Hybrid MPPT Control: P&O and Neural Network for Wind Energy Conversion System

Kaoutar Dahmane [1]*, El Mahfoud Boulaoutaq [2], Brahim Bouachrine [3], Mohamed Ajaamoum [4], Belkasem Imodane [5], Sana Mouslim [6], Mohamed Benydir [7]
[1, 2, 3, 4,5,6,7] Engineering Science & Energy Management Laboratory (LASIME), ESTA, IBN ZOHR University, Agadir, Morocco
Email: [1] kaoutar.dahmane@edu.uiz.ac.ma, [2] elmahfoud.boulaoutaq@edu.uiz.ac.ma, [3] b.bouachrine@uiz.ac.ma, [4] m.ajaamoum@uiz.ac.ma, [5] b.imodane@uiz.ac.ma, [6] sana.mouslim@uiz.ac.ma,[7] benydirmed@gmail.com
*Corresponding Author

***Abstract*—In the field of wind turbine performance optimization, many techniques are employed to track the maximum power point (MPPT), one of the most commonly used MPPT algorithms is the perturb and observe technique (P&O) because of its ease of implementation. However, the main disadvantage of this method is the lack of accuracy due to fluctuations around the maximum power point. In contrast, MPPT control employing neural networks proved to be an effective solution, in terms of accuracy. The contribution of this work is to propose a hybrid maximum power point tracking control using two types of MPPT control: neural network control (NNC) and the perturbation and observe method (P&O), thus the P&O method can offer better performance. Furthermore, this study aims to provide a comparison of the hybrid method with each algorithm $P\&O$ and NNC. At the resulting duty cycle of the 2 methods, we applied the combination operation. A DC-DC boost converter is subjected to the hybrid MPPT control. This converter is part of a wind energy conversion system employing a permanent magnet synchronous generator (PMSG). The chain is modeled using MATLAB/Simulink software. The effectiveness of the controller is tested at varying wind speeds. In terms of the Integral time absolute error (ITAE), using the P&O technique, the ITAE is 9.72. But, if we apply the suggested technique, it is smaller at 4.55. The corresponding simulation results show that the proposed hybrid method performs best compared to the P&O method. Simulation results ensure the performance of the proposed hybrid MPPT control.**

Keywords*—Wind Energy Conversion System (WECS); PMSG; MPPT; Hybrid control; neural network control (NNC); perturb and observe (P&O).

I. INTRODUCTION

The energy crisis is one of the greatest threats facing our civilization since access to electricity is a mandatory condition for socio-economic development which we cannot do without. The most consuming part of this energy comes from fossil fuels such as petroleum, excessive exploitation of fossil fuels has given rise to problems such as high cost, and negative environmental impacts. Faced with this challenge, we have recourse to renewable energies which have become a competitive alternative given that they are inexhaustible and respectful of the environment to supply energy to the electrical networks [1-4]. Exploiting energy sources can reduce greenhouse gas emissions and complement and replace the use of fossil fuels [5]. Wind energy is considered a renewable energy source that responds to the increasing demand for energy [6]. Producing electricity with environmental concerns at an affordable price has become a key challenge [7, 8]. Because of their many advantages, the technology of variable speed wind power generation has become a research hotspot in this field [9, 10]. Compared to fixed-speed wind turbine technology, variable-speed wind turbines have the advantage of increased energy collecting [11-13], improved efficiency, and reduced installation and maintenance costs [14, 15]. Due to the random and varying conditions of wind speed which changes throughout the day, wind turbines can influence the stability of the electrical systems. For this reason, the energy production control strategy has a great impact on the overall operating performance [16]. Hence, wind power generation systems need to adopt different control methods according to diverse wind speed intervals [17]. In order to extract the maximum energy from the WECS in the MPPT interval where the WECS produces the maximum available wind power, it is necessary to design a maximum power point tracking controller (MPPT) [18-23].

Several maximum power point (MPP) extraction techniques have been proposed in the literature [24-30]. It can be divided into indirect and direct MPPT methods [31, 32]. The indirect method is based on knowledge of the wind turbine system properties [33]. Indirect techniques include the optimal torque (OT) method. In this method, control is achieved by monitoring optimum torque to achieve optimum wind energy utilization [34-36]. In [37] the authors described the power signal feedback (PSF), an indirect technique for maximizing the output power of a PMSG generator by determining the reference power for a particular wind speed. However, the mentioned indirect approaches have problems with their reliance on the climate and their need for knowledge of the characteristics of the wind turbine [38-43]. As opposed to indirect methods, the usage of direct methods no longer requires information about the characteristics of the wind turbine [44]. The example taken in [45], is the perturb & observe (P&O) approach, which tracks the maximum point by constantly varying the maximizing variable and observing the power captured [46]. The last-mentioned approach is one of the conventional MPPT techniques, owning a simple design and ease of implementation, the perturbation and observation technique is characterized by way of its simplicity and independence from the characteristics of the wind turbine [47-51]. The major drawback of this MPPT algorithm is that it cannot respond accurately, and has a poor ability to track the

MPP under rapid environmental changes. The step size of the P&O MPPT algorithm always makes the operating point always oscillate [52, 53]. Larger step sizes lead to larger steady-state oscillations around the MPP, while smaller step sizes slow down the dynamic response. Each of these 2 situations would incur more power loss and slower response [54-56]. Therefore, in order to solve this problem, it is necessary to use an adequate method to obtain MPP when the environment changes rapidly. Therefore, to resolve this problem, for obtaining MPP at rapid environmental changes a powerful method must be used. In this context, many researchers have estimated the MPP by the fuzzy logic (FL) method [57-60], it has a faster response and high accuracy even in the rapid variations of wind speed. FLC-based MPPT control provides high-performance control, but it leads to a high amount of computational burden and its usage is inflexible in complex systems [61, 62]. Neural network control (NNC) is also used to detect the maximum power point, this control proposed in [63] is operated for non-linear power electronics circuits, to track the output voltage and improve the performance of power. NNC is essentially a nonlinear control approach and extensively increases system effectivity with greater effectiveness [64-68]. This approach can successfully cope with the nonlinear behavior of the system besides any data about the mathematical model [69-73]. In addition, the dynamic features of the DC-DC converter with the neural network can be realized excellent dynamic characteristics, compared with the conventional methods [74]. Without any prior knowledge, NN controllers can handle the problem, showing good performance under rapidly varying [75,76]. Recently, genetic algorithms [77-80], pattern swarm optimization (PSO) [81-83], ant colony MPPT [84, 85], grey wolf MPPT [86], hybrid models such as hybrid particle swarm optimization and salp swarm optimization algorithm [87], and the MPPT control of wind turbines by using ANN-PSO wind speed estimator [88] have been proposed but each of the above-mentioned techniques has complexity levels based on their applications. MPPT controls vary in their effectiveness and complexity. Selecting an MPPT control method that should be able to track MPP properly, at variable wind speeds presents our main aim.

The main contributions of this paper are: the application of hybrid MPPT control using neural networks and P&O control, as well as the proposed hybrid method is compared with each of the conventional P&O and the NNC methods. Considering all the problems summarized above, the ease of implementation of P&O and the accuracy of the neural network are exploited in the suggested novel hybrid method. By this combination, maintaining maximum power and increasing efficiency under varying environmental conditions is guaranteed. Thus, we can make the most of the advantages of the conventional strategy and eliminate its disadvantages. In this research paper, a PMSG-based wind power conversion chain modeling is used in order to apply the hybrid MPPT controls on the DC-DC boost converter which is an element of the chain. The simulation results are confirmed by different cases of wind speed profiles, using the MATLAB/SIMULINK environment.

The present work is composed of 4 parts: the first one is for the introduction, the second part is devoted to presenting modeling of the wind and the components of the aerodynamic system with mathematical equations, the third section presents the MPPT control part giving the research methodology, and then we have the results and discussion part, the last section is consecrated to the conclusion that summarizes the main important points of this paper and gives futures works.

II. WIND MODELING

The wind is a stochastic, intermittent quantity dependent on a set of factors such as location and temperature [89-93]. In order to test the wind power conversion chain in intermittent conditions close to reality, it is necessary to have a wind reconstruction block. To evaluate the control approach proposed in our work, we resort to the application of a variable wind profile modeled in this section. The change in wind speed over time is modeled by a scalar function that changes over time. The wind model is given by a Fourier series representation which presents the wind as a signal consisting of a superposition of several harmonics. It is given by equation (1) [94, 95].

$$V = F(t) \tag{1}$$

The method used for the modeling of the wind consists in generating the temporal characteristic of the wind from a white noise to which is applied a transfer function to be determined which depends on the characteristics of the place and the nature of the wind. The wind speed at a point $V_0(t)$ can be decomposed into a sum of an average component V_{avrg} which varies slowly and of a variable component representing the fluctuations $V_t(t)$ [96]. V_{avrg} is the mean wind speeds and $V_t(t)$ is component representing wind turbulence.

$$V_0(t) = V_{avrg} + V_t(t) \tag{2}$$

At a given point in space, the wind turbulence is described by the power spectrum, based on the Von Karman filter, in a stochastic manner, and represented by the following transfer function [97].

$$H_t(jw) = \frac{K_f}{(1 + jw * T_F)^{\frac{5}{6}}} \tag{3}$$

Where K_f is gain of the filter and T_F is the constant filter time.

