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MAXIMUM POWER POINT PREDICTION AND WIND POWER SYSTEM TRACKING

AOUED MEHARRAR[1], MUSTAPHA HATTI[2,*]

[1]Tissemsilt University Center, Sciences and Technology Department, Tissemsilt, Algeria
[2]UDES, Unité de Développement des Equipements Solaires, EPST/CDER, 11th National Road, Bou Ismail, Tipasa, Algeria
*Corresponding Author: mustapha.hatti@ieee.org

Abstract

In this work, a new intelligent method is developed to predict the maximum power point and to wind system tracking and increase their productivity, reliability and quality of energy, which reduces the cost of wind Kwh. The method developed combines two intelligent techniques (prediction and tracking), which at first allows prediction of a maximum power point, which is then corrected by the application of fuzzy logic, this results in a rapid and accurate convergence to the optimum power point. The generator used in this study is a synchronous permanent magnet (PMSG), controlled by an electronic converter with Pulse Width Modulation (PWM); this last use of a vector and an MPPT (Maximum Power Point Tracking) controller to check the electromechanical magnitudes such as the torque or the rotational speed of the generator in order to extract the maximum wind energy. The simulation results show the effectiveness and robustness of the proposed control.

Keywords: Fuzzy logic, MPPT, PMSG, Prediction, Tracking, Wind turbine.

1. Introduction

Faced with the depletion of fossil energy resources and the environmental problems caused by the emission of greenhouse gases during the exploitation of these resources, other alternative energy resources have been and should continue to be developed [1]. Among them, wind power does not reject greenhouse gases and can be meet the requirements of green electricity production. Wind energy tends to become an essential energy in the energetic mix, as is the case for artificial intelligence methods.

A wind energy conversion system is composed of a wind turbine its operating principle depends on design parameters, which define its potential to collect the energy of the air mass moving.

The mechanical characteristic of a wind turbine is naturally nonlinear and are imperative to adopt a research strategy of maximum power points (MPPT). For this, several control algorithms have been developed, such as that based on fuzzy logic [2, 3], artificial neural network [4, 5] or both (Neuro-Fuzzy) [6]. As explained by Kamal et al. [7], the modelling by bond graph was performed in less time and easier than another analytical method. In our case, the MPPT proposed a device based on a combination of two intelligent methods (prediction and tracking). At first, a maximum power point is predicted and then corrected by the application of the fuzzy logic method, which results in a rapid and accurate convergence to the optimum power point.

The control of the (PMS) generator used is vector type made using a type of electronic converter (PWM). For the modelling and simulation of all the conversion chains, the MATLAB/SIMULINK was used.

2. Wind Conversion Chain Model

The wind power conversion chain used in this work is given by Fig. 1.

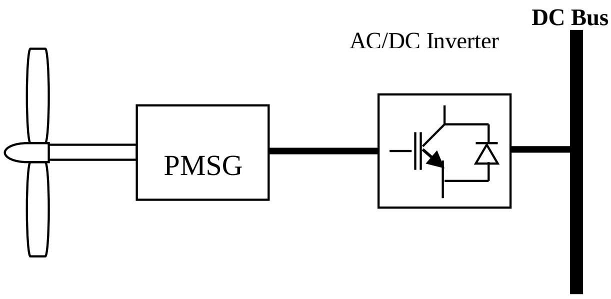


Fig. 1. Wind conversion chain.

According to Cherif and Belhadj [8] and Errami et al. [9], the mechanical power of the wind turbine can be written as:

$$P_t = \frac{1}{2}\rho A C_p v^3 \quad (1)$$

where, v: Wind speed (m/s), ρ: Air density (kg/m^3), C_p: Power coefficient and

A: Area swept by the rotor blades (m^2).

The C_p is a dimensionless parameter expressing the efficiency of the wing in the conversion of kinetic energy of the wind into mechanical energy. This coefficient depends on the wind speed, the number of blades, their radius and their pitch angle and speed of rotation; it is generally given in terms of reduced speed λ defined by:

$$\lambda = \frac{\Omega R}{v} \tag{2}$$

where Ω: Rotational speed (rad/s) and R: Blade radius (m).

