turbines is specified as the ratio of rotational speed of the tip of a blade to the wind velocity. Mathematically,

$$\lambda = \frac{R\omega}{V} \tag{11}$$

where R is the radius of turbine (m), ω is angular speed (rad/s), V is the average wind speed (m/s). The power created by wind could be acquired by

$$Q_w = P \times (time) \left[kWh \right]$$ (12)

Occasionally, because of different factors, the velocity of wind at any particular height cannot be obtained via direct measurement. In that case, the data for any reference height could be in state or extrapolated to detect the wind speed at any particular height. The wind velocity measured at a lower height could be subject to error due to vegetation, and shading or obstacles in the vicinity

$$v(z) \ln\left(\frac{z_r}{z_0}\right) = v(z_r) \ln\left(\frac{z}{z_0}\right)$$ (13)

where Z_r is reference height (m), Z is the height where wind speed is to be determined, Z_0 is the measure of surface roughness (0.1-0.25 for crop land), v(z) is wind speed at height z (m/s), and v(z_r) is wind speed at reference height z (m/s).

Cut-in speed is a low wind speed at which the turbine first starts to rotate and create energy. Cut-out speed is the high wind speed in which the forces on the turbine structure are high as a result there is a hazard of harming the rotor. To avoid harm, the braking system is used to bring the rotor to stand still. Rated output speed is the wind speed between cut-in speed and cut-out speed where the energy output extends the highest limit that the electrical generator is eligible for and is called estimated energy output. The energy output in terms of wind speed could be evaluated using

$$P_w(v) = \begin{cases} \dfrac{v^k - v_c^k}{v_R^k - v_c^k}.P_R ; v_c \leq v \leq v_R \\ P_R ; v_R \leq v \leq v_F \\ 0; v \leq v_c \ and , v \geq v_F \end{cases}$$ (14)

where P_R is the rated power, v_C is the cut-in wind speed, v_R is the rated wind speed, v_F is the rated cut-out speed, and k is the Weibull shape factor.

2. MPPT Tracking in hybrid system

The power compensation that could be attained through the wind does not only rely upon the wind velocity unless it is at most streaked via tip speed ratio. In order to reproduce top power from wind in a changing speed situation, the rotational speed must be diversified to preserve optimal value of tip speed ratio each time.

Similarly, the energy produced via the PV system relies on insolation and temperature. The relation between voltage and current and the relation between voltage and energy are nonlinear as displayed in Figure 2. Maximum power point (MPP) must be tracked for active extraction of solar power in PV system through varying solar irradiation cases. Maximum energy from a PV/wind hybrid system could be extracted when MPPT is implemented at all of them.
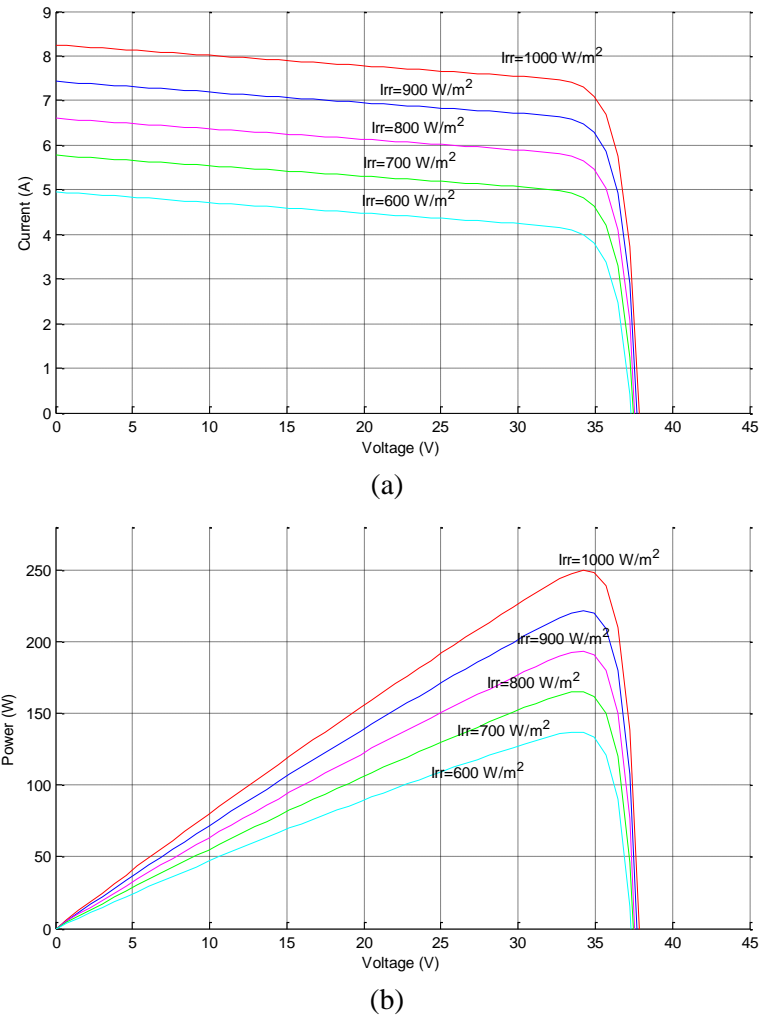
(a)