This filter is approximated by the transfer function characterized by: m_1 = 0.4 and m_2 = 0.25.

$$H_t(jw) = \frac{K_f\ (1 + m_1 * T_F * S)}{(1 + T_F * S)(1 + m_2 * T_F * S)} \tag{4}$$

High-frequency fluctuations are filtered out by the wind turbine. For this purpose, the low pass filter with the transfer function is simplified and given by:

$$G(s) = \frac{1}{(1 + S * b)} \tag{5}$$

$$b = \gamma \frac{R}{V_{avrg}} \tag{6}$$

Where γ attenuation factor on the rotor (γ = 1.3).

The value of the time constant depends on the diameter of the rotor, the intensity of the wind turbulence, and the average wind speed, ($\tau 1 = 0.11375s$).

$$G_f = \frac{1}{(1 + \tau_1 * S)} \quad (7)$$

This modeling concerning the wind is seen as necessary in order to define the operating conditions of the wind turbine, also describe the stresses that apply to the blades, and refine the modeling of the rotor.

III. Aerodynamic System Modeling

The wind flow creates a driving torque at the drive shaft. The wind has a certain velocity V at a given time and passes through a certain area "S", where "ρ" is the density of the air, The aerodynamic power extracted by the wind turbine is quantified using the following equation [98].

$$Pa \;\; = \frac{1}{2} C_p \, (\lambda, \beta) \rho \pi \, R^2 V^3 \quad (8)$$

Where R is the wind turbine rotor radius, C_p (λ, β), the power coefficient, represents the aerodynamic efficiency of the wind turbine, which describes the capacity of the turbine to transform the wind kinetic power to mechanical power.

C_p is a nonlinear function of the tip-speed ratio λ and blade pitch angle β. The tip-speed ratio is defined as:

$$\lambda = \frac{W_t}{V} R \quad (9)$$

where W_t is angular shaft speed of the turbine.

The aerodynamic power can be expressed also as follows:

$$P_a = W_t T_a \quad (10)$$

Hence, following the previous Equations (8)-(10), the aerodynamic torque Ta on the wind turbine shaft can also be expressed as follows:

$$T_a \;\; = \frac{1}{2} \frac{C_p(\lambda, \beta)}{\lambda} \rho \pi \, R^3 V^2 \quad (11)$$

Where $C_p(\lambda, \beta)$ is usually modeled by empirical equations it considered approximate expression can be given by [99, 100]

$$c_p = c_1 \left(\frac{C_2}{c_1} - c_3 \beta - c_4 \right) e^{\frac{C_5}{\lambda}} + c_6 \lambda \quad (12)$$

IV. MPPT Control

To optimize the energy efficiency of the system by following the optimal operating point, the MPPT technique is used to extract the most power from accessible wind speed by tracking the peak point. In this paper, the MPPT strategy proposed consists of a combination of 2 techniques: neural network and therefore the P&O. Additionally, this paper compares the hybrid technique with each of the standard MPPT techniques perturb and observe technique (P&O), and neural network technique (NNC). The present hybrid approach is applied to the wind energy conversion system. To track the maximum power point and generates the appropriate duty cycle for the switch within the DC-DC boost device, the DC-link voltage is employed as shown in Fig. 1.

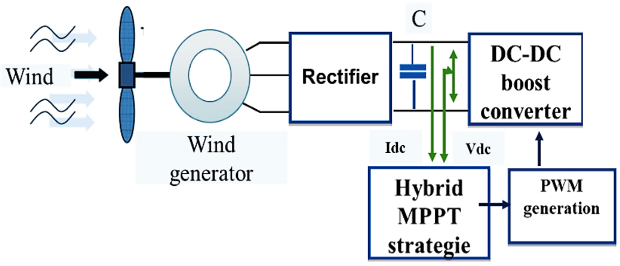


Fig. 1. Configuration of a WECS based on PMSG

The proposed topology shown within the Fig. 1 is developed via MATLAB/Simulink software according to the block diagram presented in Fig. 2. As shown within the given system block diagram of the WECS, the chain consists of the wind signal reconstruction block. The variable wind speed generated is transmitted to the turbine, coupled to a synchronous generator with permanent magnets. The PMSG is employed in direct drive. An AC-DC power electronic interface with a diode bridge corrected the output of the PMSG. Then this output is filtered to get rid of large ripple voltage components, and fed to the DC-DC boost converter. Thus, the converter unit is used for the wind turbine's variable speed operation, providing a DC voltage load.

This system is meant to realize maximum power tracking MPPT under wind speed variations, by means of hybrid NNC and P&O control according to the methodology provided through the flowchart in Fig. 3. As shown in the algorithm, the inputs are the current and the voltage pre-requisited on the input side of the converter. Both techniques P&O and NNC work separately depending on the inputs and then the neural network duty cycle output is combined with the P&O duty cycle output. After that, the average of the duty cycle generated is given to the PWM generator for generating pulses to trigger the IGBT switch in the DC–DC converter.

The NNC control employed in this work uses an artificial neural network as a design methodology. NNC is less difficult to design, and performs higher than different controllers. Neurons are linked by using weighted links. The weighted links lift the signal. Each neuron has a single threshold value. The weighted sum of the input is shaped and then subtracted from the threshold value to get the activation sign of the neuron. As illustrated in Fig. 3 in the neural network architecture, it is necessary to define the number of layers to exploit, in our case, there are three layers, that are: the input layer, the hidden layer that functions to companion the input and output layers and the output layer.

The NNC structure is built using gensim instruction in MATLAB. In addition to the NNC method, the algorithm also includes the PO method. By measuring the voltage and current, As shown in Fig. 3, the working precept of the P&O method is to increase the voltage by means of adjusting the duty cycle on the power side DC-DC converter, also the maximum output power of the generator can be optimized. The algorithm compares the power and voltages of time (k) with the sample at a time (k-1) and predicts the time to strategy to the maximum power point (MPP). A small voltage perturbation changes the power and if the power alteration is positive, voltage perturbation is endured in the identical track.

But if delta energy is negative, otherwise, the sign of the perturbation is inverted to tune in the way of growing power. The output power generated is compared to the preceding electrical power. If the generated power increases, then the variable ΔD will be fixed, if it decreases, then the ΔD will change. This is a continuous procedure of observation and perturbation until the operating point converges at the MPP.

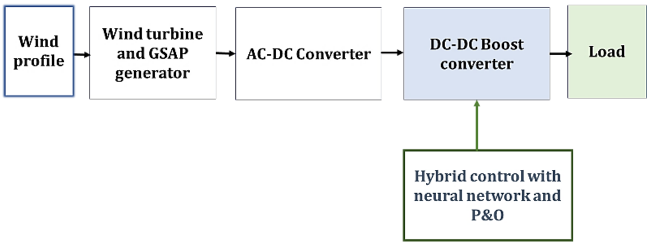


Fig. 2. Block diagram of the proposed wind energy conversion chain

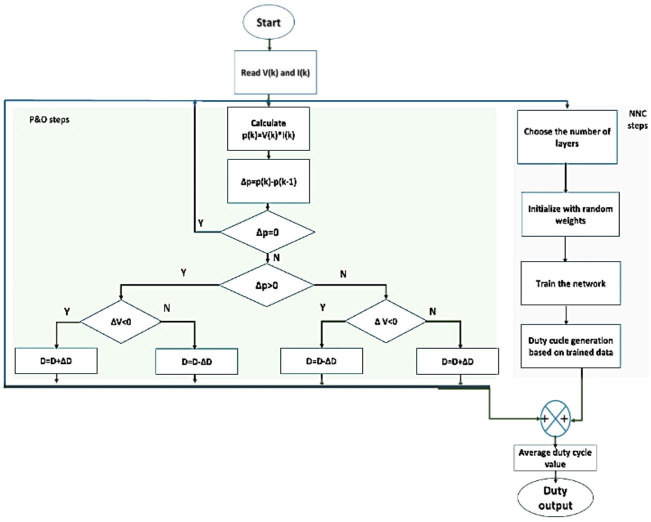


Fig. 3. Flow chart for hybrid MPPT based on P&O and neural network

V. RESULTS AND DISCUSSION

To evaluate the consistency and effectiveness of the proposed MPP tracking control scheme, the PMSG-based WECS was simulated in the MATLAB/Simulink software environment. In this section, we test the hybrid MPPT technique based on NNC and P&O and compare it with the techniques already in use. The performance of the proposed control is investigated for two different wind speed profiles. The first is the profile where the wind speed changes step by step during the operating time. In addition to the previous wind speed profile, there is a rapidly changing profile that is closer to the real wind speed. For the first scenario, Fig. 4 shows the step change in wind speed, WECS is evaluated for this study with variable wind speed, passes from 8m/s, 12m/s, 9m/s, 10m/s, to 8m/s, then to 12 m/s.

