MPPT using PSO Technique Comparing to Fuzzy Logic and P&O Algorithms for Wind Energy Conversion System

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Abstract: - This paper proposes a new maximum power point tracking (MPPT) technique for wind turbine Connection to a permanent magnet synchronous generator (PMSG), based on the Particle Swarm Optimization (PSO) algorithm. The PSO technique aims to control the boost converter by calculating the duty cycle value based on the voltage and current values. The Wind Energy Conversion System (WECS) includes a wind turbine, a PMSG, rectifier and a DC/DC boost converter that is connected to a load. To verify the performance of the suggested algorithm PSO, The results of the simulation are compared with those of fuzzy logic and (Perturb and Observe)P&O techniques, under step wind variations, using MATLAB/SIMULINK. The results of the simulation show that the proposed PSO technique ensures a good tracking of the maximum power point as the results obtained are more stable and the oscillations are eliminated.

Key-Words: Wind Turbine, PMSG, WECS, PSO, Fuzzy Logic, P&O.

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1 Introduction

The consumption of energy worldwide is principally covered by the fossil fuels (oil, coal, natural gas and nuclear) which are having a negative impact on the environment. [1]-[4]. Climate change, as one of the major problems facing humanity in this century, is caused by greenhouse gas emissions, in particular by the combustion of fossil fuels [1,2]. Considering the evolution of the actual standard of living of human beings, the increase in energy demand has allowed a significant development of renewable energies [5]. These clean and durable energies have become very important because they are considered an alternative to fossil fuels, which are decreasing, that meet the objectives of the Kyoto protocol. [4]

Renewable energies are clean and natural sources of energy, coming from the sun (photovoltaic), wind (wind turbine), geothermal, waterfalls, tides or biomass, capable of satisfying most of our needs. Their use generates almost no waste and polluting emissions. Wind energy systems are the fastest growing technology. Indeed, Wind energy is among the largest sources of renewable energy in the world.

For efficient functioning of WECS, various maximum power point tracking (MPPT) strategies are developed in the literature [6]. These algorithms can be categorized into two types, The first category includes techniques such as optimal torque (OT) [7], top speed ratio (TSR) [8]... this type of algorithms control the electrical power output of WTs through maximization the mechanical power generated by the wind. While the second category maximizes directly the electrical power produced at the output.

TSR is characterized by its simplicity and speed of response, however, its performance dependent on the measurement techniques or the precision of the wind speed estimation. L'OT is an effective and simple technique which does not require any previous knowledge of wind speed. However, it is based on optimal torque curves or look-up tables based on experiments.

The second category of MPPT algorithms consists of strategies such as incremental conductance (IC), hill-climbing search (HCS) [9], [10], perturbation and observation (P&O) [11]. In the literature there are also smart MPPT algorithms based on artificial intelligence techniques particularly fuzzy logic controllers (FLC) and artificial neural networks (ANN).[12]

Many published papers have been compared between several MPPT techniques for WECS, for example in [13], three MPPT controllers P&O, PI and FLC are modeled for wind power and the output is compared under a varying wind speed conditions, The efficiency of each controller is evaluated and the authors have concluded that the FLC controller is more efficient and more reliable than the P&O and PI controllers.

In this paper we propose new MPPT technique based on the PSO technique, the results of this algorithm will be compared to the FL and P&O techniques. For this purpose we have proposed a system that contains a wind turbine connected to a synchronous machine, a rectifier, and a boost converter, as shown in Figure1. The results of three controllers are verified in MATLAB/Simulink for different wind speed values.

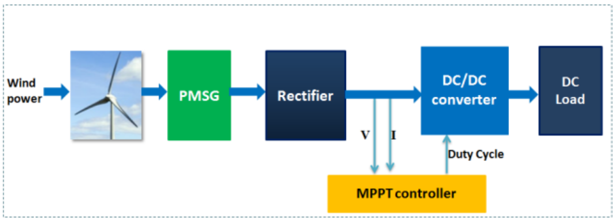


Fig. 1: Diagram of MPPT in WT system

The paper is organized as follows:

Section 2 presents the modeling of the wind power system. Section 3 is about the converter modeling. Section 4 explains the proposed approaches. Section 5 deals with the results obtained and the efficiency of the proposed algorithms, section 6 presents the conclusion.

2 Modelling of a Wind Turbine

A wind turbine is therefore a system that is able to transform the kinetic energy of the wind into mechanical or electrical energy. This kinetic energy is received by the blades of the turbine before being transformed into mechanical energy, which in turn is transformed by a synchronous or asynchronous generator into electrical energy. The classification of wind turbines is based on the orientation of the axis of rotation in relation to the wind direction (horizontal or vertical). For the model proposed in this paper we have chosen to work with a turbine connected to a synchronous generator.

