

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) consists of a wind turbine, a PMSG, rectifier and a DC/DC boost converter which is connected to a load. To demonstrate the performance of the proposed algorithm PSO, its simulation results are compared with the simulation results of fuzzy logic (FL) and perturbation and observation (P&O) techniques under step wind variations, using MATLAB/Simulink. The simulation results 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.

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1. INTRODUCTION

The world's energy consumption is mainly covered by fossil fuels (oil, coal, natural gas, and nuclear) which have a negative effect on the environment [1]-[4]. Climate change, which is one of the serious problems facing humanity in this century, is due to greenhouse gas emissions, especially from the burning of fossil fuels [1], [2]. Given the evolution of the current standard of living of human beings, the increasing demand for energy has allowed a remarkable development of renewable energies [5]. These clean and sustainable energies have become of great importance because they are considered as an alternative to fossil energies which are decreasing, that meet the objectives of the Kyoto protocol [4], [6].

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 one of the most important renewable energy sources worldwide.

The production of electricity from renewable sources has experienced a strong revival of interest since the 1990. This increase in the production of electricity from wind turbines requires the improvement and development of techniques and tools for efficient production of this energy. For this purpose, a lot of research work has been done to take advantage of the maximum energy of the wind turbine, using maximum power point tracking (MPPT) techniques.

For a efficient operation of wind energy conversion system (WECS), several MPPT algorithms are developed in the literature [7]. These algorithms can be divided into two categories, The first category includes techniques such as optimal torque (OT) [8], peak speed ratio (TSR) [9] this type of algorithms control the electrical power output of wind turbines (WTs) by maximizing the mechanical power produced 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, but its performance depends 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 OT curves or look-up tables based on experiments. The second category of MPPT algorithms consists of strategies such as hill-climbing search (HCS) [10], [11], perturbation and observation (P&O) and incremental conductance (IC) [12]. In the literature there are also smart MPPT algorithms based on artificial intelligence (AI) techniques including artificial neural networks (ANN) and fuzzy logic controllers (FLC) [13].

Many published papers have been compared between several MPPT techniques for WECS, for example in [14], three MPPT controllers PI, P&O, and FLC are modeled for wind power and the output is compared under 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 PI and P&O controllers. In this paper we propose a new MPPT technique based on the particle swarm optimization (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 Figure 1. The results of three controllers are verified in MATLAB/Simulink for different wind speed values.

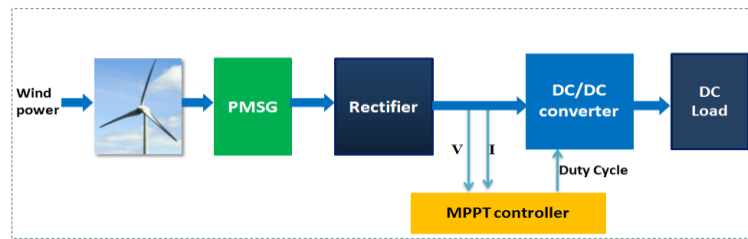


Figure 1. Diagram of MPPT in WT system

The paper is organized: 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 captured 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 C_p [15].

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

The parameter C_p 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.

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

The power coefficient is (3) and (4):

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

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

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 T making the rotor rotating at a speed ω . The expression of the aerodynamic torque can be written in (5).

$$T = \frac{P_m}{\omega} = \frac{1}{2\lambda} \rho \pi R^3 V w^2 C_p(\lambda, \beta) \quad (5)$$

The Figure 2 describes the relationship between the variation of the power coefficient and the tip ratio speed λ for different values of β . 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. The parameters of the turbine generator used in this paper are listed in the Table 1.