(b)

Figure 2. Solar cell characteristics (a) voltage-current characteristics and
(b) voltage-power characteristics

Wind turbines could function in two different processes: first, constant velocity turbine generators could be grid- or load-linked. Second, variable-pace turbine energy electronic tools are utilized to transform inconstant frequency and inconstant energy into constant frequency and energy. Figure 3 displays the relationship between tip speed ratio (λ) and coefficient of performance (Cp). We noted that, as the turbine velocity is variable, there will be an identical top produce energy which is acquired when Cp is maximized. The major theme of MPPT monitoring on wind is to consider the maximum Cp case for changing wind speed. MPP could be seized in a changing wind speed by conserving the tip ratio in its optimal rate in a fickle pace generation system.
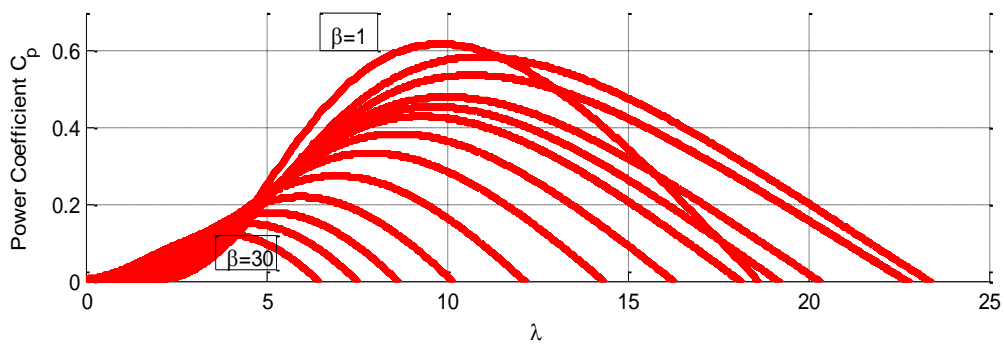

Figure 3. The performance coefficient Cp (λ, β), which depends on speed ratio λ
and blade pitch angle β

A model of the wind turbine is needful to estimate the torque and energy production for a given wind speed and the impact of wind speed variations on the generated torque.

The distinctiveness of PV cells is dependent on the solar irradiation, temperature level and array voltage. Therefore, it is necessary to perform MPPT in order to progress the operating voltage lock to MPP under changing atmospheric situations. MPPT in the PV system is influential because it decreases the PV array cost by reducing the size of solar module prerequisites to gain the required output.