Based on studies by Lalouni et al. [10] and Bu et al. [11], the electromechanical equation of the turbine and the generator is given by the following equation:

$$J\frac{d\Omega}{dt} = T_m - T_{em} - f\Omega \tag{3}$$

where J: Inertia of turbine and generator (kg/m^2), Ω: Rotational speed (rad/s), f: friction coefficient (N.m.s.rad-1), T_{em}: Electromagnetic torque (N.m) and T_m is the mechanical torque (N.m).

PMSG model

According to Bu et al. [11] and Wu et al. [12], the theory of the space vector gives the dynamic equation of the stator currents as follows:

$$\frac{dI_{sd}}{dt} = \frac{1}{L_d}(V_{sd} - R_s I_{sd} + p\Omega\Omega_q I_{sq}) \tag{4}$$

$$\frac{dI_{sq}}{dt} = \frac{1}{L_q}(V_{sq} - R_s I_{sq} - pL_{sd} I_{sd}\Omega - p\Omega\Phi_m) \tag{5}$$

where Rs: Stator resistance (Ω), Ld and Lq: Inductances of the stator (H), Φ_m: Flux of the permanent magnet (Wb), V_{sd}, V_{sq}: Stator voltages (V), Isd, Isq: Stator currents (A), P: Number of pairs of poles and Ω: Rotation speed (rad/s).

The electromagnetic torque is given by the following equation:

$$T_{em} = p(\Phi_m I_{sq} + (L_d - L_q) I_{sd} I_{sq}) \tag{6}$$

3. Maximum Power Point Prediction and Tracking

The power characteristic of a wind turbine is naturally nonlinear as shown in Fig. 2 because the position of the maximum power varies with the wind speed v, for each wind speed, it is necessary that the system finds the maximum power.

To approach this goal, a specific command must be used. In this work, our method of research of Maximum Power Point Tracking (MPPT) is performed as follows:

They predict a maximum power point, then we track it by the application of fuzzy logic algorithm until the optimum power is obtained, where, the application of the prediction we quickly approach the maximum power point, then with the application of fuzzy logic we track the maximum power point until you get exactly the point of optimum power.

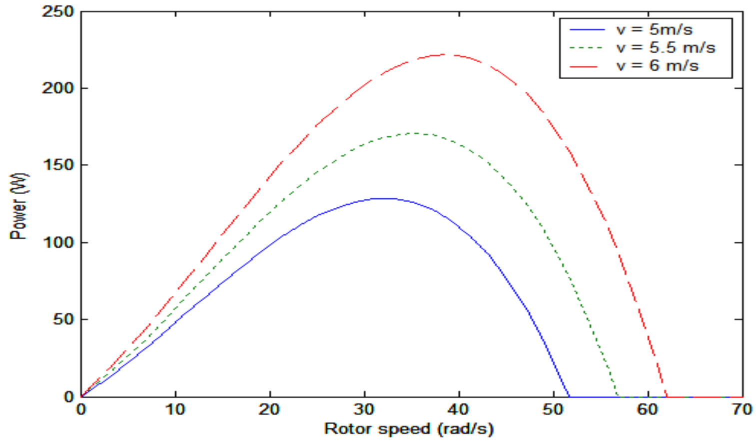


Fig. 2. The mechanical characteristic of the wind turbine.

3.1. Maximum power point prediction

The details of this method can be well explained by the following example:

It is considered that the wind speed varies from v_1 to v_2 as shown in Fig. 3, where point A matches the optimum power point Po_{p1} dedicated to the speed v_1.

In this case, the optimum power P_{op1} can be expressed by Eq. (7):

$$P_{op_1} = \frac{1}{2} \rho A C_{op} v_1^{\,3} \tag{7}$$

where ρ: Air density (kg/m^3), v_1: Wind speed (m/s), A: Area swept by the rotor blades (m^2) and C_{op}: Optimal power coefficient.