Simulation result presented in Fig. 5, shows the power extracted from the wind conversion chain without application of any MPPT control. It can be observed that it leads to results with the presence of a significant oscillation. It is clear that oscillations occur frequently and that tracking is lost.

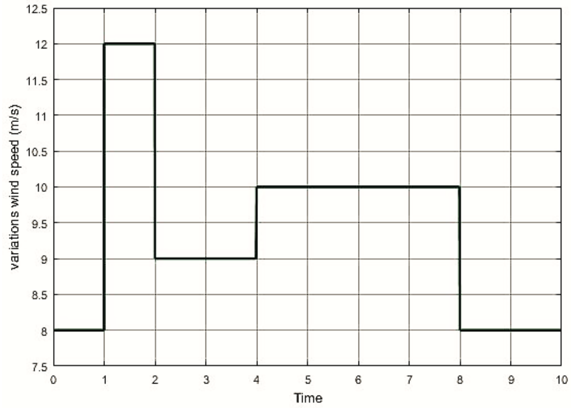


Fig. 4. Wind speed profile

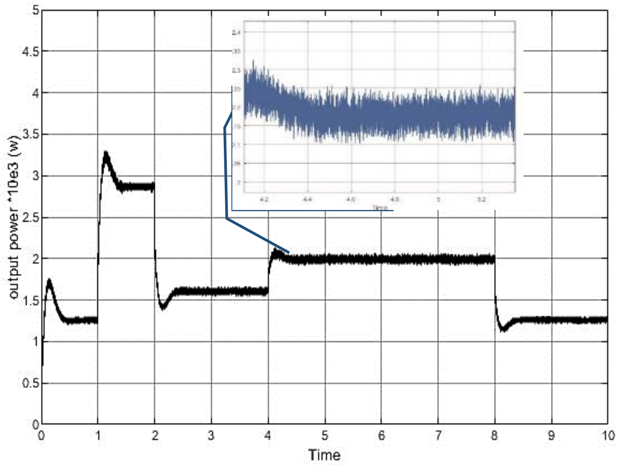


Fig. 5. Power extracted without using any MPPT control

After applying the MPPT P&O control, the evolution of the extracted power changed as shown in Fig. 6. Compared to the above result, moderate oscillations are present after reaching a maximum limit of power points. The variations of the wind signal show the main drawback of the P&O control, that is, the presence of oscillations around the MPP due to the fixed step size, which leads to a loss of the generated power. Any variation in the wind speed profile introduces a variation in the extracted power represented. The main weakness of this type of MPPT algorithm is the lack of precision.

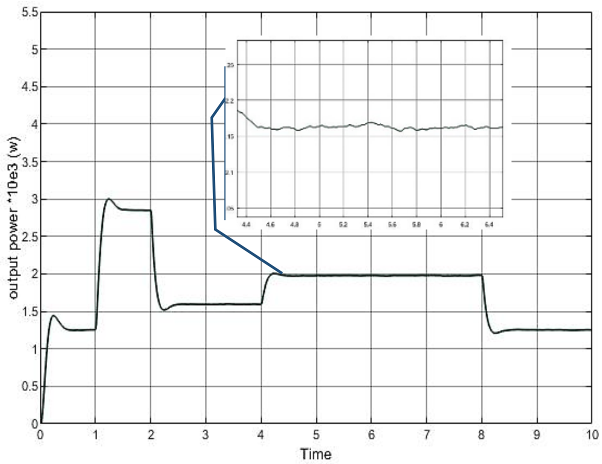


Fig. 6. Power extracted using P&O MPPT control

The resulting waveform of the extracted power as a function of wind speed variation with the application of the NNC command is shown in Fig. 7. Result shows that the NNC control give faster responses and less oscillation around the maximum power than the basic P&O control. This present control has advantages such as rapidity and damping of the overshoot when the wind speed changes.

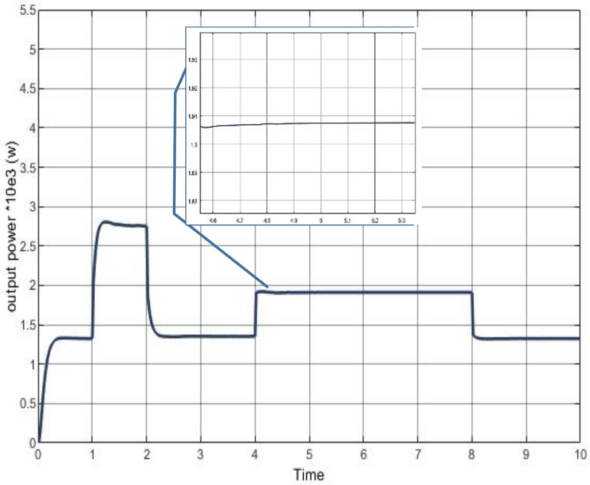
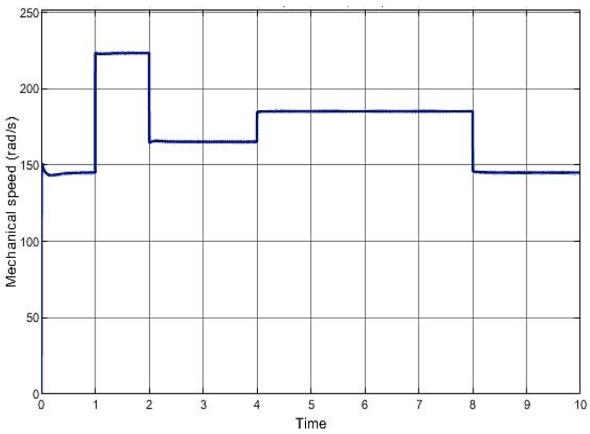
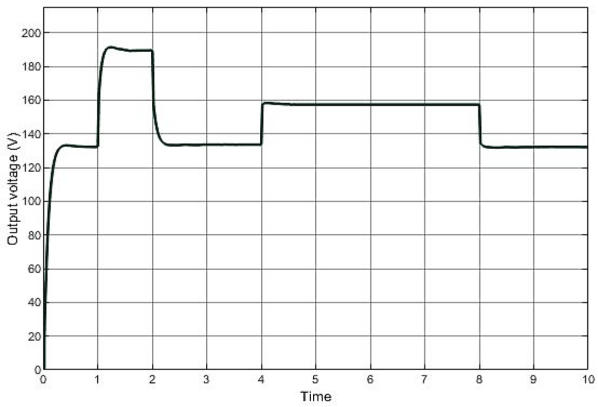


Fig. 7. Power extracted using NNC MPPT control

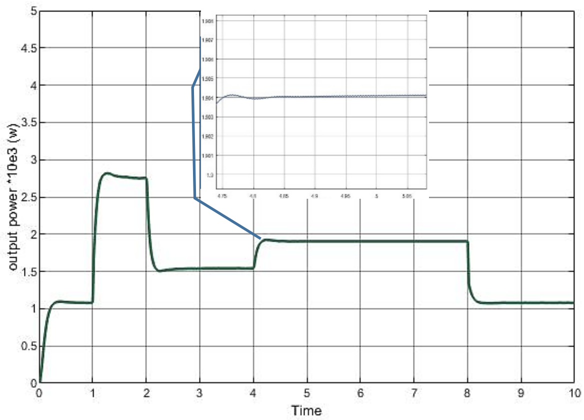
The results in Fig. 8 included: mechanical speed of the generator shaft in Fig. 8(a), voltage output in Fig. 8(b), extracted power in Fig. 8(c). As shown in Fig. 8(a), according to the change in wind speed, the mechanical speed is regulated. When the wind speed increases, the mechanical speed increases and the output power increases, in this case, the PMSG delivers the maximum allowable wind energy which is clearly realized in Fig. 8(c). Fig. 8(b) shows the instantaneous output voltage from the WECS, during the step change in wind speed. The output voltage also varies with the wind speed and has the smallest oscillation levels around the MPP, meaning that after reaching the maximum power point, our controlled system becomes comparatively stable. The matching of graphs of the two methods P&O and the proposed method in steady state conditions, indicates the accuracy of the proposed method. The output power in Fig. 8(c) is much smoother and has lesser speed fluctuations, it can be clearly observed that WECS with the hybrid MPPT control has better wind energy tracking capability with fast response time.



(a)



(b)



(c)

Fig. 8. (a) Mechanical speed, (b) Voltage output, (c) Output power with Hybrid P&O, NNC

The simulation of WESC under intermittent wind speed conditions is done in order to evaluate the tracking and to study the robustness of our system adopting hybrid control. Variations in wind speed used in the simulation are shown in Fig. 9, in this figure, the mean wind speed is 10m/s.