P&O algorithm is the most widely utilized mechanism because of its unpretentious composition and small measured parameters. P&O into the solar system includes periodically boosting or reducing solar voltage and appearance for the subsequent energy alteration. The P&O algorithm flowchart for the PV system is illustrated in Figure 4.
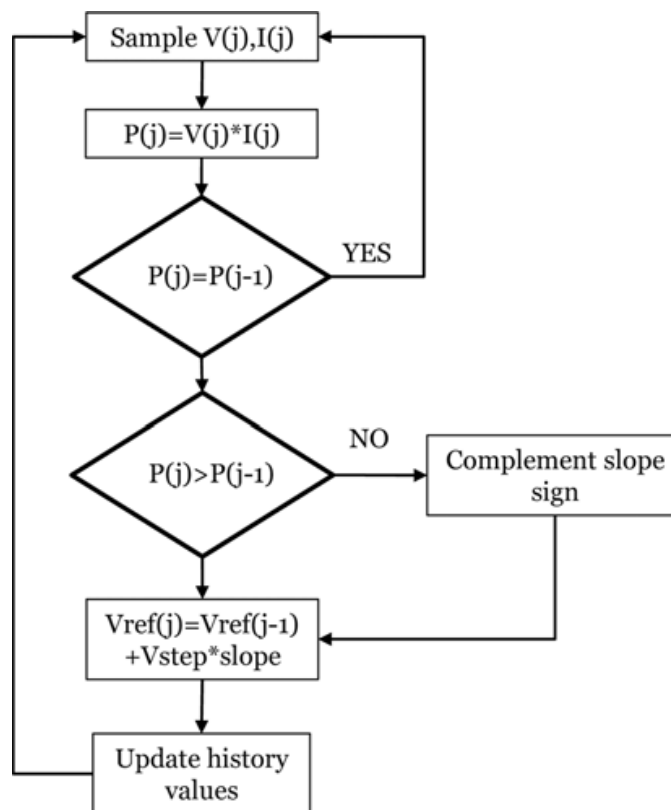

Figure 4. Flow chart of P&O algorithm

Incremenetal Conductance (IncCond) mode is an alternative to P&O control where solar module terminal voltage could be regulated proportionally to the MPP voltage via measuring the incremental and instant array conductance (dI/dV and I/V). It appear to beat the restrictions of P&O through using IncCond for estimating the value of dP/dV without perturbation.