From Eq. (7), the AC_{op} can be calculated, as shown in the following equation:

$$AC_{op} = 2 \frac{P_{op_1}}{\rho v_1^{\,3}} \tag{8}$$

So, if the wind speed varies from v_1 to v_2 as in Fig. 3, the operating point varies from point A to point B, at this time (at point B) we can predict the new maximum power point C that corresponds to the speed $v2$ simply by applying Eq. (9):

$$P_{op_2} = \frac{1}{2} \rho A C_{op} v_2^{\,3} \tag{9}$$

where the product A_{Cop} is already calculated using Eq. (8).

Finally, the fuzzy logic theory is applied until the true value of the optimum power (point D) dedicated to the wind speed V_2 is obtained.

In case the wind speed changes its value from v_2 to v_3, the search of optimum power point is carried out by the same method mentioned above.

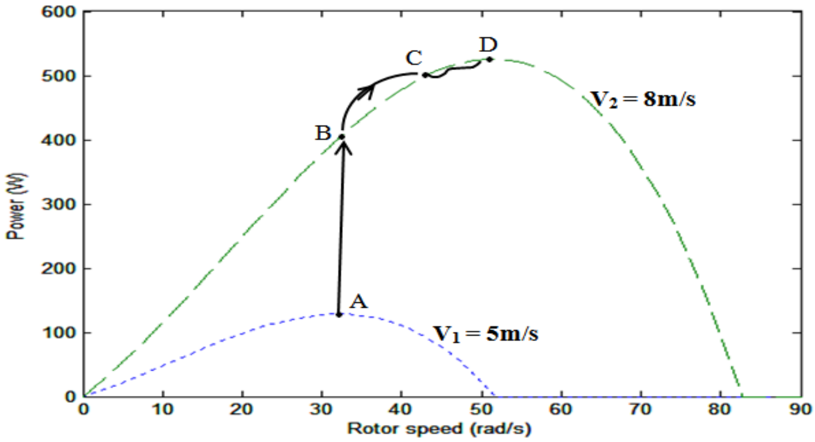


Fig. 3. Principle of the maximum Power Point Prediction then Tracking (MPPPT).

3.2. Fuzzy MPPT controller

The fuzzy logic system is based on the rules of classical logic without using binary representations. The basic of fuzzy rules is generally the most used in fuzzy logic applications. As presented by Abikoye et al. [13], a fuzzy rule has three functional steps and are summarized in Fig. 4.

In our case, the fuzzy input variables are: the variation of the rotational speed of generator $\Delta\Omega$ and the variation of mechanical power ΔP, the output variable is: the variation of the desired speed $\Delta\Omega_{ref}$.

Three fuzzy sets (P, Z, N) are attributed to these variables, signify respectively: a positive variation, a zero variation and a negative variation, of which, each variable ($\Delta\Omega$, ΔP or $\Delta\Omega_{ref}$) still belongs to two membership function.

The membership functions can take any form; in this case, it is triangular, mainly to simplify the calculations. The fuzzification means to evaluate the membership functions used where each fuzzy set, is characterized by a degree of membership μ, this represents the degree of truth of the membership function, as shown in Figs. 5 and 6.

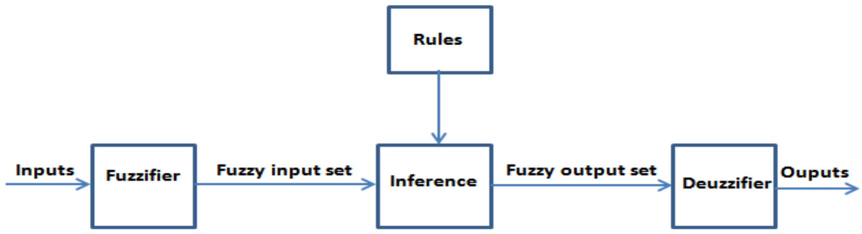
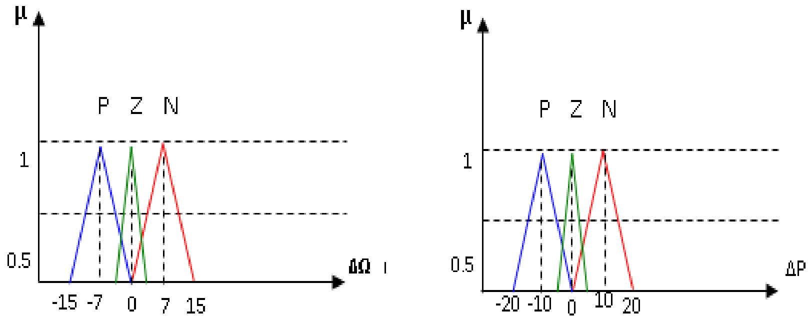


Fig. 4. Fuzzy logic system.