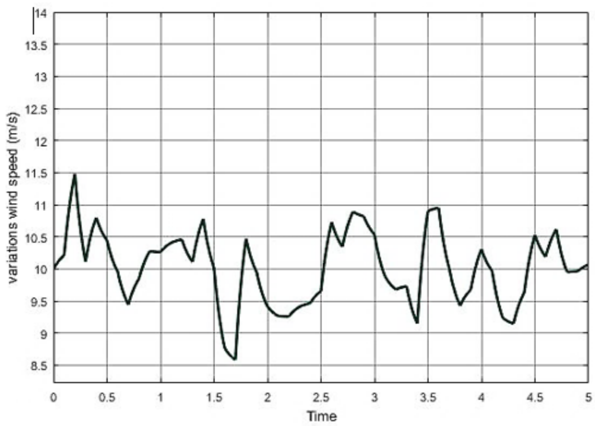


Fig. 9. Wind profile used

For mean wind velocity (10 m/s), simulation results have carried out under randomly and fast changeable wind rapidity. The curve presented in Fig. 10 shows the power extracted directly without application of any MPPT control, it is clear that it leads to results with the presence of a significant oscillation. Fig. 11(a) shows the rotor speed responses to described wind speed turbulence. As shown, the variation of actual rotor speed is in accordance with wind speed fluctuation. The output voltage is given in Fig. 11(b) varies with the wind speed, and demonstrates the energy management technique and controllers' high stability. From Fig. 11, we can note that the proposed strategy adjusts the generator speed and output power with satisfactory tracking performance. From the overall results, the proposed combined P&O MPPT control with NNC presents outputs with much even, less distortion, and less fluctuation at the rapid various wind speed conditions.

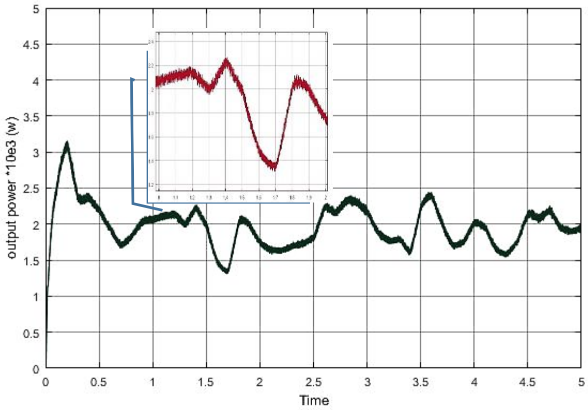
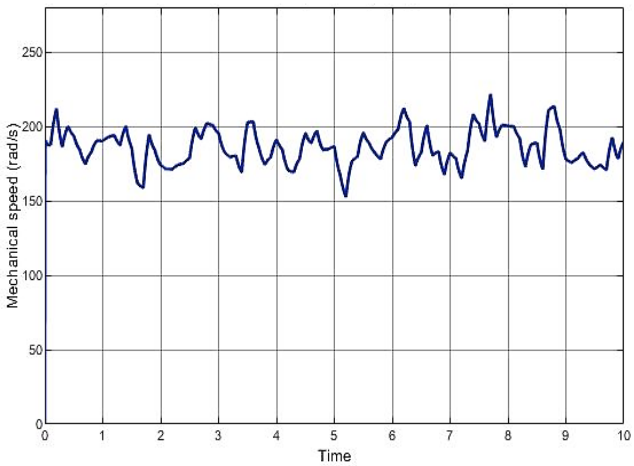
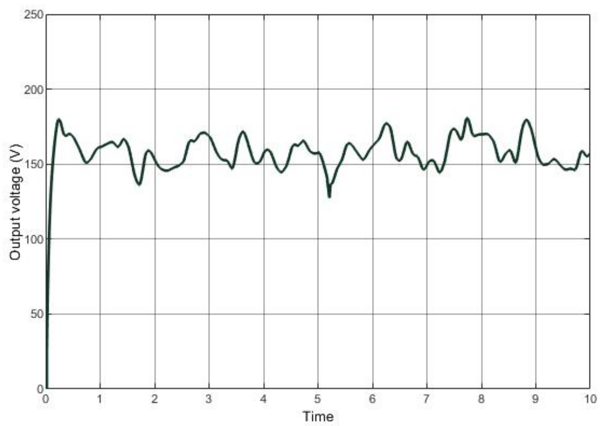


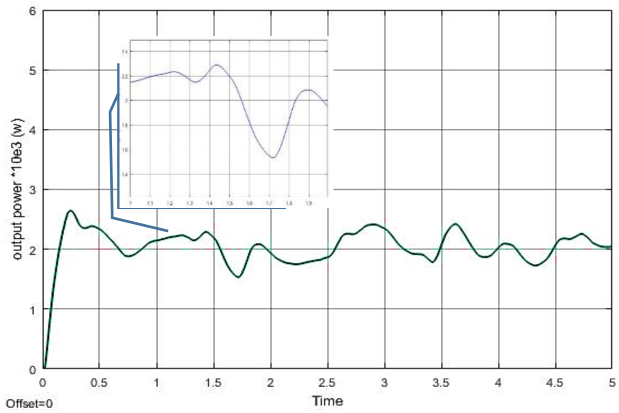
Fig. 10. Power extracted using recreated wind profile without MPPT control



(a)



(b)



(c)

Fig. 11. (a) Mechanical speed, (b) voltage output, (c) output power with Hybrid P&O, NNC MPPT control using reconstructed wind profile

To further evaluate the performance of the control schemes, performance indices such as absolute integral error (IAE), squared integral error (ISE), and absolute time integral error (ITAE) are calculated here. Below and are presented in Table 1. Performances of the proposed hybrid are compared with those of the conventional P&O controller, NNC control, conventional SMC, and optimized SMC: second-order sliding mode controller proposed in another similar study. The index ISE, IAE and $ITAE$ [101, 102] is expressed as:

$$ISE = \int_0^\infty e^2(t)dt \tag{13}$$

$$IAE = \int_0^\infty |e(t)|dt \tag{14}$$

$$ITAE = \int_0^\infty t|e(t)|dt \tag{15}$$

These indices demonstrate characteristics like, overshoot, settling time and response speed. Also, these are calculated as a function of time and/or error.

TABLE I. ERROR CRITERIA OF THE MPPT CONTROLLERS.

MPPT Method	Error criteria		
	ISE	***IAE***	***ITAE***
Conventional P&O	13.552	21.4356	9.728
Proposed hybrid P&O and NNC method	12.464	19.498	4.55
Sliding Mode (SMC) [103]	274.5	22.86	95.49
Optimized SMC: Second-Order Sliding Mode Controller [103]	226.1	15.03	63.18

Table 1 gives a comparison of the generally used performance criteria under wind step change. The optimal controller is defined as the technique that decreases those indexes. It is shown that the error magnitude obtained in different criteria for conventional method P&O is big as compared to the proposed method based on NNC-P&O algorithm. From a comparison of index of all the controllers presented in the table above, it can be deduced that the hybrid control: P&O with NNC maintains a better performance. The lowest values of ISE and ITAE are given by the hybrid control. However, the Optimized SMC: Second-Order Sliding Mode Controller provides minimal values for IAE. This is explained by the fact that the hybrid control controller has a smaller peak overshoot than the optimized SMC, but this last controller will tolerate small oscillation in terms of tracking time. To further improve the performance of the system, we can exploit the algorithm optimized SMC.

For Table 2, performance evaluation is based on analysis of the hybrid with other techniques, which are commonly used for the MPPT problem. The hybrid algorithm performed very well, reaching the peak performance point in all cases, including changes in environmental conditions. In comparison, the algorithms like PSF are fast and simple. Nevertheless, for PSF control, sensors are required which is costly. Algorithms like P&O and INC are basic, these are sensor less calculation, which makes it less expensive. However, requires less memory, also the application of these techniques isn't considerable under wind speed variations. with the P&O technique Efficiency is reduced because of the variances around the MPP. The fuzzy control MPPT is great yet Neural Network based MPPT control gives a superior compromise regarding dynamic speed and power reactions of the system, but prior-knowledge of parameters is required, and the complexity is increased. The neural system must be intermittently prepared to ensure the precise MPPT. By using hybrid algorithms, the drawbacks of individual MPPT algorithm can be eliminated for achieving fast tracking speed with higher efficiency. But the system complexity is determined by the participated algorithms on a hybrid algorithm and that is the problem with the Hybrid PSO-FLC. In wind farm installation, it is recommended to apply simple and effective MPPT algorithm, which reduces the cost of sensors. The hybrid P&O, NNC algorithms take into account these features developing new technique that enhance the overall WECS performance with limited shortcomings as deliberated in this section.