3. Results and discussion

Figure 4 shows the MPPT control (a: P&O and b: IncCond) used in SIMULINK/Matlab for solar PV and Wind turbine conversion systems.
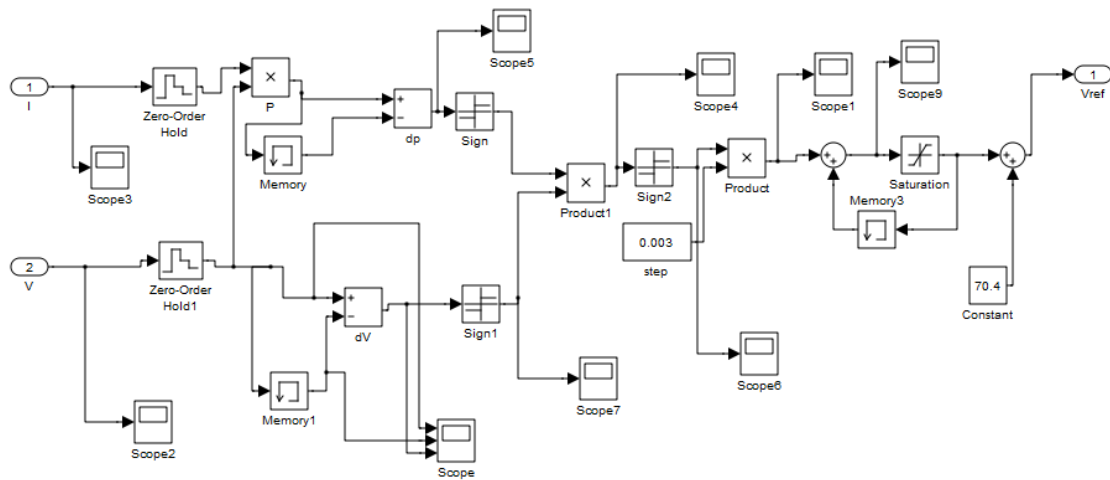
Figure 4a. Simulink model of P&O MPPT control for hybrid conversion system
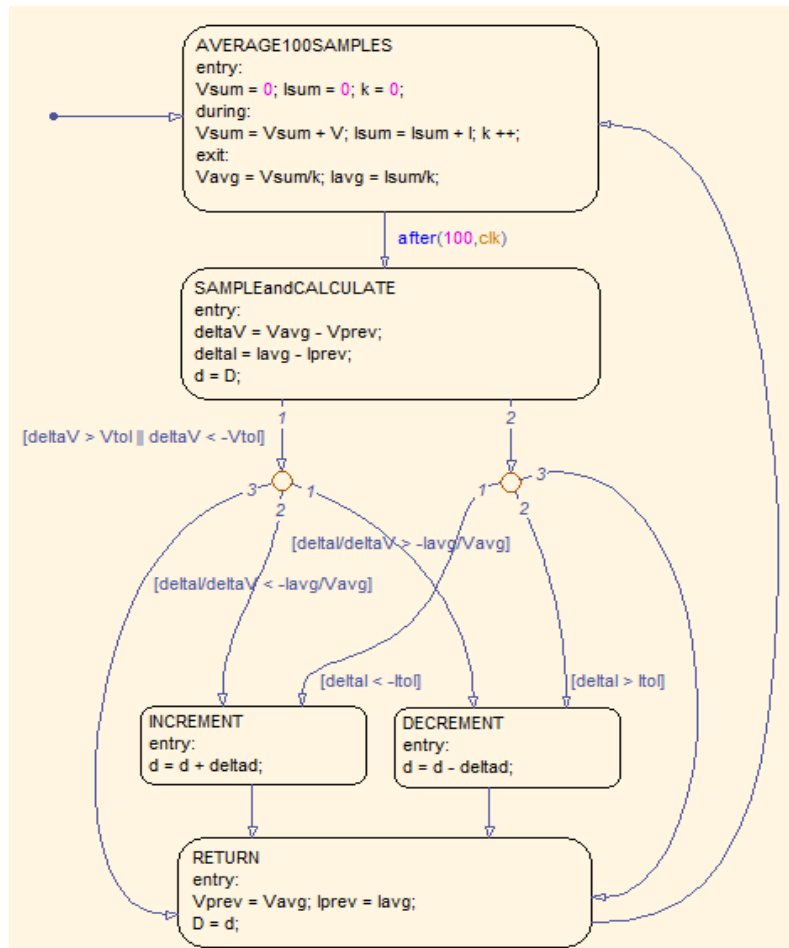