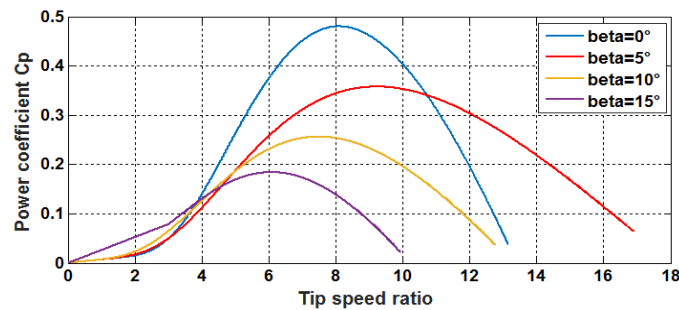


Figure 2. Characteristics of power coefficient

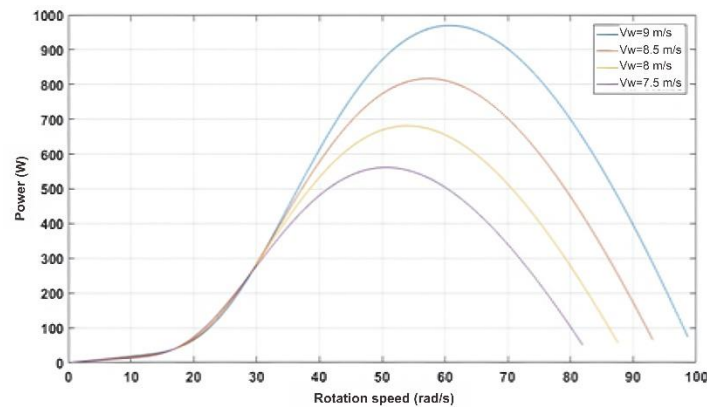


Figure 3. The power curves under different wind speeds ($\beta = 0$)

Table 1. WT generator system characteristics

Characteristics	Values
Rated voltage	90 V
Rated power	1,000 W
Synchronous inductance	1 mH
Rated current	4.8 A
Number of poles	8
Synchronous resistance	1.13 Ω
Friction coefficient	0.006 N.m.s/rad
Magnetic flux	0.16 Wb
Moment of inertia	0.005 N.m
Blade length	1.2 m
Air density	1.2 kg/m ³

3. CONVERTER MODELLING

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

Switching regulators or DC/DC converters use electronic switches, based on semiconductors such as: thyristor, power transistor or insulated gate bipolar transistor (IGBT), because they generate a low power loss when switching from one state to another. These converters assure high energy conversion efficiencies and they can operate at high frequencies. The dynamic characteristics of DC/DC converters improve with increasing operating frequencies [16].

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

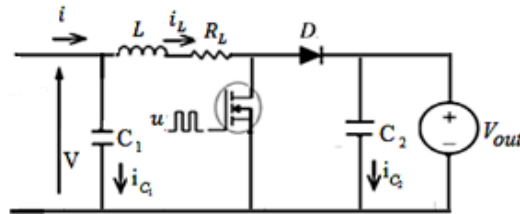


Figure 4. Configuration of boost converter

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). Filters is composed of capacitors are added to the output of the converter to reduce the output voltage ripple; the inductor is connected in series with the input source to reduce 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 assumes two states for each switching cycle. The circuit operates by changing the states of the diode and the switch between ON and OFF.

When the switch is turned on, the diode is automatically turned off, as its voltage becomes negative. Also, when the switch is turned 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.

- Case 1: 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 (6) and (7).

$$\frac{di_L}{dt} = \frac{V}{L} - \frac{i_L}{L} R_L \quad (6)$$

$$\frac{dV}{dt} = \frac{i}{C_1} - \frac{i_L}{C_1} \quad (7)$$

- 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 (8) and (9).

$$\frac{di_L}{dt} = \frac{V}{L} - \frac{i_L}{L} R_L - V_{out} \quad (8)$$

$$\frac{dV}{dt} = \frac{i}{C_1} - \frac{i_L}{C_1} \quad (9)$$

The combination of the two steps gives us (10). The ratio between the input and output voltage is given by (10):

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

D is the duty cycle.