The aerodynamic power P (a) extracted by the turbine rotor is expressed, in general, in terms of the power coefficient Cp and is given by the following expression: [14]

$$P_a = \frac{1}{2}\rho\pi R^2 C_p(\lambda,\beta)v^3 \qquad (1)$$

Where R means the turbine ratio, v is the wind speed (m/s).

The parameter Cp is dimensionless. This characteristic parameter of the wind turbine is a non-linear function depending, on the wedge angle β and the specific speed λ. the latter is represented as the ratio between the tangential speed of the blade tip and the wind speed.

$$\lambda = \frac{\omega_r R}{v} \qquad (2)$$

The power coefficient is given below:

$$Cp(\lambda,\beta) = 0.22\left(\frac{116}{\lambda i} - 0.4\beta - 5\right)e^{\frac{-21}{\lambda i}} \qquad (3)$$

$$\frac{1}{\lambda i} = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \qquad (4)$$

The kinetic energy of the wind that is extracted by the aero-turbine is converted into mechanical power which is translated into a driving torque Ta making the rotor rotating at a speed ω. the expression of the aerodynamic torque can be written in the following form:

$$T = \frac{Pm}{\omega} = \frac{1}{2\lambda}\rho\pi R^3 Vw^2 Cp(\lambda,\beta) \qquad (5)$$

The following figure describes the relationship between the variation of the power coefficient and the tip ration speed λ for different values of β:

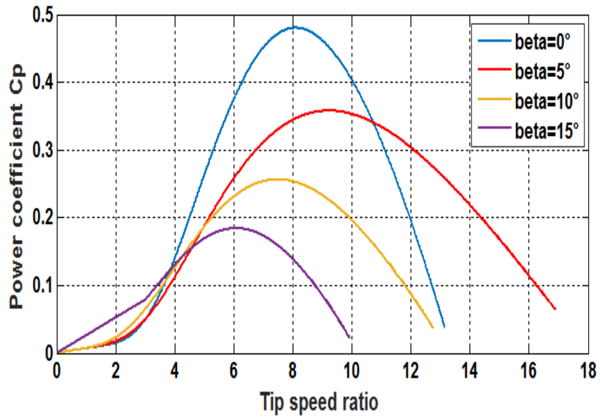


Fig. 2: Characteristics of power coefficient.

The figure 3 shows the variation of the mechanical power of the wind turbine, as a function of the variation of the rotation speed for different wind speed values, and that for the turbine used in this paper:

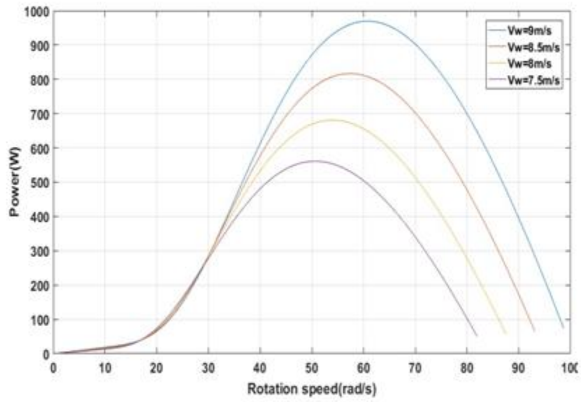


Fig. 3. The power curves under different wind speeds (β=0).

The parameters of the turbine generator used in this paper are listed in the table 1:

Table 1. WT generator system characteristics

Characteristics	Values
Rated Voltage	90 V
Rated Power	1000W
Synchronous inductance	1mH
Rated Current	4.8A
Number of poles	8
Synchronous resistance	1.13Ω
Friction coefficient	0.006N.m.s/rad
Magnetic flux	0.16Wb
Moment of inertia	0.005N.m
Blade length	1.2m
Air density	1.2 kg/ m3

3 Converter Modelling

Emerging electronic devices must meet certain criteria such as high quality, reliability, size, weight and low cost. Linear power regulators, whose functioning principle is based on a current or voltage divider, can give a very high quality output voltage. However, this type of regulator remains ineffective because their principal area of use involves low power levels.

Switching regulators or DC/DC converters use electronic switches, based on semiconductors such as: thyristor, power transistor or IGBT...etc, because they generate a low power loss when switching from one state to another. These converters assure high energy conversion efficiencies and they can be used at high frequencies. The dynamic characteristics of DC/DC converters increase with higher operating frequencies. [15]

DC/DC converters are the main part of a MPPT system. They are used to convert an unregulated DC input to a regulated DC output voltage, in our case presented in this paper, the DC/DC converter is used as an interface between the wind model and the load to ensure that the WT model operates at its maximum power point, and this is achieved through the control of the duty cycle D using the MPPT algorithms. There are many topologies of DC-DC converter used today, such as Buck, Boost, Buck / Boost, CUK and Sepic. In this paper we chose a boost converter. [16]

Figure 4 shows a boost converter that converts the input DC voltage to a higher output voltage.