(a) Fuzzification of ΔΩ. **(b) Fuzzification of Δ*P*.**

Fig. 5. Member functions of input variables.

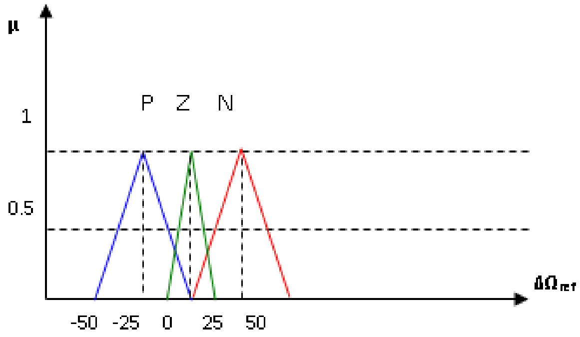


Fig. 6. Membership function of output variable (fuzzification of $\Delta\Omega_{ref}$).

The fuzzy system used in this work is Mamdani type using the inputs (ΔΩ and Δ*P*) and the output ($\Delta\Omega_{ref}$) as data, where the fuzzy implication and the logical and is realized by the formation of the minimum and the logical OR is realized by the formation of the maximum. The fuzzy rules are indicated in Table 1, which are all of the type:

If: «Condition 1» and « Condition 2» Then «Condition 3».

For example, if a positive variation of the speed of rotation causes an increase in power, we continue to increase the rotational speed.

Conditions were interconnected by a logical and the degree of membership of the membership function, which is the conclusion, will then be equal to the minimum of two degrees of membership conditions. The output membership functions are constructed from aggregations of membership functions obtained by the set of rules, for example: the degree of the output membership function *(*Δ*Ωref* = N) will be calculated three times because there are exactly three rules that lead to this conclusion, so the maximum between these four functions of memberships was calculated.

To pass from the fuzzy domain to the real domain (defuzzification), we calculate the numerical value of the output membership functions and we use for this case, the gravitation centre method.

Table 1. Fuzzy logic rules used.

$\Delta\Omega_{input}$	ΔP_{input}	$\Delta\Omega_{ref}$
P	P	P
P	Z	Z
P	N	N
Z	P	P
Z	Z	Z
Z	N	N
N	P	N
N	Z	Z
N	N	P

4. Results and Discussion

In this work, a small horizontal turbine with three blades was used, where, the power extracted by the turbine depending on the speed of rotation Ω, for different wind values is shown in Fig. 7.

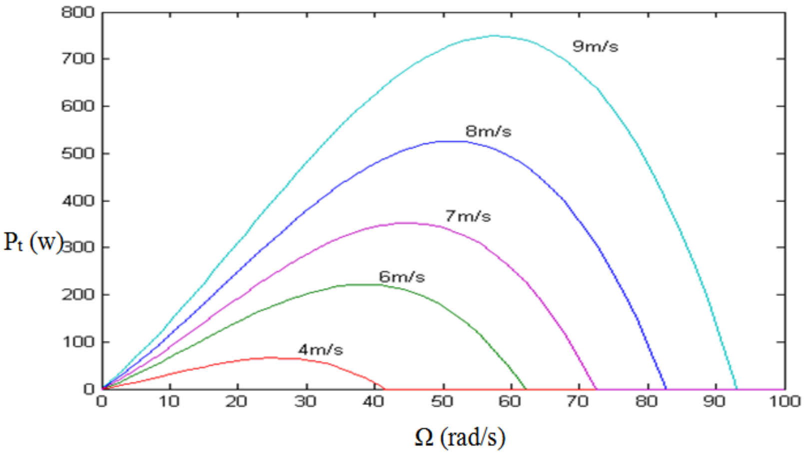


Fig. 7. Mechanical power/speed characteristic.