Figure 4b. Simulink model of IncCond MPPT control for hybrid conversion system

The simulation model for the suggested hybrid power system with DC/DC converter (Boost), and MPPT, is shown in (Figure 5a -5b). Thus, it is fundamental to assure an observer that it could reach the maximum peak regardless of insolation and wind speed. The obtainable MPPT algorithms could be disturbing as either with or without scout, as well as approving the method utilized to determine the highest peak.
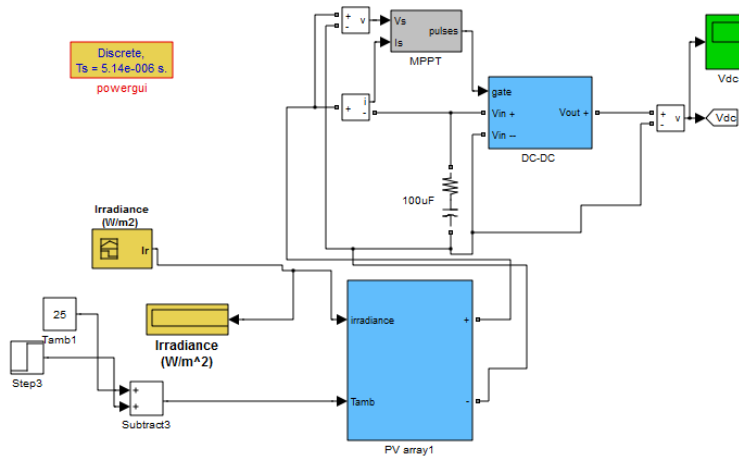
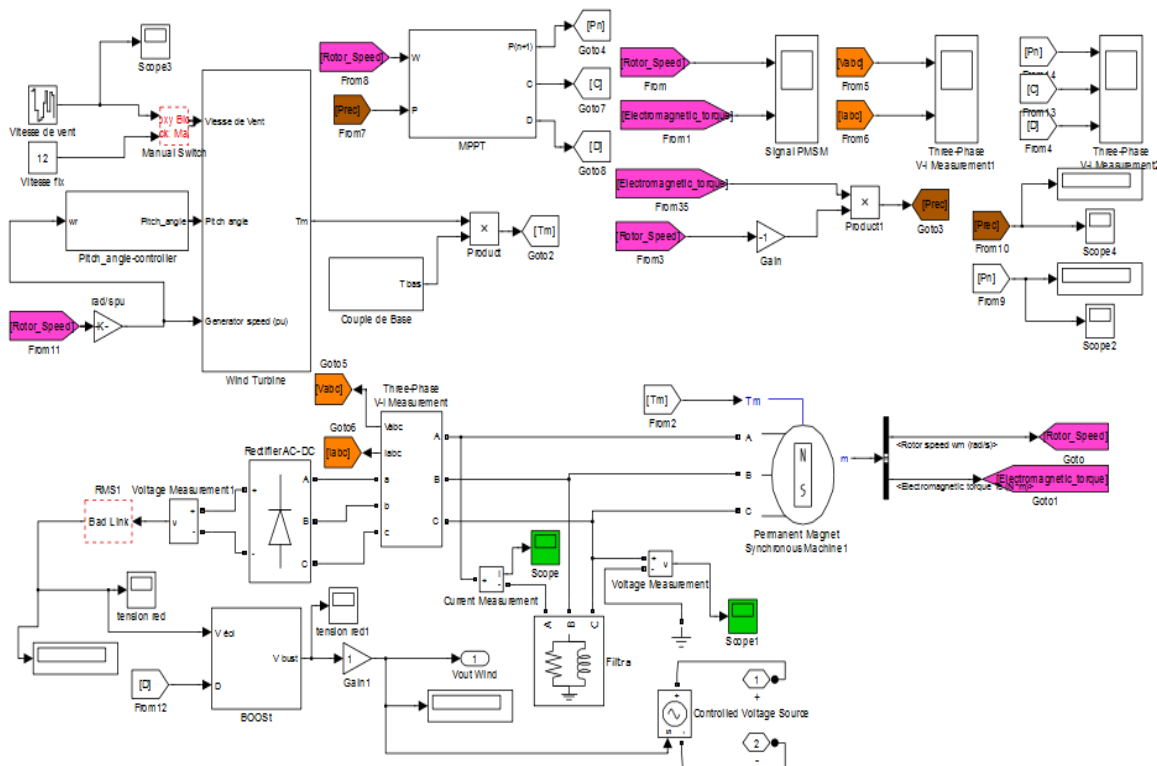**Figure 5a.** Simulink model of solar PV system

Figure 5b. Simulink model of wind system

Simulation results using MatLab/Simulink prove the possibility of using the smart control approach in grid connected-hybrid PV/Wind conversion systems. The result of PV array is connected to a DC/DC (Boost) converter. In modern wind turbines, MPPT control schemes must be performed to get the full benefits from the wind speed.