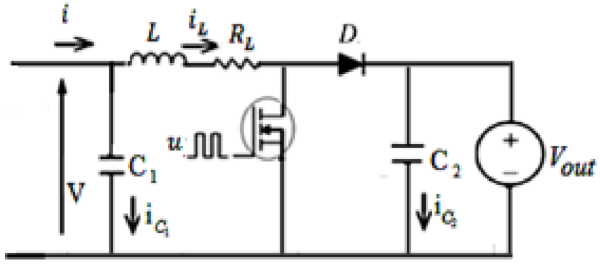


Fig. 4: Configuration of Boost converter.

The boost structure includes a switch which is controlled for firing and blocking (bipolar, MOS or IGBT), a diode and at least one energy storage element (capacitor and/or inductor).

The filters are composed of capacitors that are added to the output of the converter to minimize the output voltage ripple; the inductor is placed in series with the input source to minimize the current ripple. The series resistance mimics the aggregate ohmic losses introduced by the parasitic resistances of the inductor. The continuous conduction mode of a boost converter has two states for each commutation cycle. The circuit operates by changing the states of the diode and the switch between ON and OFF.

When the switch is on, the diode is automatically turned off, as its voltage becomes negative. Also, when the switch is off, the diode is turned on. Such behavior is controlled using the duty cycle signal that controls the IGBT, can take normalized values between 0 and 1.

Case1: The transistor is in the ON state and the diode is in the OFF state.

During this phase, the inductance L stocks energy, which gives us the following equations:

$$\frac{diL}{dt} = \frac{V}{L} - \frac{iL}{L}R_L \quad (6)$$

$$\frac{dV}{dt} = \frac{i}{C1} - \frac{iL}{C1} \quad (7)$$

Case 2: the transistor is in the OFF state and the diode is in the ON state.

The switch opens so the only path for the inductor current to pass is through the D diode and the parallel combination of capacitor and load. This allows the capacitor to transfer the energy acquired during the operating period. The state functions then become:

$$\frac{diL}{dt} = \frac{V}{L} - \frac{iL}{L}RL - Vout \quad (8)$$

$$\frac{dV}{dt} = \frac{i}{C1} - \frac{iL}{C1} \quad (9)$$

The combination of the two steps gives us the following equations:

The ratio that relates the input and output voltage is defined by :

$$\frac{Vout}{V} = \frac{1}{1-D} \quad (10)$$

D is the duty cycle.

The inductance of the boost converter, L, is calculated as follows:

$$L = \frac{VD}{\Delta iLf} \quad (11)$$

Where Δi_L is the current ripple in the inductor and is the switching frequency.

The value of the output capacitor is given as follows:

$$C2 = \frac{IoutD}{f.\Delta Vout} \quad (12)$$

I_{out} and ΔV_{out} successively the output current and the output voltage ripple.[16]

4 MPPT Controllers

4.1 Proposed PSO MPPT Technique

The PSO technique was inspired by Russel Eberhart and James Kennedy from the behavior of birds, during a computer simulation of grouped flights of birds and schools of fish.[17]

The swarm of particles is a population of simple agents, called particles. The swarm of particles is a population of simple agents, called particles. The principle of the PSO algorithm is to move the particle to find its best position. In the first step, the particles are positioned in a search space in a random way. Each of these particles is characterized by a speed that allows it to move, and during the iterations, the particle changes position according to its previous position, its neighbor and its best position, at the end of these iterations the particle can fall on its best position.

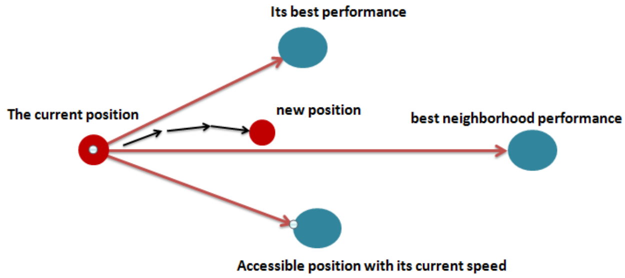


Fig. 5: Principle of the movement of a particle

At the beginning of the algorithm, the particles of the swarm are initialized in a random/regular way in the search space. Then, for each iteration the particles move.