TABLE II. COMPARISON OF HYBRID MPPT CONTROL WITH SIMILAR EMPLOYED TECHNIQUES

MPPT Algorithm features	**Indirect MPPT algo-rithms**	**Direct MPPT algo-rithms**	**Smart MPPT Algorithms**		**Hybrid MPPT algorithms**	
	PSF [104]	***Conventional P&O [105]***	***NN [106]***	***Fuzzy logic [107]***	***Hybrid PSO-FLC [108]***	***Hybrid P&O-NNC***
Complexity	Simple	Simple	High	High	High	Simple
Prior knowledge of system parameters	Required	Not required	Required	Required	Required	Required
Wind speed measurements	Yes	No	No	No	No	No
Memory requirement	Yes	No	Yes	Yes	-	Yes
Oscillation at MPP	No	Yes	No	No	No	No
Efficiency	Moderate	Low	High	High	High	High

VI. Conclusion

Wind turbines have grown over the last several years considerably. To ensure high performance, we use the wind turbine with control algorithms, among which is maximum power-point tracking (MPPT). It is used to bring the turbine to the MPP over a full wind speed range and aims to maximize the efficiency of a wind turbine. Within this work, we combine the P&O method and neural network control (NNC). A hybrid algorithm is applied to the variable speed wind power conversion chain including the permanent magnet synchronous generator, by acting directly on the duty cycle of the DC-DC boost converter. Simulation done in MATLAB/SIMULINK software proved the viability of the model. Simulation realized in this work demonstrates that the maximum power point tracking based on the NNC and P&O MPPT control can track and preserve the maximum power carried for every wind speed value. This approach used has been confirmed to be a contributor to successfully extracting the maximum power from the wind energy conversion system (WECS). Hence, the developed system has good prospects in the WECS grid application. As a future work, the proposed MPPT controller method will be experimentally tested to estimate the performance of the control for optimal power generation from realistic wind energy resources, and further evolved as a prototype for validation for application to the real grid-connected wind turbines.

References

[1] B. Sarsembayev, K. Suleimenov, B. Mirzagalikova, and T. D. Do, "SDRE-Based Integral Sliding Mode Control for Wind Energy Conversion Systems," IEEE Access, vol. 8, pp. 51100–51113, 2020, doi: 10.1109/access.2020.2980239.

[2] J. Jurasz, F. A. Canales, A. Kies, M. Guezgouz, and A. Beluco, "A review on the complementarity of renewable energy sources: Concept, metrics, application and future research directions," Solar Energy, vol. 195, pp. 703–724, Jan. 2020, doi: 10.1016/j.solener.2019.11.087.

[3] M. Daneshvar, B. Mohammadi-Ivatloo, M. Abapour, S. Asadi, and R. Khanjani, "Distributionally Robust Chance-Constrained Transactive Energy Framework for Coupled Electrical and Gas Microgrids," IEEE Transactions on Industrial Electronics, vol. 68, no. 1, pp. 347–357, Jan. 2021, doi: 10.1109/tie.2020.2965431.

[4] S. Pira, "The Importance of Renewable Energies with Emphasize on Wind Power," International Journal of Engineering Research & Technology (Ijert), vol. 9, no. 6, 2020.

[5] M. Chentouf and M. Allouch, "Analysis of environmental impacts of renewable energy on the Moroccan electricity sector: A System Dynamics approach," E3S Web of Conferences, vol. 37, p. 03002, 2018, doi: 10.1051/e3sconf/20183703002.

[6] A. Zhour, G. Sihem, and D. Djalel, "A New Approach to Fault Detection in the Power Converter in Wind Turbine Conversion Systems," International Journal of Robotics and Control Systems, vol. 1, no. 4, pp. 428–439, Oct. 2021, doi: 10.31763/ijrcs. v1i4.443.

[7] R. Alayi and J. Javad Velayti, "Modeling / Optimization and Effect of Environmental Variables on Energy Production Based on PV / Wind Turbine Hybrid System," Jurnal Ilmiah Teknik Elektro Komputer dan Informatika, vol. 7, no. 1, p. 101, Apr. 2021, doi: 10.26555/jiteki. v7i1.20515.

[8] T. Güney, "Non-renewable energy and sustainable development," International Journal of Sustainable Development & World Ecology, Vol. 26, pp.389-397, 2019. https://doi.org/10.1080/13504509.2019.1595214

[9] X. Zhou, M. Liu, Y. Ma, and S. Wen, "Improved Linear Active Disturbance Rejection Controller Control Considering Bus Voltage Filtering in Permanent Magnet Synchronous Generator," IEEE Access, vol. 8, pp. 19982–19996, 2020, doi: 10.1109/access.2020.2967395.

[10] J.-S. Lee, K.-B. Lee, and F. Blaabjerg, "Predictive Control With Discrete Space-Vector Modulation of Vienna Rectifier for Driving

PMSG of Wind Turbine Systems," IEEE Transactions on Power Electronics, vol. 34, no. 12, pp. 12368–12383, Dec. 2019, doi: 10.1109/tpel.2019.2905843.

[11] K. Okedu, "Impact of power converter size on variable speed wind turbines," Onshore Wind Farms, pp. 7-1-7–8, 2021, doi: 10.1063/9780735422995_007.

[12] W. Yang and J. Yang, "Advantage of variable-speed pumped storage plants for mitigating wind power variations: Integrated modelling and performance assessment," Applied Energy, vol. 237, pp. 720–732, Mar. 2019, doi: 10.1016/j.apenergy.2018.12.090.

[13] M. Ayadi, "High-order sliding mode control for variable speed PMSG wind turbine based disturbance observer," International Journal of Modelling, Identification and Control, vol. 1, no. 1, p. 1, 2019, doi: 10.1504/ijmic.2019.10023119.

[14] C. Hung Tran, F. Nollet, N. Essounbouli, and A. Hamzaoui, "Maximum power point tracking techniques for wind energy systems using three levels boost converter," IOP Conference Series: Earth and Environmental Science, vol. 154, p. 012016, May 2018, doi: 10.1088/1755-1315/154/1/012016.

[15] S. Rhaili et al., "Robust Sliding Mode Control with Five Sliding Surfaces of Five-Phase PMSG Based Variable Speed Wind Energy Conversion System," International Journal of Intelligent Engineering and Systems, vol. 13, no. 4, pp. 346–357, Aug. 2020, doi: 10.22266/ijies2020.0831.30.

[16] Y. Yusong and E. Solomin, "The Control Strategy and Simulation of the Yaw System for MW Rated Wind Turbine," 2020 Russian Workshop on Power Engineering and Automation of Metallurgy Industry: Research & Practice (PEAMI), Sep. 2020, doi: 10.1109/peami49900.2020.9234343.

[17] A. S. Samosir and A. Riszal, "The effect analysis of wind speed variation to the horizontal axis wind turbine design with Q-blade," IOP Conference Series: Materials Science and Engineering, vol. 1173, no. 1, p. 012009, Aug. 2021, doi: 10.1088/1757-899x/1173/1/012009.

[18] P. Sudwilai, "A Design and Development of P I Controlled Based MPPT for Photovoltaic Systems," 2018 21st International Conference on Electrical Machines and Systems (ICEMS), Oct. 2018, doi: 10.23919/icems.2018.8549278.

[19] M. Hannachi, O. Elbeji, M. Benhamed, and L. Sbita, "Maximum power point tracking of a PMSG wind turbine with On-Off control-based particle swarm optimization," 2019 International Conference on Signal, Control and Communication (SCC), Dec. 2019, doi: 10.1109/scc47175.2019.9116142.

[20] F. Mohd Zaihidee, S. Mekhilef, and M. Mubin, "Robust Speed Control of PMSM Using Sliding Mode Control (SMC)—A Review," Energies, vol. 12, no. 9, p. 1669, May 2019, doi: 10.3390/en12091669.

[21] S. G. Karad and R. Thakur, "Fractional order controller based maximum power point tracking controller for wind turbine system," International Journal of Electronics, vol. 109, no. 5, pp. 875–899, Jul. 2021, doi: 10.1080/00207217.2021.1941296.

[22] X. Zhang, Z. Zhang, J. Jia, and L. Zheng, "A Maximum Power Point Tracking Control Method Based on Rotor Speed PDF Shape for Wind Turbines," Applied Sciences, vol. 12, no. 18, p. 9108, Sep. 2022, doi: 10.3390/app12189108.

[23] A. E. Yaakoubi, L. Amhaimar, K. Attari, M. H. Harrak, M. E. Halaoui, and A. Asselman, "Non-linear and intelligent maximum power point tracking strategies for small size wind turbines: Performance analysis and comparison," Energy Reports, vol. 5, pp. 545–554, Nov. 2019, doi: 10.1016/j.egyr.2019.03.001.

[24] M. B. Hemanth Kumar, B. Saravanan, P. Sanjeevikumar, and F. Blaabjerg, "Review on control techniques and methodologies for maximum power extraction from wind energy systems," IET Renewable Power Generation, vol. 12, no. 14, pp. 1609–1622, Sep. 2018, doi: 10.1049/iet-rpg.2018.5206.

[25] K. Palanimuthu, G. Mayilsamy, S. R. Lee, S. Y. Jung, and Y. H. Joo, "Comparative analysis of maximum power extraction and control methods between PMSG and PMVG-based wind turbine systems," International Journal of Electrical Power & Energy Systems, vol. 143, p. 108475, Dec. 2022, doi: 10.1016/j.ijepes.2022.108475.