In this paper, we provide a comparative study of challenges, opportunities and solutions of hybrid solar PV and wind energy systems using MPPT control. Optimization quality of energy obtained from renewable energy sources is a major issue for both stand-alone and grid-connected systems with high impact in case of weak grids. This could be determined to a big extent via a suitable design, advanced rapid response control facilities, and better optimization of the hybrid systems. A suitable optimization is desired to guarantee an optimal size and number of PV and wind generators. Figure 6 illustrates the PV solar power at different solar irradiation levels and various MPPT control algorithms like P&O/IncCond.
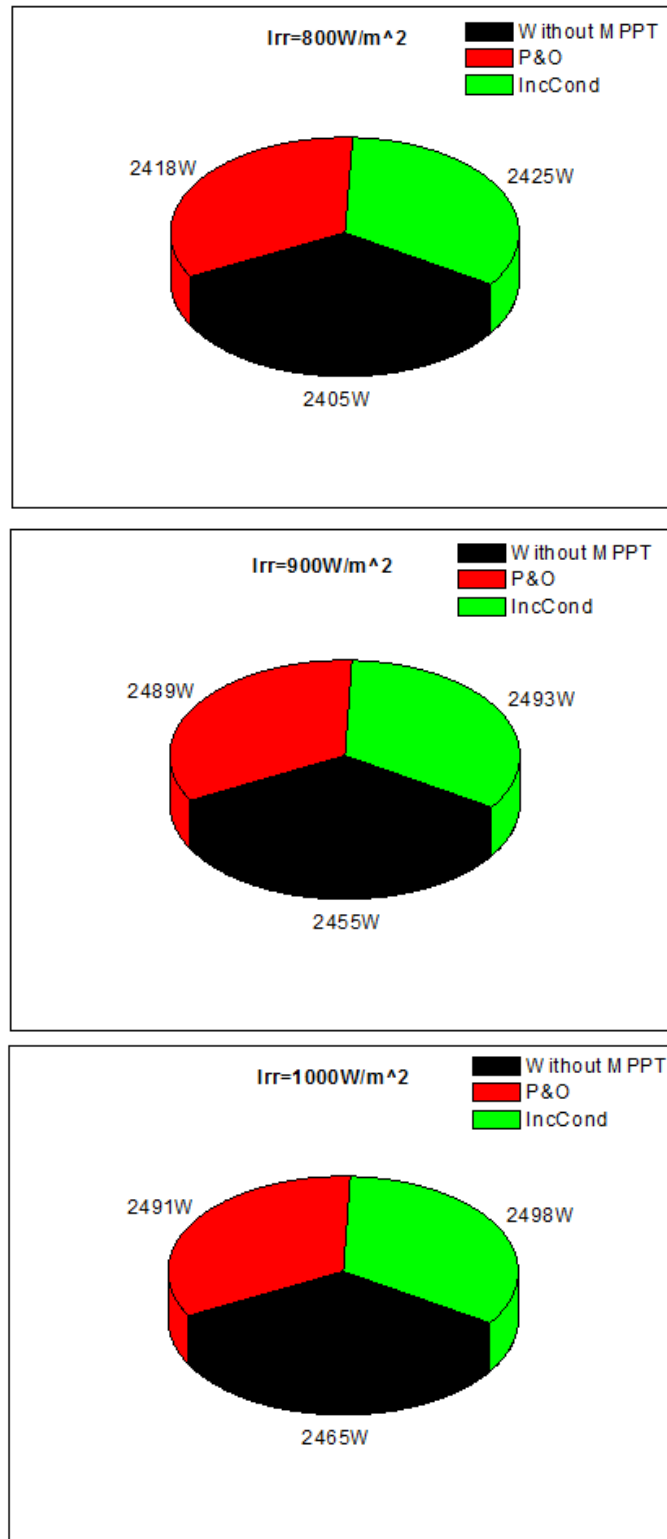
Figure 6. PV solar power vs insolation and various MPPT control algorithms