The position of the particle is corrected according to its updated speed (velocity), the best personal position obtained (PBest) and the best position obtained in the neighborhood (GBest). The PSO is based on the rules of updating the local and global positions of particles and the group, given by the equations: [18]

$$v_i(t+1) = \omega.v_i(t) + c_1 \times r_1 \times \left(PBest_i(t) - D_{Fitness_i}(t)\right) + c_2 \times r_2 \times \left(GBest_i(t) - P_i(t)\right) \quad (13)$$

$$P_i(t+1) = P_i(t) + v_i(t+1) \quad (14)$$

c1 and c2 are acceleration constants.
P : Position of the particle.
V: Velocity.
PBest: Best position of the particle which corresponds to Local_Dbest.
GBest : Best position of the group of particles which corresponds to Global_Dbest.
r1 and r2: Random variable uniformly distributed on an interval of [0, 1] (function defined in Matlab).
D: Duty cycle.

In our case, the objective of the PSO technique is to calculate the Duty cycle value D, based on the power value P calculated from the inputs V, I.

In order to find the optimal value of D, we implemented the PSO algorithm in this paper as follow:

- Measure V,I.
- Calculate P.
- Initialize the size of the swarm, the maximum number of iterations, and the PSO constants c1, c2 and w; determine the random numbers r1 and r2.
- Attribute the value Zero to the previous and new Powerbest vectors:

$$Powerbest = zeros(swarms, 1) \quad (15)$$

- Initialize the Duty Cycle value.
- Initialize velocity:

$$velocity = zeros(swarms, 1) \quad (16)$$

- Update of the velocity value using the PSO parameters described in table 2, and calculate its final value:

$$velocity = updatevelocity(velocity, pbest, particals, gbest) \quad (17)$$

$$vfinal = updatevelocity(velocity, pobest, d, gwbest \quad (18)$$

$$vfinal = (w * velocity) + (c1 * r1 * (pobest - d)) + (c2 * r1 * (gwbest - d)) \quad (19)$$

- calculate the final value of the duty cycle:

$$dfinal = updateduty(d, velocity) \quad (20)$$

The following table includes the PSO parameters we have chosen during the simulation:

Table 2. PSO parameters

	symbol	value
Weight of local information	C_1	0.1
Global information weight	C_2	0.1
Weight of inertia	W	0.5

4.2 P&O Controller

Among the classical techniques used for MPPT research for a wind turbine system, we find in the literature the P&O technique which is a famous algorithm widely used in research papers because of its simplicity, and its ease of implementation. We have chosen this algorithm to validate the PSO technique proposed in this paper.

The following diagram explains the functioning principle of this algorithm to find the MPPT for a wind system connected to a PMSG. The objective of the P&O technique is to calculate the Duty cycle value D, based on the value of DeltaP, DeltaV calculated from the inputs V, I.

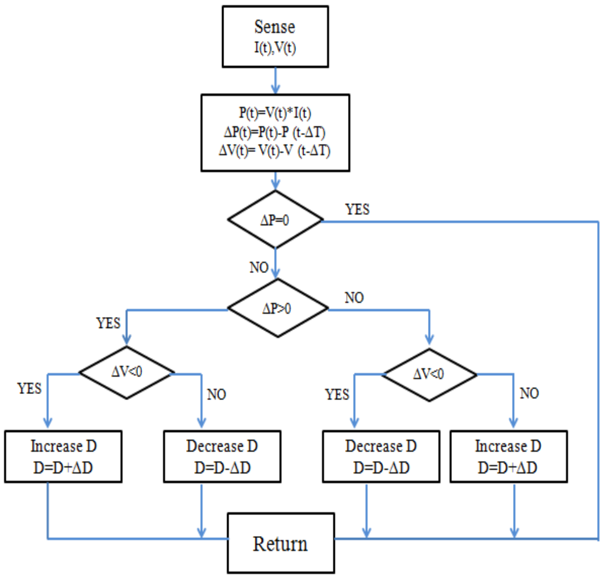


Fig. 6: Perturb and Observe Approach (P&O)

The P&O algorithm, in spite of its known advantages, also presents a problem of oscillations around the MPP which is produced in permanent regime and this is caused by the MPP search process that must be repeated regularly, which obliges the system to oscillate continuously around the MPP. [19]

The principle of the P&O technique is to perturb the voltage by a small amplitude around its initial value and to analyze the behavior of the resulting power variation. If a positive increment of the voltage generates an increase of the power, it means that the operating point is to the left of the PPM. If, on the other hand, the power decreases, this means that the system has surpassed the PPM. The same reasoning can be applied when the voltage decreases. Based on these different analyses it is then easy to situate the operating point in regard to the PPM, and to make it converge towards the maximum power through an appropriate control order.