For a rapid change in wind speed as shown in Fig. 8, the mechanical power variation of the wind with the use of an MPPPT controller is presented in Fig. 9.

Figure 9 shows that the maximum power point prediction method gives rapidly an approximate power and the MPPT fuzzy logic controller gives the optimal power but slowly.

However, the combination of the prediction and the fuzzy logic controller not only help to get a better accuracy of the system but also permits to achieve optimal power rapidly.

For a real variation of the wind speed as shown in Fig. 10, the maximum power point tracking using a fuzzy logic control with and without prediction is presented in Fig. 11.

Figure 12 gives the system effectiveness when using the MPPT by a fuzzy logic control is used with and without prediction.

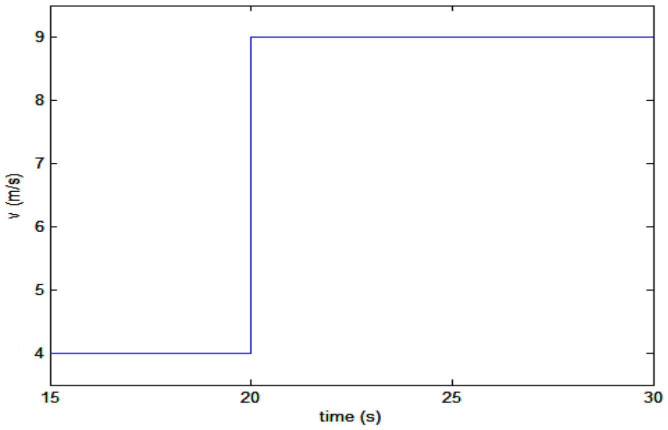


Fig. 8. Wind speed variation profiles used for simulations studies.

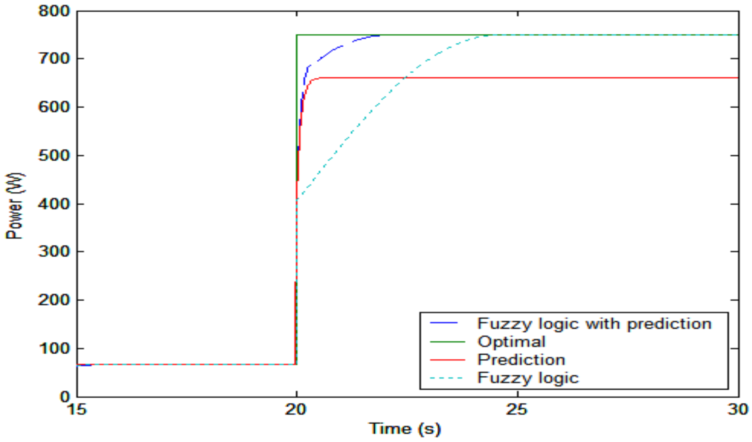


Fig. 9. Output mechanical power response under wind speed changes.

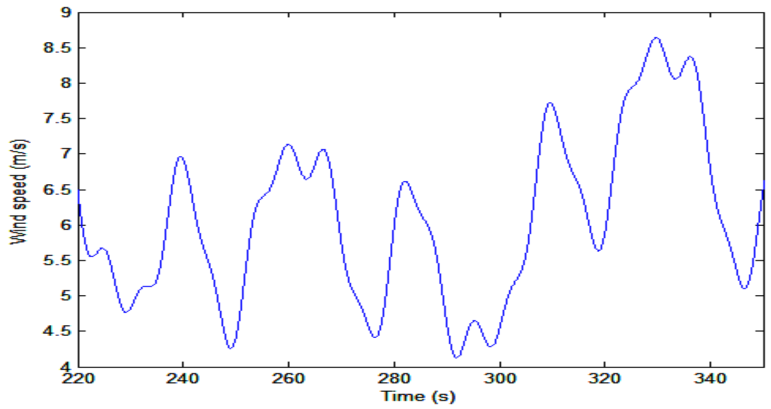


Fig. 10. Realistic variations profile of the wind speed.