The inductance of the boost converter, L , is calculated (11):

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

where Δi_L is the current ripple in the inductor and f is the switching frequency. The value of the output capacitor is given (12):

$$C_2 = \frac{I_{out} D}{f \Delta V_{out}} \quad (12)$$

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

4. MAXIMUM POWER POINT TRACKING CONTROLLERS

4.1. Proposed particle swarm optimization maximum power point tracking 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 [18]. 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 as shown in Figure 5.

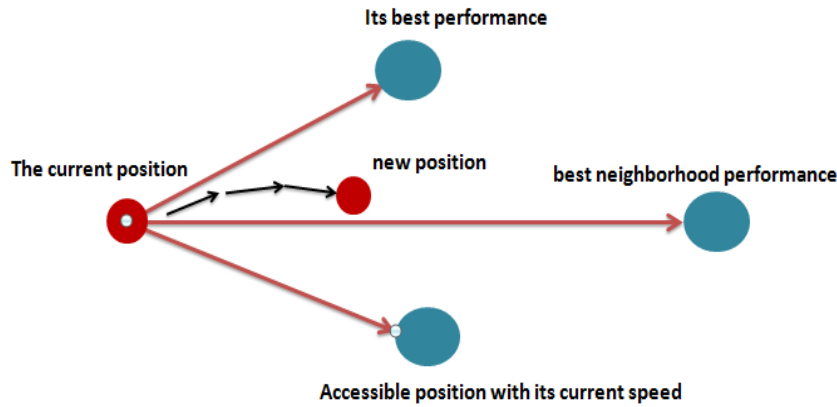


Figure 5. Principle of the movement of a particle

The overall step of the PSO technique is summarized as shown in Algorithm 1. 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 [19].

$$v_i(t+1) = \omega \cdot v_i(t) + c_1 \times r_1 \times (PBest_i(t) - P_i(t)) + c_2 \times r_2 \times (GBest_i(t) - P_i(t)) \quad (13)$$

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

Where, c_1 and c_2 are acceleration constants, P is position of the particle, V is velocity, PBest is best position of the particle which corresponds to Local_Dbest, GBest is best position of the group of particles which

corresponds to Global_Dbest, r_1 and r_2 are random variables uniformly distributed on an interval of $[0, 1]$ (function defined in MATLAB). 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 and I . The Table 2 includes the PSO parameters we have chosen during the simulation.

Algorithm 1. Particle swarm optimization

Step 1: initialize the size of the swarm, the size of the search space, the maximum number of iterations, and the PSO constants c_1 , c_2 and w . Determine the random numbers r_1 and r_2 .

Step 2: determine the current shape of each particle in the population.

Step 3: assign random positions and initial velocities to the particles.

Step 4: evaluate the value of fitness for each particle.

Step 5: determine the global best fitness value.

Step 6: update the position and velocity of the particle for the next iteration. Define the current fitness of each particle: If current fitness < local best fitness, set local best fitness = current fitness.

Step 7: define the current global best fitness: if current global best fitness < global best fitness, then global best fitness = current global best fitness. The position corresponding to global best fitness is assigned to Gbest.

Step 8: restart steps 6 and 7 until the maximum number of iterations is reached or there is no increase in the global best fitness value.

Step 9: terminate the iterative algorithm when the criterion is reached.

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. Perturbation and observation 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 permanent magnet synchronous generator (PMSG) as shown in Figure 6. The objective of the P&O technique is to calculate the duty cycle value D , based on the value of Delta P and Delta V calculated from the inputs V and I .