In another way we can say that the principle is as follows: at the beginning the voltage V is perturbed, then we measure the power supplied by the WT at the output of the rectifier at the moment k, and then we compare it to the preceding one at the moment (k-1). If the difference is positive, the power is increasing, it means that we are approaching the MPP and that the change of the duty cycle is kept in one direction. On the other hand, if the difference is negative, the power is decreasing, we are moving away from the MPP. We must therefore reverse the direction of the variation of the duty cycle.

4.3 Fuzzy Logic Controller

FL is a new approach based on artificial intelligence. FL represents an improvement of the classical IC algorithm in terms of robustness, stability and ease of implementation. Like other MPPT controllers, the main task of the FL controller is to achieve the MPP. However, the performance of this controller depends mainly on human expertise.

The FL approach is derived from decomposing a range of variation of a real variable into linguistic variables and assigning the membership function for each variable. The rules developed from the human operator's expertise are expressed in linguistic form. These rules determine the dynamic performance of the FL controller. The proposed FL controller consists of four basic components: fuzzification unit, basic rules inference engine and Defuzzification.[15]

Fuzzification: Convert numeric input variables into linguistic variables based on a membership function. Before fuzzifying the data, it must first be normalized to match the range of the universe of discourse that is appropriate for the controller input.

Rule base: Before starting this phase ,the user must define the fuzzy set database which consists of defining the fuzzy sets of input and output variables, the partition of the input and output fuzzy space, and the choice of membership functions that describe the fuzzy sets of input and output variables

The fuzzy rules describe the relationship between the output and the input of the fuzzy control. These fuzzy rules encode an expert's knowledge of the process control in linguistic terms in the general form of "if premise then conclusion", where the premises relate to the inputs of the fuzzy controller and the conclusions relate to the outputs. The number of fuzzy rules depends, in particular, on the partition of the universes of discourse of the input and output variables.

Inference: A fuzzy inference is a relation defined between fuzzy subsets. This fuzzy relation can intervene any fuzzy operator.

Defuzzification is the process of converting a linguistic value into a numerical value. [19]

The Fuzzy Logic Controller process for our case is illustrated in Figure 7.The objective of the Fuzzy Logic technique is to calculate the Duty cycle value D, based on the Delta P, Delta V.

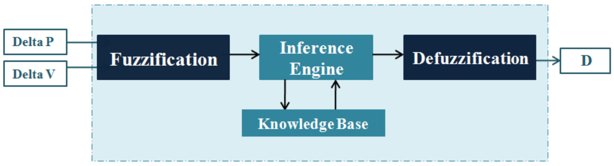


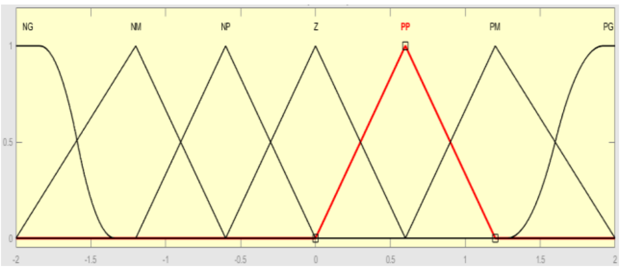
Fig . 7: Structure of a fuzzy controller.

The inputs DeltaP and DeltaV are represented by the equations given below:

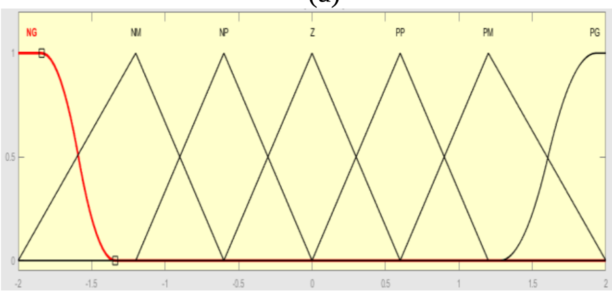
$$\text{DeltaP}(k) = P(k) - P(k-1) \quad (16)$$

$$\text{DeltaV}(k) = V(k) - V(k-1) \quad (17)$$

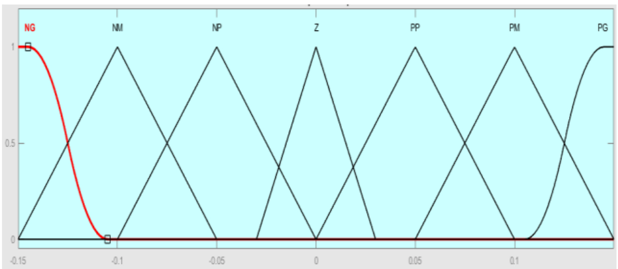
The membership functions of DeltaP, DeltaV and D are respectively shown in Figure 8 (a), Figure 8 (b) and Figure 8 (c).