[26] M. Hannachi, O. Elbeji, M. Benhamed, and L. Sbita, "Comparative study of four MPPT for a wind power system," Wind Engineering, vol. 45, no. 6, pp. 1613–1622, May 2021, doi: 10.1177/0309524x21995946.

[27] C. Voloşencu, "A Comparative Analysis of Some Methods for Wind Turbine Maximum Power Point Tracking," Mathematics, vol. 9, no. 19, p. 2399, Sep. 2021, doi: 10.3390/math9192399.

[28] M. El Malah, A. Barazzouk, E. Abdelmounim, and M. Madark, "Robust Nonlinear Sensorless MPPT Control with Unity Power Factor for Grid Connected DFIG Wind Turbines," International Review on Modelling and Simulations (IREMOS), vol. 11, no. 5, p. 313, Oct. 2018, doi: 10.15866/iremos.v11i5.15018.

[29] M. Karabacak, "A new perturb and observe based higher order sliding mode MPPT control of wind turbines eliminating the rotor inertial effect," Renewable Energy, vol. 133, pp. 807–827, Apr. 2019, doi: 10.1016/j.renene.2018.10.079.

[30] M. G. Mousa, S. M. Allam, and E. M. Rashad, "Maximum power extraction under different vector-control schemes and grid-synchronization strategy of a wind-driven Brushless Doubly-Fed Reluctance Generator," ISA Transactions, vol. 72, pp. 287–297, Jan. 2018, doi: 10.1016/j.isatra.2017.10.005.

[31] E. Kandemir, S. Borekci, and N. S. Cetin, "Conventional and Soft-Computing Based MPPT Methods Comparisons in Direct and Indirect Modes for Single Stage PV Systems," Elektronika ir Elektrotechnika, vol. 24, no. 4, Aug. 2018, doi: 10.5755/j01.eie.24.4.21477.

[32] Y. Sahri, S. Tamalouzt, and S. Belaid Lalouni, "Enhanced Direct Power Control Strategy of a DFIG-Based Wind Energy Conversion System Operating Under Random Conditions," Periodica Polytechnica Electrical Engineering and Computer Science, vol. 65, no. 3, pp. 196–206, Jun. 2021, doi: 10.3311/ppee.16656.

[33] J. Castelló, J. M. Espí, and R. García-Gil, "Development details and performance assessment of a Wind Turbine Emulator," Renewable Energy, vol. 86, pp. 848–857, Feb. 2016, doi: 10.1016/j.renene.2015.09.010.

[34] Errami, M. Ouassaid, and M. Maaroufi, "Optimal Power Control Strategy of Maximizing Wind Energy Tracking and Different Operating Conditions for Permanent Magnet Synchronous Generator Wind Farm," Energy Procedia, vol. 74, pp. 477–490, Aug. 2015, doi: 10.1016/j.egypro.2015.07.732.

[35] J. Liu, H. Meng, Y. Hu, Z. Lin, and W. Wang, "A novel MPPT method for enhancing energy conversion efficiency taking power smoothing into account," Energy Conversion and Management, vol. 101, pp. 738–748, Sep. 2015, doi: 10.1016/j.enconman.2015.06.005.

[36] B. Meghni, H. Chojaa, and A. Boulmaiz, "An Optimal Torque Control based on Intelligent Tracking Range (MPPT-OTC-ANN) for Permanent Magnet Direct Drive WECS," 2020 IEEE 2nd International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS), Dec. 2020, doi: 10.1109/icecocs50124.2020.9314304.

[37] O. Zebraoui and M. Bouzi, "Comparative study of different MPPT methods for wind energy conversion system," IOP Conference Series: Earth and Environmental Science, vol. 161, p. 012023, Jun. 2018, doi: 10.1088/1755-1315/161/1/012023.

[38] Pande, P. Nasikkar, K. Kotecha, and V. Varadarajan, "A Review of Maximum Power Point Tracking Algorithms for Wind Energy Conversion Systems," Journal of Marine Science and Engineering, vol. 9, no. 11, p. 1187, Oct. 2021, doi: 10.3390/jmse9111187.

[39] D. Kumar and K. Chatterjee, "A review of conventional and advanced MPPT algorithms for wind energy systems," Renewable and Sustainable Energy Reviews, vol. 55, pp. 957–970, Mar. 2016, doi: 10.1016/j.rser.2015.11.013.

[40] K. Karthi, R. Radhakrishnan, JM. Baskaran, and L. S. Titus, "Analysis of Adaptive MPPT Control Algorithm for Direct Driven Permanent Magnet Synchronous Generator," 2019 2nd International Conference on Power and Embedded Drive Control (ICPEDC), Aug. 2019, doi: 10.1109/icpedc47771.2019.9036708.

[41] D. Cortes-Vega, F. Ornelas-Tellez, and J. Anzurez-Marin, "Comparative analysis of MPPT techniques and Optimal Control for a PMSG-based WECS," 2019 IEEE 4th Colombian Conference on Automatic Control (CCAC), Oct. 2019, doi: 10.1109/ccac.2019.8921183.

[42] M. Zine, A. Chemsa, C. Labiod, M. Ikhlef, K. Srairi, and M. Benbouzid, "Coupled Indirect Torque Control and Maximum Power Point Tracking Technique for Optimal Performance of 12/8 Switched Reluctance Generator-Based Wind Turbines," Machines, vol. 10, no. 11, p. 1046, Nov. 2022, doi: 10.3390/machines10111046.

[43] M. B. Hemanth Kumar, B. Saravanan, P. Sanjeevikumar, and F. Blaabjerg, "Review on control techniques and methodologies for maximum power extraction from wind energy systems," IET Renewable Power Generation, vol. 12, no. 14, pp. 1609–1622, Sep. 2018, doi: 10.1049/iet-rpg.2018.5206.

[44] M. Hossam H. H., A.-R. Youssef, and M. Essam E. M., "Improved Perturb and Observe MPPT Algorithm of Multi-Phase PMSG Based Wind Energy Conversion System," 2019 21st International Middle East Power Systems Conference (MEPCON), Dec. 2019, doi: 10.1109/mepcon47431.2019.9008004.

[45] S. Azzouz, S. Messalti, and A. Harrag, "A Novel Hybrid MPPT Controller Using (P&O)-neural Networks for Variable Speed Wind Turbine Based on DFIG," Modelling, Measurement and Control A, vol. 92, no. 1, pp. 23–29, Mar. 2019, doi: 10.18280/mmc_a.920104.

[46] K. Saidi, M. Maamoun, and M. Bounekhla, "Simulation and analysis of variable step size P&O MPPT algorithm for photovoltaic power control," 2017 International Conference on Green Energy Conversion Systems (GECS), Mar. 2017, doi: 10.1109/gecs.2017.8066265.

[47] P. K. Gupta, "Optimized Fuzzy Logic Solar Module MPPT Controller Modelling using PSO," International Journal of Emerging Trends in Engineering Research, vol. 8, no. 8, pp. 4220–4225, Aug. 2020, doi: 10.30534/ijeter/2020/30882020.

[48] Soedibyo, M. Ridwan, A. Pradipta, S. Anam, and M. Ashari, "Comparison of P&O and inceremental conductance based maximum power point tracking for wind turbine application in remote area (Case study: Gili genting Island, Madura, East Java, Indonesia)," 2018 IEEE International Conference on Innovative Research and Development (ICIRD), May 2018, doi: 10.1109/icird.2018.8376298.

[49] A. Borni, N. Bouarroudj, A. Bouchakour, and L. Zaghba, "P&O-PI and fuzzy-PI MPPT Controllers and their time domain optimization using PSO and GA for grid-connected photovoltaic system: a comparative study," International Journal of Power Electronics, vol. 8, no. 4, p. 300, 2017, doi: 10.1504/ijpelec.2017.085199.

[50] A. Harrag and S. Messalti, "Variable step size modified P&O MPPT algorithm using GA-based hybrid offline/online PID controller," Renewable and Sustainable Energy Reviews, vol. 49, pp. 1247–1260, Sep. 2015, doi: 10.1016/j.rser.2015.05.003.

[51] A. G. Abo-Khalil, A. M. Eltamaly, P. R.P., A. S. Alghamdi, and I. Tlili, "A Sensorless Wind Speed and Rotor Position Control of PMSG in Wind Power Generation Systems," Sustainability, vol. 12, no. 20, p. 8481, Oct. 2020, doi: 10.3390/su12208481.

[52] H. H. H. Mousa, A.-R. Youssef, and E. E. M. Mohamed, "Hybrid and adaptive sectors P&O MPPT algorithm based wind generation system," Renewable Energy, vol. 145, pp. 1412–1429, Jan. 2020, doi: 10.1016/j.renene.2019.06.078.