Through integrating the two renewable sources is an optimal combination, the effect of the changing nature of insolation and wind speed resources could be partially resolved by using MPPT control and the total system be more credible, economical to run, and highly efficient. MPPT for PV systems using IncCond control performs better than that in wind power systems because the insolation change is relatively slower compared with wind generators as shown in Figure 7 P&O control showed good performance in rapidly variable atmospheric situations in wind turbines.
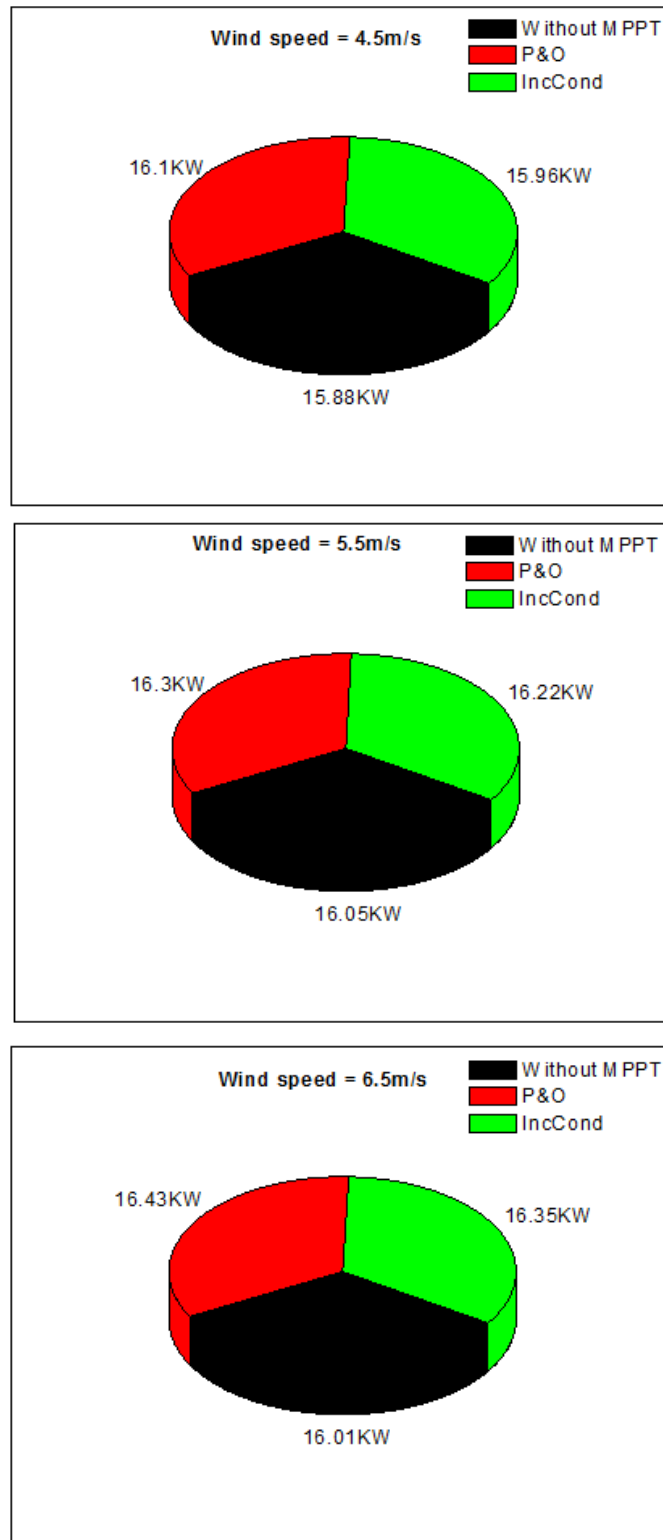
Figure 7. Wind turbine power vs wind speed and various MPPT control algorithms

4. Conclusion

In this work, a comparative study of hybrid PV/Wind power systems was optimized using different MPPT algorithms like P&O and IncCond control by graphical method through variation of meteorological data in the context of power supply. The simulation model obtained using MATLAB/Simulink has been sophisticated to analyze and compare the performances for both the

solar PV module and the wind turbine. The proposed model of a hybrid PV/Wind system enables one to carry out studies for modeled DC and AC consumers. MPPT for PV systems using IncCond control does better than that for wind power systems because the insolation change is relatively slower compared with the changes in wind generators. P&O control showed good performance under rapidly variable atmospheric situations in wind turbines. In case of the MPPT strategy, the first estimation is adapted for DC voltage reference. Then DC output energy would be achieved after the respective measurement using the Incremental conductance (IncCond) technique.

Conflict of Interests

Herewith authors have confirmed that, this article has no conflict of interests.

REFERENCES

1. Abdullah, M. A., Yatim, A. H. M., Tan, C. W., & Saidur, R. (2012). *A review of maximum power point tracking algorithms for wind energy systems*. Renewable and sustainable energy reviews, 2012, vol. 16, no 5, pp. 3220-322.