(a)



(b)



(c)

Fig . 8: Membership functions related to (a) DeltaP, (b) DeltaV, (c) D.

Table 3 gives the inference rules for different combinations of the input variables DeltaP, DeltaV with the output duty cycle D.

Table 3. Inference Rules related to Fuzzy Logic WT.

DeltaV / Delta P	NG	NM	NP	Z	PP	PM	PG
NG	NG	NG	NG	NM	NM	NP	Z
NM	NG	NG	NM	NM	NP	Z	PP
NP	NG	NM	NM	NP	Z	PP	PM
Z	NM	Z	NP	Z	PP	PM	PM
PP	NM	NP	Z	PP	PM	PM	PG
PM	NP	Z	PP	PM	PM	PG	PG
PG	Z	PP	PM	PM	PG	PG	PG

5 Simulation and Discussion

In this section, we will compare through simulations, the convergence to MPP using one of the three techniques "P&O", "Fuzzy Logic" and "PSO", for a wind energy conversion system. This is achieved by simulation under Matlab/Simulink, as shown in the following figure:

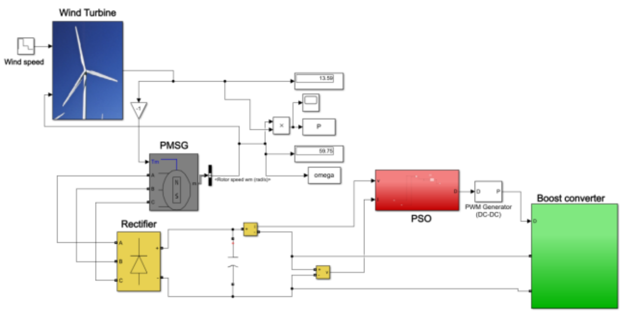


Fig . 9: The proposed model in Matlab/Simulink.

The system contains the following components: wind turbine, permanent magnet synchronous generator (PMSG), rectifier, boost converter, controllers block (P&O/Fuzzy Logic/PSO). The wind speed varied in three steps, from 8.5 m/s to 8.1 m/s, then to 7.9 m/s. As shown in the figure 10.

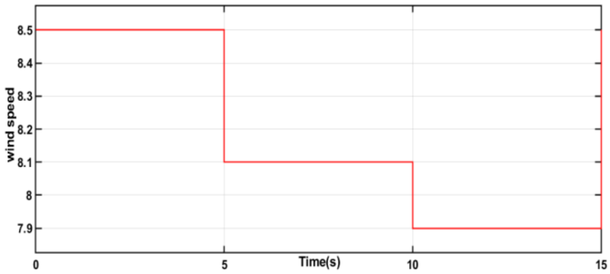


Fig. 10: Wind speed variation.

Figures 11, 12, 13 show respectively the Cp curve for wind speed values varying between 8.5m/s, 8.1m/s, and 7.9m/s, using respectively the FL, P&O, PSO techniques.

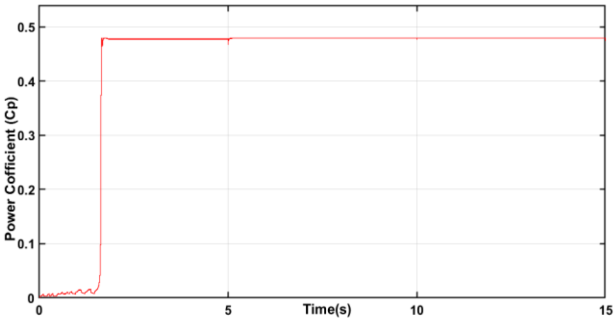


Fig. 11: Power Coefficient curve using PSO Controller.

We notice from the evolution of Cp that the PSO technique allows us to continue the MPP because the Cp reaches the maximum value 0.48 which means that the power produced by the system is maximal, and this is with a high stability and with an absence of any oscillations.

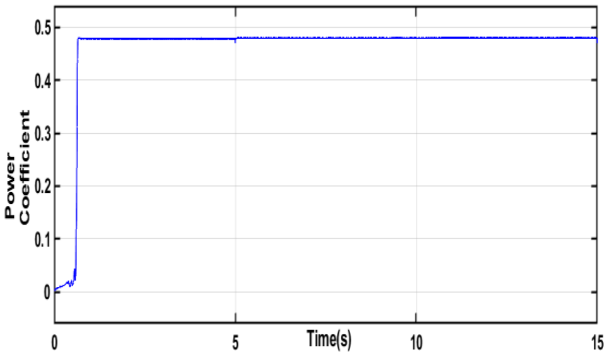


Fig. 12: Power Coefficient curve using Fuzzy Logic Controller

We see from the evolution of Cp that the FLC technique allows us to continue the MPP because the Cp reaches the maximum value 0.48 but with some oscillations.