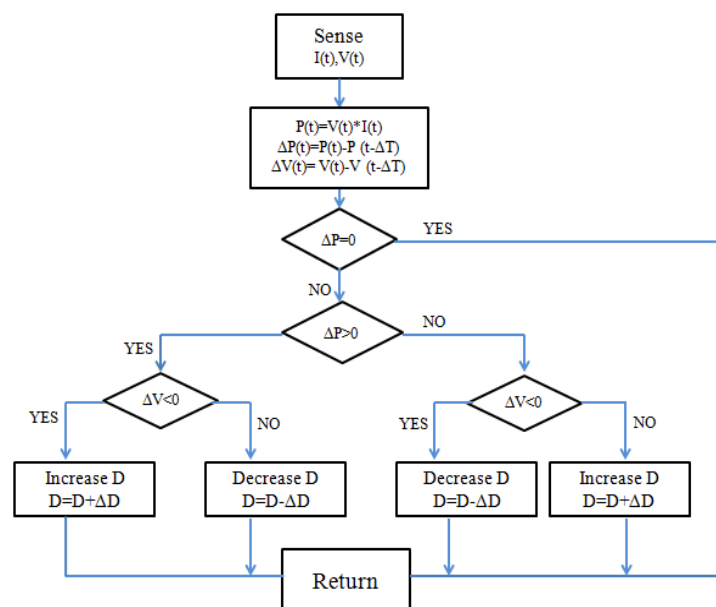


Figure 6. P&O approach

The P&O algorithm, in spite of its known advantages, also presents some problems related to the oscillations around the MPP that it generates in steady state and this is caused by the MPP search process that must be repeated regularly, which obliges the system to oscillate continuously around the MPP [20]. 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 implies that the system has exceeded the MPP. The same reasoning can be applied when the voltage decreases. From 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: 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 variation of the duty cycle is maintained in the same 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

Fuzzy logic (FL) is a new approach based on AI. 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 FLC 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 FLC. The proposed FLC consists of four basic components: fuzzification unit, basic rules, inference engine, and defuzzification [16].

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 [20]. The FLC process for our case is illustrated in Figure 7. The objective of the FL technique is to calculate the duty cycle value D , based on the Delta P and Delta V .

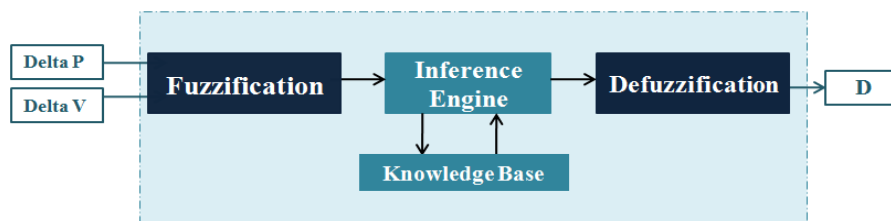


Figure 7. Structure of a fuzzy controller

The inputs Delta P and Delta V are represented by (15) and (16):

$$\Delta P(k) = P(k) - P(k-1) \quad (15)$$

$$\Delta V(k) = V(k) - V(k-1) \quad (16)$$

The membership functions of Delta P, Delta V, and D are respectively shown in Figures 8(a) to (c). Table 3 gives the inference rules for different combinations of the input variables Delta P and Delta V with the output duty cycle D.