[53] I. Toumi et al., "Robust Variable-Step Perturb-and-Observe Sliding Mode Controller for Grid-Connected Wind-Energy-Conversion Systems," Entropy, vol. 24, no. 5, p. 731, May 2022, doi: 10.3390/e24050731.

[54] X. Zhang, D. Gamage, B. Wang, and A. Ukil, "Hybrid Maximum Power Point Tracking Method Based on Iterative Learning Control and Perturb & Observe Method," 2021 IEEE Power & Energy Society General Meeting (PESGM), Jul. 2021, doi: 10.1109/pesgm46819.2021.9638241.

[55] M. Mohammadinodoushan, R. Abbassi, H. Jerbi, F. Waly Ahmed, H. Abdalqadir kh ahmed, and A. Rezvani, "A new MPPT design using variable step size perturb and observe method for PV system under partially shaded conditions by modified shuffled frog leaping algorithm- SMC controller," Sustainable Energy Technologies and Assessments, vol. 45, p. 101056, Jun. 2021, doi: 10.1016/j.seta.2021.101056.

[56] H. H. H. Mousa, A.-R. Youssef, and E. E. M. Mohamed, "State of the art perturb and observe MPPT algorithms based wind energy conversion systems: A technology review," International Journal of Electrical Power &Energy Systems, vol. 126, p. 106598, Mar. 2021, doi: 10.1016/j.ijepes.2020.106598.

[57] H. E. Aissaoui, A. E. Ougli, and B. Tidhaf, "Neural Networks and Fuzzy Logic Based Maximum Power Point Tracking Control for Wind Energy Conversion System," Advances in Science, Technology and Engineering Systems Journal, vol. 6, no. 2, pp. 586–592, Mar. 2021, doi: 10.25046/aj060267.

[58] A. Asgharnia, R. Shahnazi, and A. Jamali, "Performance and robustness of optimal fractional fuzzy PID controllers for pitch control of a wind turbine using chaotic optimization algorithms," ISA Transactions, vol. 79, pp. 27–44, Aug. 2018, doi: 10.1016/j.isatra.2018.04.016.

[59] H. Gouabi, A. Hazzab, M. Habbab, M. Rezkallah, and A. Chandra, "Experimental implementation of a novel scheduling algorithm for adaptive and modified P&O MPPT controller using fuzzy logic for WECS," International Journal of Adaptive Control and Signal Processing, vol. 35, no. 9, pp. 1732–1753, Jun. 2021, doi: 10.1002/acs.3288.

[60] M. J. Khan, "An AIAPO MPPT controller based real time adaptive maximum power point tracking technique for wind turbine system," ISA Transactions, vol. 123, pp. 492–504, Apr. 2022, doi: 10.1016/j.isatra.2021.06.008.

[61] R. Tiwari, K. Krishnamurthy, R. Neelakandan, S. Padmanaban, and P. Wheeler, "Neural Network Based Maximum Power Point Tracking Control with Quadratic Boost Converter for PMSG—Wind Energy Conversion System," Electronics, vol. 7, no. 2, p. 20, Feb. 2018, doi: 10.3390/electronics7020020.

[62] A. V. Hemeyine, A. Abbou, A. Bakouri, M. Mokhlis, and S. M. ould M. El Moustapha, "A Robust Interval Type-2 Fuzzy Logic Controller for Variable Speed Wind Turbines Based on a Doubly Fed Induction Generator," Inventions, vol. 6, no. 2, p. 21, Mar. 2021, doi: 10.3390/inventions6020021.

[63] K. J. Rathi and M. S. Ali, "Neural Network Controller for Power Electronics Circuits," IAES International Journal of Artificial Intelligence (IJ-AI), vol. 6, no. 2, p. 49, Jun. 2017, doi: 10.11591/ijai.v6.i2.pp49-55.

[64] W. I. Hameed, B. A. Sawadi, and A. Muayed, "Voltage Tracking Control of DC- DC Boost Converter Using Fuzzy Neural Network," International Journal of Power Electronics and Drive Systems (IJPEDS), vol. 9, no. 4, p. 1657, Dec. 2018, doi: 10.11591/ijpeds.v9.i4.pp1657-1665.

[65] J. E. Sierra-Garcia and M. Santos, "Improving Wind Turbine Pitch Control by Effective Wind Neuro-Estimators," IEEE Access, vol. 9, pp. 10413–10425, 2021, doi: 10.1109/access.2021.3051063.

[66] S. E. RHAILI, A. ABBOU, N. E. HICHAMI, and S. MARHRAOUI, "A New Strategy Based Neural Networks MPPT Controller for Five-phase PMSG Based Variable-Speed Wind Turbine," 2018 7th International Conference on Renewable Energy Research and Applications (ICRERA), Oct. 2018, doi: 10.1109/icrera.2018.8566822.

[67] A. Dahbi, N. Nait-Said, and M.-S. Nait-Said, "A novel combined MPPT-pitch angle control for wide range variable speed wind turbine based on neural network," International Journal of Hydrogen Energy, vol. 41, no. 22, pp. 9427–9442, Jun. 2016, doi: 10.1016/j.ijhydene.2016.03.105.

[68] T. K. Nizami and A. Chakravarty, "Neural Network Integrated Adaptive Backstepping Control of DC-DC Boost Converter," IFAC-PapersOnLine, vol. 53, no. 1, pp. 549–554, 2020, doi: 10.1016/j.ifacol.2020.06.092.

[69] P. Bhatia, S. Mittal, S. Raizada, and V. Verma, "Hybrid ANN based Incremental Conductance MPPT-Current Control Algorithm for Constant Power Generation of PV fed DC Microgrid," 2020 IEEE First International Conference on Smart Technologies for Power, Energy and Control (STPEC), Sep. 2020, doi: 10.1109/stpec49749.2020.9297751.

[70] S. Srinivasan, R. Tiwari, M. Krishnamoorthy, M. P. Lalitha, and K. K. Raj, "Neural network based MPPT control with reconfigured quadratic boost converter for fuel cell application," International Journal of Hydrogen Energy, vol. 46, no. 9, pp. 6709–6719, Feb. 2021, doi: 10.1016/j.ijhydene.2020.11.121.

[71] M. Fathi and J. A. Parian, "Intelligent MPPT for photovoltaic panels using a novel fuzzy logic and artificial neural networks based on evolutionary algorithms," Energy Reports, vol. 7, pp. 1338–1348, Nov. 2021, doi: 10.1016/j.egyr.2021.02.051.

[72] H. Chojaa, A. Derouich, S. E. Chehaidia, O. Zamzoum, M. Taoussi, and H. Elouatouat, "Integral sliding mode control for DFIG based WECS with MPPT based on artificial neural network under a real wind profile," Energy Reports, vol. 7, pp. 4809–4824, Nov. 2021, doi: 10.1016/j.egyr.2021.07.066.

[73] S. Afrasiabi, M. Afrasiabi, B. Parang, M. Mohammadi, M. M. Arefi, and M. Rastegar, "Wind Turbine Fault Diagnosis with Generative-Temporal Convolutional Neural Network," 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE

Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Jun. 2019, doi: 10.1109/eeeic.2019.8783233.

[74] M. Lwin and H. Lin, "Neural network based high-performance double boost DC-DC converter in using renewable energy system," Int. Journal of Science, Engineering and Technology Research, vol. 7, is. 5, pp. 337– 339, 2018.

[75] H. Gaied et al., "Comparative analysis of MPPT techniques for enhancing a wind energy conversion system," Frontiers in Energy Research, vol. 10, Aug. 2022, doi: 10.3389/fenrg.2022.975134.

[76] A. G. Abo-Khalil, A. Sobhy, and K. Sayed, "Multiple Linear Regression Approach for Sensorless MPPT of PMSG Wind Power Generation Systems," Nov. 2022, doi: 10.21203/rs.3.rs-2250710/v1.

[77] Y. Belgaid, M. Helaimi, R. Taleb, and M. Benali Youcef, "Optimal tuning of PI controller using genetic algorithm for wind turbine application," Indonesian Journal of Electrical Engineering and Computer Science, vol. 18, no. 1, p. 167, Apr. 2020, doi: 10.11591/ijeecs. v18.i1. pp167-178.

[78] S. Subramanian, C. Sankaralingam, R. M. Elavarasan, R. R. Vijayaraghavan, K. Raju, and L. Mihet-Popa, "An Evaluation on Wind Energy Potential Using Multi-Objective Optimization Based Non-Dominated Sorting Genetic Algorithm III," Sustainability, vol. 13, no. 1, p. 410, Jan. 2021, doi: 10.3390/su13010410.

[79] S. Hadji, J.-P. Gaubert, and F. Krim, "Real-Time Genetic Algorithms-Based MPPT: Study and Comparison (Theoretical an Experimental) with Conventional Methods," Energies, vol. 11, no. 2, p. 459, Feb. 2018, doi: 10.3390/en11020459.