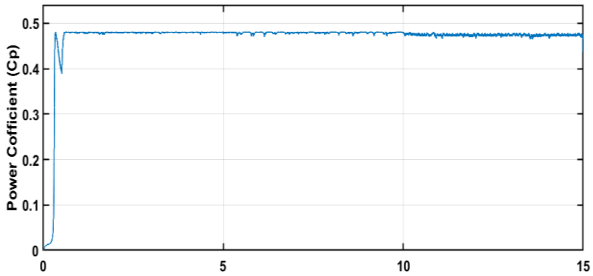


Fig. 13: Power Coefficient curve using P&O Controller.

We can see from the evolution of Cp that the P&O technique does not allow us to continue the MPP for all the tested wind speed values because the Cp does not always reach the maximum value of 0.48, and we notice that this technique presents a considerable rate of oscillations.

Figures 14, 15, 16 show respectively the mechanical power curve for wind speed values varying between 8.5m/s, 8.1m/s, and 7.9m/s, using respectively the PSO, FL, P&O techniques.

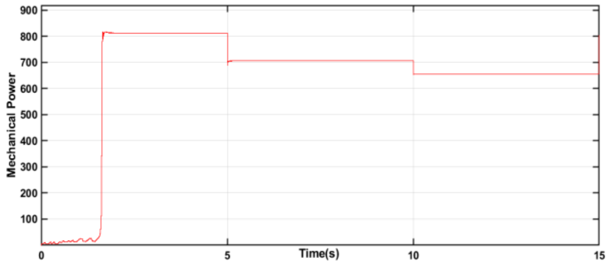


Fig. 14: Variation of the mechanical power using PSO controller.

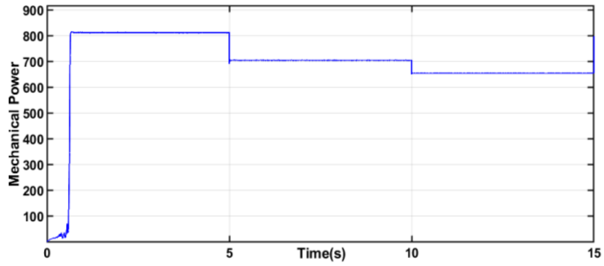


Fig. 15: Mechanical Power using Fuzzy Logic Controller

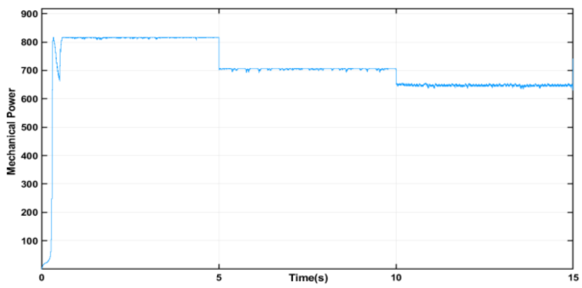


Fig. 16: Mechanical Power using P&O controller.

Comparing the curves of evolution of the power produced by WT using respectively PSO, FL, P&O, controllers, with the characteristic of the turbine (figure 3), we deduce that the PSO technique allows reaching the maximum power for each value of wind speed with a high stability more than the FL and P&O techniques.

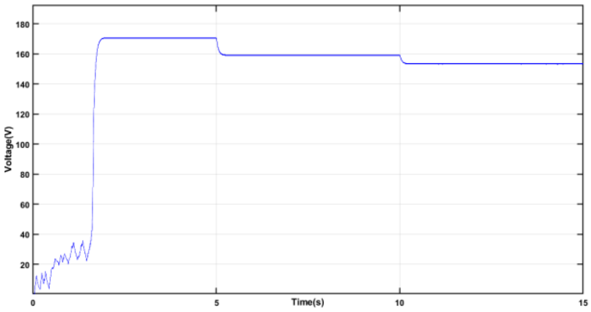


Fig. 17: The variation of the voltage at the output of the boost converter, using PSO controller.

6 Conclusions

The objective of this paper is to design a new MPPT control based on the PSO technique for a WECS system. This paper proposes to analyze the selected MPPT methods (PSO, FL and P&O) and to evaluate their behaviors in terms of stability, efficiency in order to compare them. The simulation is performed for variable wind speed values.

The PSO technique is used to control the boost converter by determining the duty cycle value as a function of the voltage and current values.