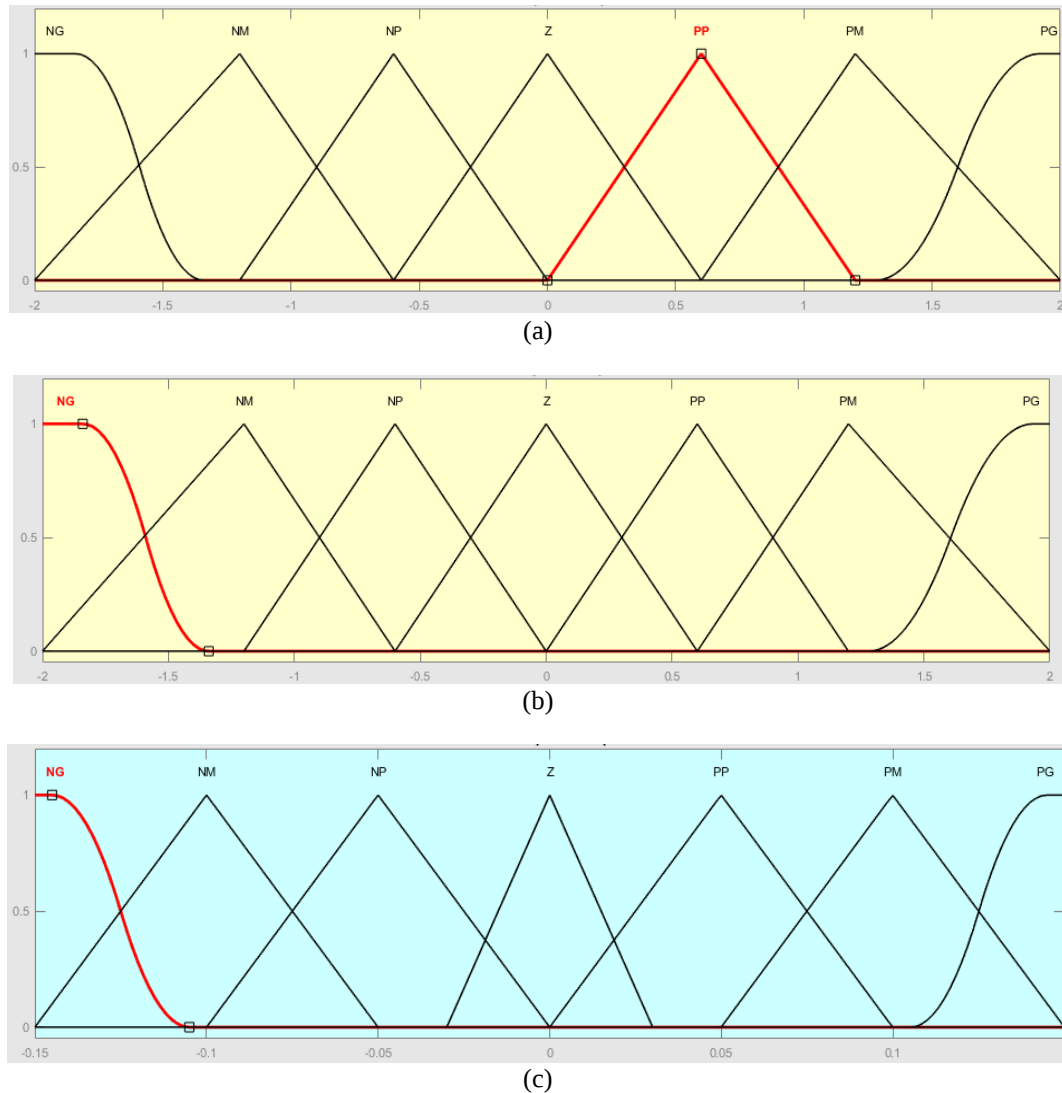


Figure 8. Membership functions related to: (a) Delta P, (b) Delta V, and (c) D

Table 3. Inference rules related to FL WT

Delta P	Delta V						
	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, FL, and PSO, for a WECS. This is achieved by simulation under MATLAB/Simulink, as shown in the Figure 9. The system contains the following components: wind turbine, PMSG, rectifier, boost converter, and controllers block (P&O/FL/PSO). The wind speed varied in three steps, from 8.5 to 8.1 m/s,

MPPT using PSO technique comparing to fuzzy logic and P&O algorithms for wind ... (Hayat El Aissaoui)

then to 7.9 m/s, as shown in the Figure 10. Figures 11 to 13 show respectively the C_p curve for wind speed values varying between 8.5, 8.1, and 7.9 m/s, using respectively the PSO, FL, and P&O techniques.