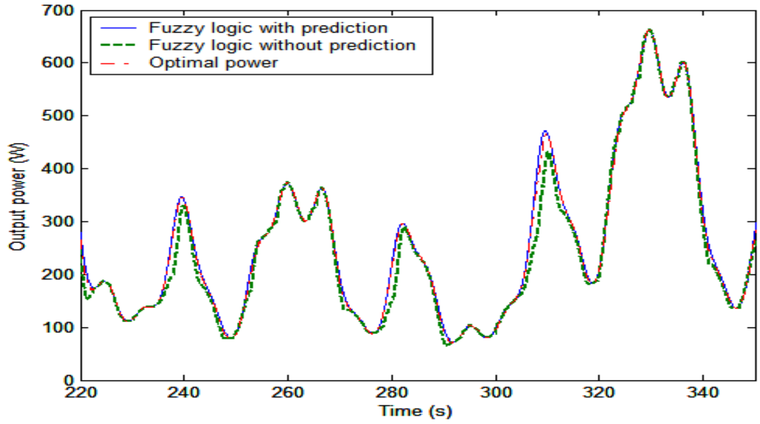


Fig. 11. MPPT using a fuzzy logic control with and without prediction.

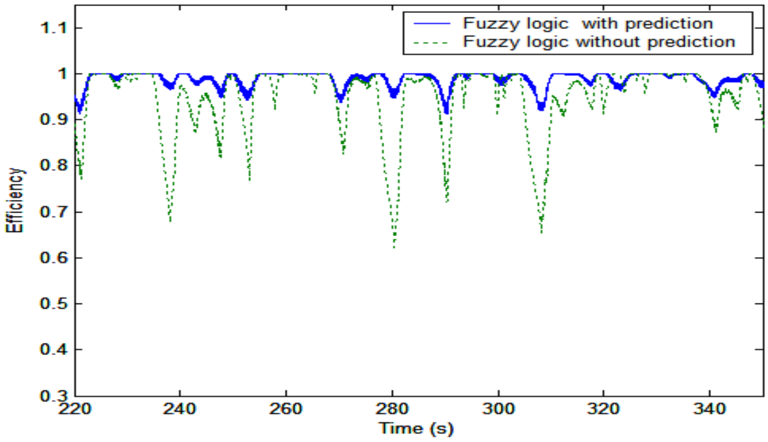


Fig. 12. Performance of the MPPT controller.

5. Conclusions

In this paper, modelling and numerical simulation of a wind conversion chain, with permanent magnet synchronous generator and a PWM converter are presented. The search for the Maximum Power Operating Point (MPPT) has been proposed with an algorithm based on the prediction and tracking by fuzzy logic. The simulation results show that when only the prediction method is used, the approximate power is rapidly obtained and when only the fuzzy logic controller is used an optimal power is obtained but slower. However, the use of the combination of these two methods (prediction and tracking by fuzzy logic) gives an optimal power rapidly. Simulation results verified the proposed model of the control system and the MPPT approach. Hence, the combination of the prediction and the fuzzy logic controller not only help to get a better accuracy of the system but also permits to achieve optimal power rapidly. The developed model can be used for investigating the dynamic behaviour of small-scale power generation systems.

Nomenclatures

A	Area swept by the rotor blades, m^2
C_{op}	Optimal power coefficient
Cp	Power coefficient
f	Friction coefficient, $N.m/s.rad^{-1}$
I_{sd}, I_{sq}	Stator currents, A
J	Inertia of turbine and generator, kg/m^2
L_d, L_q	Inductances of the stator, H
P	Number of pairs of poles
R	Blade radius, m
R_s	Stator resistance, Ω
T_{em}	Electromagnetic torque, N.m
T_m	Mechanical torque, N.m
V_{sd},V_{sq}	Stator voltages, V
v	Wind speed, m/s

Greek Symbols

ρ	Air density, kg/m^3
Φ_m	Flux of the permanent magnet, Wb
Ω	Rotational speed, rad/s

Abbreviations

MPPT	Maximum Power Point Tracking
PMSG	Permanent Magnet Synchronous Generator

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