The simulation results revealed that PSO ensures a good tracking of the maximum power point and it provides more efficient and stable results compared to the other proposed methods P&O and FL, the PSO technique eliminates all oscillations presented by P&O and FL.

The proposed and studied controllers are implemented in Matlab/Simulink to obtain the output response of the developed system.

References:

[1] T.J. Hammons, Transmission System Developments, Interconnections, Electricity Exchanges, Deregulation, And Implementing Technology In Power Generation With Respect To The Kyoto Protocol, *In 39th International Universities Power Engineering Conference*, Vol.3, 2004, pp. 1251-1257.

[2] H .Wang, F .Xu, Flexible Global Carbon Pricing Study: A New Method To Establish The International Cooperation On Reducing Carbon Emission, *10th International Power & Energy Conference (IPEC)*, 2012, pp. 300-304.

[3] P.F. Frack, P.F. Mercado, E. Pedro, G. Sarriegui, De. Doncker, Renewable Energy Supply Of Refugee Camps To Decrease Fuel Consumption And CO 2 Emissions, *IEEE 6th International Symposium on Power Electronics for Distributed Generation Systems*, 2015, pp. 1-6.

[4] S. Walker, K. W. Hipel, T. Inohara, Strategic Analysis Of The Kyoto Protocol, *IEEE International Conference on Systems, Man and Cybernetics*, 2007, pp. 1806-1811.

[5] I. El Karaoui, M. Maaroufi, B. Bossoufi, Fuzzy Sliding Mode Power Control For Wind Power Generation Systems Connected To The Grid, *International Journal of Science and Technology, International Journal of Power Electronics and Drive Systems*, Vol. 13, 2022, pp. 606–619.

[6] D. Kumar, K. Chatterjee, A Review of Conventional and Advanced MPPT Algorithms for Wind Energy Systems, *Renewable and sustainable energy reviews*, vol. 55, 2016, p. 957-970.

[7] S. Ganjefar, A . A. Ghassemi, M. M. Ahmadi, Improving Efficiency Of Two-Type Maximum Power Point Tracking Methods Of Tip- Speed Ratio And Optimum Torque In Wind Turbine System Using A Quantum Neural, *Energy 67,* vol. 67, 2014, pp. 444-453.

[8] J. Castelló, J . M. Espí, R. García-Gil, Development Details And Performance Assessment Of A Wind Turbine Emulator, vol. 86, 2016, pp. 848-857.

[9] B. Lahfaoui, S. Zouggar, M. L. Elhafyani, Experimental Study Of P&O MPPT Control For Wind PMSG Turbine, 2015. pp. 1-6.

[10] B. Lahfaou, S. Zouggar, M. Bourhaleb, Real Time Study Of P&O MPPT Control For Small Wind PMSG Turbine Systems Using Arduino Microcontroller, Vol. 13, 2022, pp. 606–619.

[11] Y. U. Kuo Nan, C. K. Liao, Applying Novel Fractional Order Incremental Conductance Algorithm To Design And Study The Maximum Power Tracking Of Small Wind Power Systems, *Journal of applied research and technology*, vol. 13, 2015, pp. 238–244.

[12] J. Pande, P. Nasikkar, K. Kotecha, A Review Of Maximum Power Point Tracking Algorithms For Wind Energy Conversion Systems, *Journal of Marine Science and Engineering*, vol.9, 2021.

[13] R. Tiwari, B. N. Babu, Fuzzy logic based MPPT for permanent magnet synchronous generator in wind energy conversion system, *IFAC-PapersOnLine*, vol. 49, 2016, no 1, pp. 462-467.

[14] J. R. Gowri, M.C. Nagel, F. Popuri, Neutral Networks Based Maximum Power Point Tracking (Mppt) Of Wind Power Generation, *The International Journal of Scientific Development and Research (IJSDR)*, Vol.5, No.2, 2020.

[15] N. Aouchiche, Design Of An Artificial Intelligence Based Optimal MPPT Control Of A Photovoltaic System, 2020.

[16] I. Duka, C. Noble, High Frequency DC/DC Boost Converter, 2011.

[17] L. Mitra, U.K. Rout, Optimal Control Of A High Gain DC-DC Converter, *International Journal of Power Electronics and Drive Systems*, vol.13, 2022, pp. 256–266.

[18] M.A. Hannan, K. Parvin, Y.K. Kit, Particle Swarm Optimization Based Fuzzy Logic Mppt Inverter Controller For Grid Connected Wind Turbine, *International Journal of Renewable Energy Research*, vol. 9, no. 1, 2019.

[19] S. Miqoi, Integration Of Fuzzy Logic And Robust Control Techniques For Maximum Power Point Tracking In A Photovoltaic Pumping System, 2019.