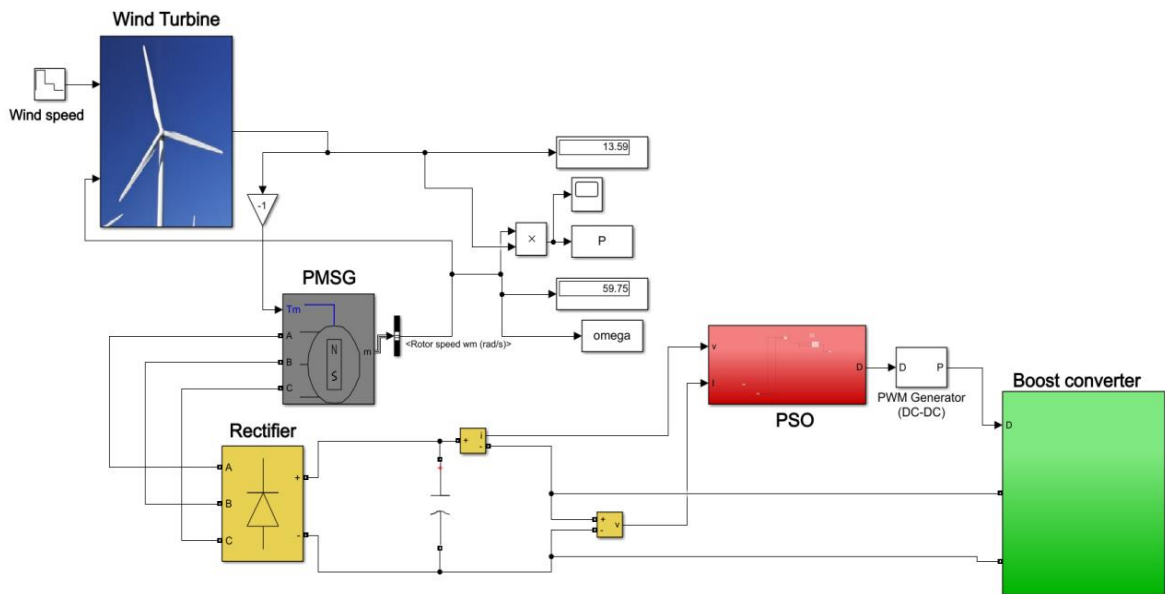


Figure 9. The proposed model in MATLAB/Simulink

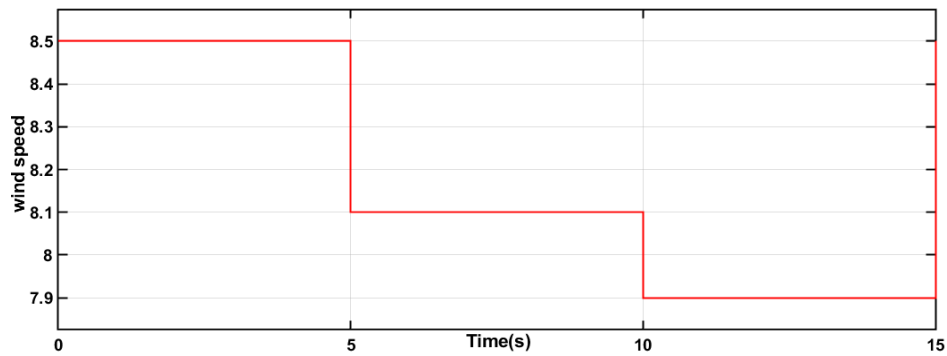


Figure 10. Wind speed variation

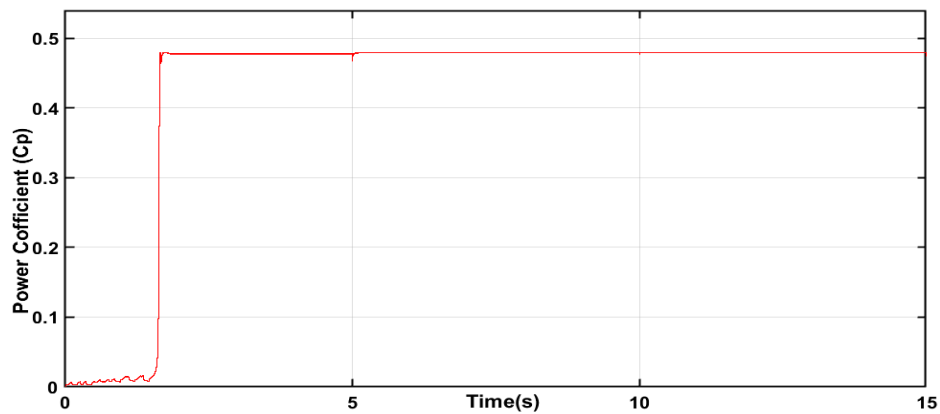


Figure 11. Power coefficient curve using PSO controller

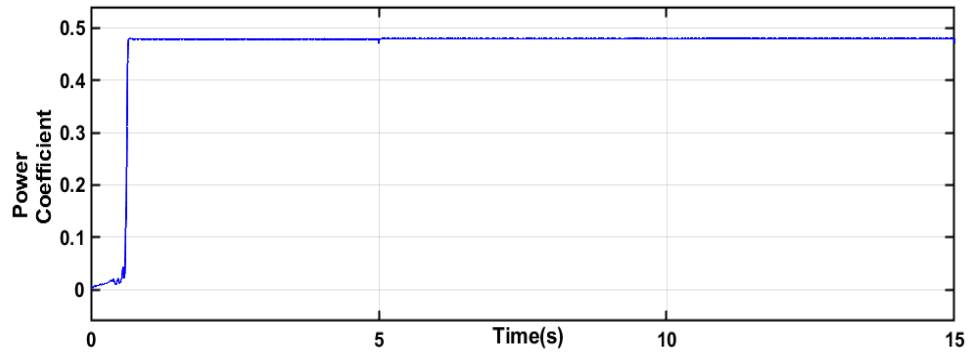


Figure 12. Power coefficient curve using FLC

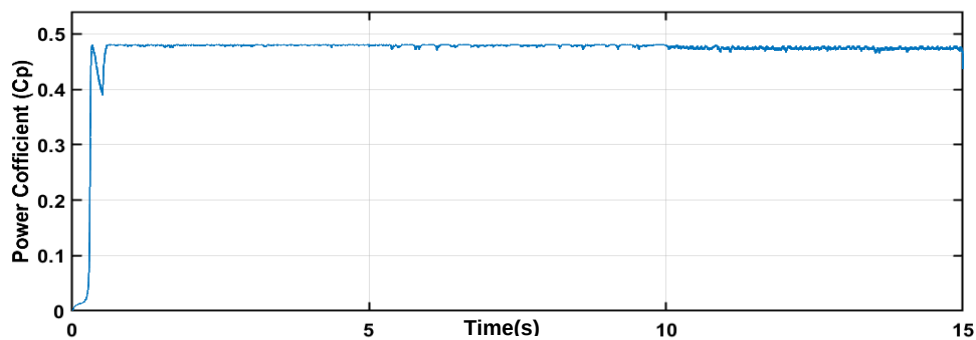


Figure 13. Power coefficient curve using P&O controller

We notice from the evolution of C_p that the PSO technique allows us to continue the MPP because the C_p 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. We see from the evolution of C_p that the FLC technique allows us to continue the MPP because the C_p reaches the maximum value 0.48 but with some oscillations. We can see from the evolution of C_p that the P&O technique does not allow us to continue the MPP for all the tested wind speed values because the C_p does not always reach the maximum value of 0.48, and we notice that this technique presents a considerable rate of oscillations. Figures 14 to 16 show respectively the mechanical power curve for wind speed values varying between 8.5, 8.1, and 7.9 m/s, using respectively the PSO, FL, and P&O techniques. Comparing the curves of evolution of the power produced by WT using respectively PSO, FL, and P&O, controllers, with the characteristic of the turbine as shown in 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.