2. BADWAWI, Rashid Al, ABUSARA, Mohammad, et MALLICK, Tapas (2015). *A review of hybrid solar PV and wind energy system*. Smart Science, 2015, vol. 3, no. 3, pp. 127-138.

3. Bhandari, B., Poudel, S. R., Lee, K. T., & Ahn, S. H. (2014). *Mathematical modeling of hybrid renewable energy system: A review on small hydro-solar-wind power generation*. International journal of precision engineering and manufacturing-green technology, 2014, vol. 1, no. 2, pp. 157-173.

4. EID, Ahmad (2014). *Utility integration of PV-wind-fuel cell hybrid distributed generation systems under variable load demands*. International Journal of Electrical Power & Energy Systems, 2014, vol. 62, pp. 689-699.

5. Indragandhi, V., Subramaniyaswamy, V., Logesh, R. (2017). *Resources, configurations, and soft computing techniques for power management and control of PV/wind hybrid system*. Renewable and Sustainable Energy Reviews, 2017, vol. 69, pp. 129-143.

6. Janevska, Gordana (2017). *Mathematical Modeling of Hybrid Renewable Energy System*. In : Proceedings of 3rd Virtual International Conference on Science, Technology and Management in Energy eNergetics 2017. Research and Development Center "ALFATEC", Niš, Serbia, 2017. pp. 9-15.

7. Karabacak, Kerim, Cetin, Numan (2014). *Artificial neural networks for controlling wind–PV power systems: A review*. Renewable and Sustainable Energy Reviews, 2014, vol. 29, pp. 804-827.

8. Khan, M. W., Wang, J., Ma, M., Xiong, L., Li, P., Wu, F. (2019). *Optimal energy management and control aspects of distributed microgrid using multi-agent systems*. Sustainable Cities and Society, 2019, vol. 44, pp. 855-870.

9. Krishna, K. Shivarama, Kumar, K. Sathish (2015). *A review on hybrid renewable energy systems. Renewable and Sustainable Energy Reviews*, 2015, vol. 52, pp. 907-916.

10. Kumar, K., Babu, N. Ramesh, et Prabhu, K. R. (2017). *Design and analysis of an integrated Cuk-SEPIC converter with MPPT for standalone wind/PV hybrid system*. International Journal of Renewable Energy Research (IJRER), 2017, vol. 7, no. 1, pp. 96-106.

11. Liu, Chunhua, Chau, K. T., Zhang, Xiaodong (2009). *An efficient wind–photovoltaic hybrid generation system using doubly excited permanent-magnet brushless machine*. IEEE transactions on industrial electronics, 2009, vol. 57, no. 3, pp. 831-839.

12. Rekioua, Djamila (2020). *Hybrid Renewable Energy Systems Overview*. In: Hybrid Renewable Energy Systems. Springer, Cham, 2020, pp. 1-37.

* * *

Oumlkheir BOUCHIBA is an Assistant Professor at the Electrical Engineering department at the University of Laghouat, Algeria. Her general research interests are in the area of renewable energy systems.

Tahar MERIZGUI earned his Master's in Renewable Energies in 2015 from the Amar Telidji Laghouat University. He is presently a PhD student in the same university. His research interest includes development of innovative composite materials for multifunctional applications and renewable energy systems.

Bachir GAOUI earned his Master's in Electrical Engineering in 2014 from the Amar Telidji Laghouat University. He is currently a PhD student in the Electrical Engineering Department. His general research interests are in the area of development of composite materials and Control engineering systems.

Saliha CHETTIH earned his PhD degree in Electro-technology from the University of Amar Telidji. She joined the faculty of Technology at the University of Amar Telidji, Laghouat (Algeria), in 2008 where she is currently a professor. Her research interests optimal power flow, Artificial intelligence and optimization techniques.

* * *

Ali CHEKNANE is a Full-Professor at the Amar Telidji University of Laghouat-Algeria. He has completed his PhD in physics. He has 20 years of teaching graduate and postgraduate teaching experience at the university as a temporary, associated, and permanent position. He has published many papers in various journals and conference proceedings on renewable energy subjects.