[80] N. Priyadarshi, S. Padmanaban, M. S. Bhaskar, F. Blaabjerg, and J. B. Holm-Nielsen, "An improved hybrid PV-wind power system with MPPT for water pumping applications," International Transactions on Electrical Energy Systems, vol. 30, no. 2, Nov. 2019, doi: 10.1002/2050-7038.12210.

[81] K. Premkumar, M. Vishnupriya, T. Thamizhselvan, P. Sanjeevikumar, and B. Manikandan, "PSO optimized PI controlled DC-DC buck converter-based proton-exchange membrane fuel cell emulator for testing of MPPT algorithm and battery charger controller." International Transactions on Electrical Energy Systems, vol. 31, no. 2, 2020, doi: 10.1002/2050-7038.12754.

[82] D. Wang, D. Tan, and L. Liu, "Particle swarm optimization algorithm: an overview," Soft Computing, vol. 22, no. 2, pp. 387–408, Jan. 2017, doi: 10.1007/s00500-016-2474-6.

[83] N. Bounar, S. Labdai, and A. Boulkroune, "PSO–GSA based fuzzy sliding mode controller for DFIG-based wind turbine," ISA Transactions, vol. 85, pp. 177–188, Feb. 2019, doi: 10.1016/j.isatra.2018.10.020.

[84] Y. Mokhtari and D. Rekioua, "High performance of Maximum Power Point Tracking Using Ant Colony algorithm in wind turbine," Renewable Energy, vol. 126, pp. 1055–1063, Oct. 2018, doi: 10.1016/j.renene.2018.03.049.

[85] N. Priyadarshi, V. Ramachandaramurthy, S. Padmanaban, and F. Azam, "An Ant Colony Optimized MPPT for Standalone Hybrid PV-Wind Power System with Single Cuk Converter," Energies, vol. 12, no. 1, p. 167, Jan. 2019, doi: 10.3390/en12010167.

[86] A. H. Sule, "Optimal PI Pitch Control of Doubly-Fed Induction Generator Wind Turbine for Enhancing Dynamic Stability Using Grey Wolf Optimizer," Direct Research Journal of Engineering and Information Technology, vol. 9, no. 1, p. 1, Feb. 2022, doi: 10.26765/drjeit13263772.

[87] I. Dagal, B. Akın, and E. Akboy, "MPPT mechanism based on novel hybrid particle swarm optimization and salp swarm optimization algorithm for battery charging through simulink," Scientific Reports, vol. 12, no. 1, Feb. 2022, doi: 10.1038/s41598-022-06609-6.

[88] S. Sabzevari, A. Karimpour, M. Monfared, and M. B. Naghibi Sistani, "MPPT control of wind turbines by direct adaptive fuzzy-PI controller and using ANN-PSO wind speed estimator," Journal of Renewable and Sustainable Energy, vol. 9, no. 1, p. 013302, Jan. 2017, doi: 10.1063/1.4973447.

[89] A. Loukatou, S. Howell, P. Johnson, and P. Duck, "Stochastic wind speed modelling for estimation of expected wind power output," Applied Energy, vol. 228, pp. 1328–1340, Oct. 2018, doi: 10.1016/j.apenergy.2018.06.117.

[90] G. Notton et al., "Intermittent and stochastic character of renewable energy sources: Consequences, cost of intermittence and benefit of forecasting," Renewable and Sustainable Energy Reviews, vol. 87, pp. 96–105, May 2018, doi: 10.1016/j.rser.2018.02.007.

[91] I. L. R. GOMES, R. MELICIO, V. M. F. MENDES, and H. M. I. POUSINHO, "Wind Power with Energy Storage Arbitrage in Day-ahead Market by a Stochastic MILP Approach," Logic Journal of the IGPL, vol. 28, no. 4, pp. 570–582, Dec. 2019, doi: 10.1093/jigpal/jzz054.

[92] M. Á. Rodríguez-López, E. Cerdá, and P. del Rio, "Modeling Wind-Turbine Power Curves: Effects of Environmental Temperature on Wind Energy Generation," Energies, vol. 13, no. 18, p. 4941, Sep. 2020, doi: 10.3390/en13184941.

[93] Louassa, O. Guerri, A. Kaabeche, and N. Yassaa, "Effects of local ambient air temperatures on wind park performance: case of the Kaberten wind park," Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, pp. 1–14, Oct. 2019, doi: 10.1080/15567036.2019.1673509.

[94] S. Ghoudelbourk, D. Dib, A. Omeiri, and A. T. Azar, "MPPT control in wind energy conversion systems and the application of fractional control (PIα) in pitch wind turbine," International Journal of Modelling, Identification and Control, vol. 26, no. 2, p. 140, 2016, doi: 10.1504/ijmic.2016.078329.

[95] Y. Song, J. Chen, M. Beer, and L. Comerford, "Wind Speed Field Simulation via Stochastic Harmonic Function Representation Based on Wavenumber–Frequency Spectrum," Journal of Engineering Mechanics, vol. 145, no. 11, Nov. 2019, doi: 10.1061/(asce)em.1943-7889.0001666.

[96] A. T. Azar and F. E. Serrano, "Design and Modeling of Anti Wind Up PID Controllers," Studies in Fuzziness and Soft Computing, pp. 1–44, Nov. 2014, doi: 10.1007/978-3-319-12883-2_1.

[97] S. Das, I. Pan, S. Das, and A. Gupta, "A novel fractional order fuzzy PID controller and its optimal time domain tuning based on integral performance indices," Engineering Applications of Artificial Intelligence, vol. 25, no. 2, pp. 430–442, Mar. 2012, doi: 10.1016/j.engappai.2011.10.004.

[98] O. Carranza, E. Figueres, G. Garcerá, and R. Gonzalez-Medina, "Analysis of the control structure of wind energy generation systems based on a permanent mag-net synchronous generator," Applied Energy, vol. 103, pp. 522–538, Mar. 2013, doi: 10.1016/j.apenergy.2012.10.015.

[99] M. Carpintero-Renteria, D. Santos-Martin, A. Lent, and C. Ramos, "Wind turbine power coefficient models based on neural networks and polynomial fitting," IET Renewable Power Generation, vol. 14, no. 11, pp. 1841–1849, Jul. 2020, doi: 10.1049/iet-rpg.2019.1162.

[100] B. Majout et al., "A Review on Popular Control Applications in Wind Energy Conversion System Based on Permanent Magnet Generator PMSG," Energies, vol. 15, no. 17, p. 6238, Aug. 2022, doi: 10.3390/en15176238.

[101] A. Herizi and R. Rouabhi, "Hybrid Control Using Sliding Mode Control with Interval Type-2 Fuzzy Controller of a Doubly Fed Induction Generator for Wind Energy Conversion," International Journal of Intelligent Engineering and Systems, vol. 15, no. 1, pp. 550-564, Feb. 2022, doi: 10.22266/ijies2022.0228.50.

[102] M. Zafran, L. Khan, Q. Khan, S. Ullah, I. Sami, and J.-S. Ro, "Finite-Time Fast Dynamic Terminal Sliding Mode Maximum Power Point Tracking Control Paradigm for Permanent Magnet Synchronous Generator-Based Wind Energy Conversion System," Applied Sciences, vol. 10, no. 18, p. 6361, Sep. 2020, doi: 10.3390/app10186361.

[103] E. H. Dursun and A. A. Kulaksiz, "Second-order sliding mode voltage-regulator for improving MPPT efficiency of PMSG-based WECS," International Journal of Electrical Power & Energy Systems, vol. 121, p. 106149, Oct. 2020, doi: 10.1016/j.ijepes.2020.106149.

[104] O. Apata and D. T. O. Oyedokun, "An overview of control techniques for wind turbine systems," Scientific African, vol. 10, p. e00566, Nov. 2020, doi: 10.1016/j.sciaf.2020.e00566.

[105] M. J. Khan and L. Mathew, "Comparative Study of Optimization Techniques for Renewable Energy System," Archives of Computational Methods in Engineering, vol. 27, no. 2, pp. 351–360, Dec. 2018, doi: 10.1007/s11831-018-09306-8.

[106] R. B. Bollipo, S. Mikkili, and P. K. Bonthagorla, "Critical Review on PV MPPT Techniques: Classical, Intelligent and Optimisation," IET

Renewable Power Generation, vol. 14, no. 9, pp. 1433–1452, Jun. 2020, doi: 10.1049/iet-rpg.2019.1163.

[107] A. Rezvani, A. Esmaeily, H. Etaati, and M. Mohammadinodoushan, "Intelligent hybrid power generation system using new hybrid fuzzy-neural for photovoltaic system and RBFNSM for wind turbine in the grid connected mode," Frontiers in Energy, vol. 13, no. 1, pp. 131–148, Mar. 2017, doi: 10.1007/s11708-017-0446-x.

[108] S. Motahhir, A. El Hammoumi, and A. El Ghzizal, "The most used MPPT algorithms: Review and the suitable low-cost embedded board for each algorithm," Journal of Cleaner Production, vol. 246, p. 118983, Feb. 2020, doi: 10.1016/j.jclepro.2019.118983.