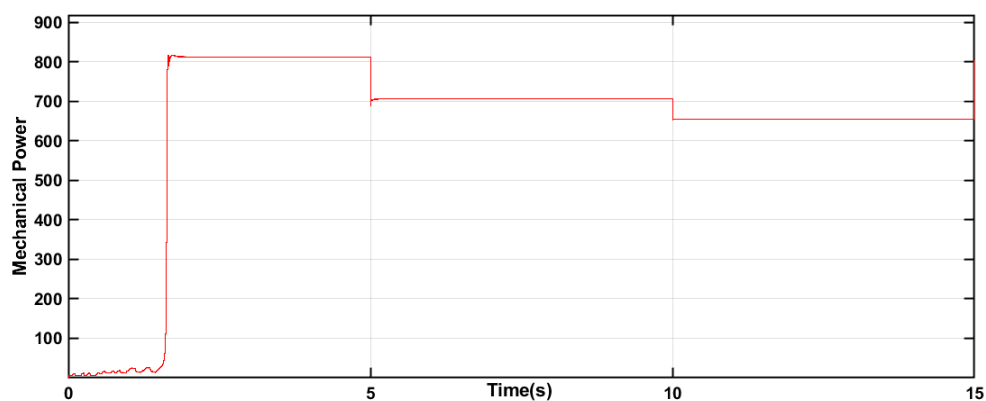


Figure 14. Mechanical power variation using PSO controller

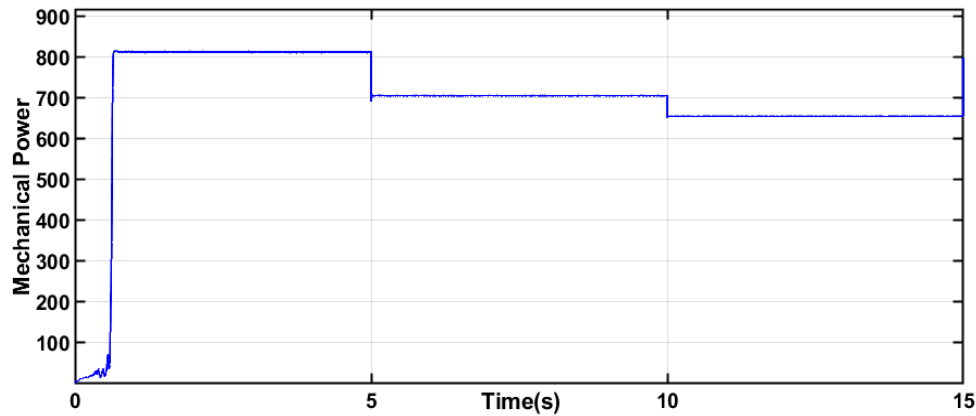


Figure 15. Mechanical power using FLC

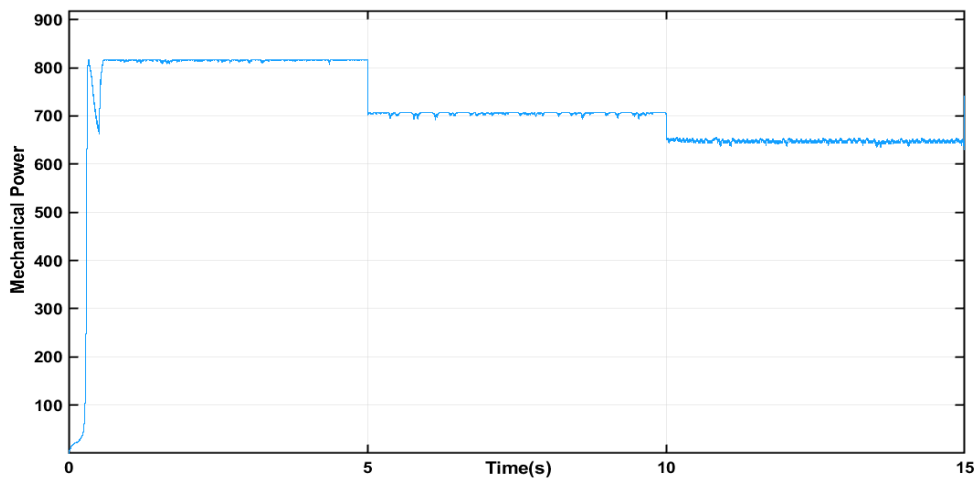


Figure 16. Mechanical power using P&O controller

6. CONCLUSION

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 simulation results revealed that PSO 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.

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