Maximization of Power for Wind Energy Production

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Abstract:- In this article, we study a conversion system of wind power to horizontal axis of small size into isolated site. The MPPT control by the knowledge a curve of airofoil will be developed. Les résultats des différentes simulations de toute la chaîne de conversion, réalisées sous environnement MATLAB/Simulink, ont permis d'évaluer les performances du système proposé. The results of simulations with all the chain conversion, realized under MATLAB/Simulink environment, make it possible to evaluate the performances of the system suggested.

Keywords:- *Wind Power, Maximization, Control Speed, Asynchronous Generator, Power Coefficient.*

I. INTRODUCTION

A conversion system of wind power is composed of the wind turbine having a characteristic which is clean for him and which depends on parameters of construction defining its capacity to take the energy of the mass of air moving. The turbine is connected to a generator via a mechanical multiplier. In the case of small airfoils, the speed of rotation is sufficient for a "dedicated" machine of the asynchronous type, with a large number of poles, can be driven directly without a multiplier [1]. This conversion system of energy seems one of most promising with a very high growth rate world [2]. Thus, its use became increasingly significant that it is by way of coupling, or not, with the electrical supply network. The curve of power in the bell shape, typical of the wind mills, requires an adaptation of the mechanical load in order to ensure a good energy taking away "the liking of the wind": we speak thus about maximization of the power, even of MPPT (Maximum Power Point Tracking), which then constitutes the object of our study.

II. SYSTEM OF STUDY

From a point of view to study the conversion system of wind turbine of small power and to test the algorithm MPPT control on a platform of simulation, it is necessary to describe the system studied, it made up of the wind mill and the asynchronous generator in accordance with the synoptic diagram of the figure fig. 1. The modern wind turbine is a sophisticated piece of machinery with aerodynamically designed rotor and efficient power generation, transmission and regulation components. Size of these turbines ranges from a few Watts to several Mega Watts. Modern trend in the wind industry is to go for bigger units of several MW capacities, as the system scaling up can reduce the unit cost of wind generated electricity.

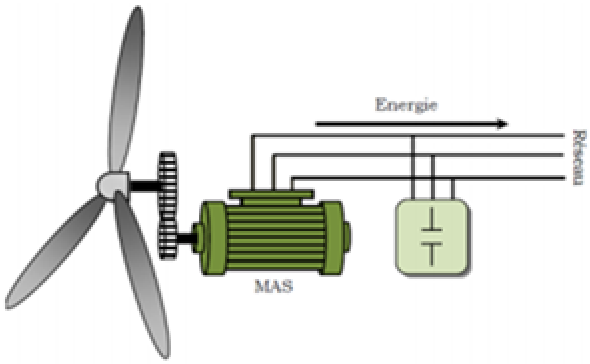

Figure 1: Wind energy conversion systems.

Energy available in wind is basically the kinetic energy of large masses of air moving over the earth's surface. The kinetic energy of a stream of air with mass m and moving with a velocity V is given by:

$$E_c = \frac{1}{2} m v^3 \qquad (1)$$

The air parcel interacting with the rotor per unit time has a cross-sectional area equal to that of the rotor and thickness equal to the wind velocity V. Hence energy per unit time, that is power, can be expressed as:

$$P_v = \frac{1}{2} \rho s v^3 \qquad (2)$$

Where: ρ is the density of air, S is a cross sectional area and V is a wind velocity.

However, this power could never be extracted in its totality by the device from conversion (aerogenerator). When the wind
stream passes the turbine; a part of its kinetic energy is transferred to the rotor and the air leaving the turbine carries the rest away [3]. So, the mechanical power developed by the turbine is given by the relation:

$$P_m = \frac{1}{2} C_p(\lambda, \beta)\rho s v^3 \qquad (3)$$

Where: C_p is a power coefficient.

λ: is the tip speed ratio, it's means the ratio between the velocity of the rotor tip and the wind velocity. Thus,

$$\lambda = \frac{R\Omega_t}{v} \qquad (4)$$

where: Ω_t is the angular velocity of the turbine.

The power coefficient C_p gives the part of the kinetic energy which is converted into mechanical energy by the wind. The wind one is characterized by the curve of C_p coefficient reactivity power according to λ and the angle of orientation β of blades. Theoretically, Albert Betz, a German physicist, in 1962 established that the maximum theoretical power coefficient of a wind turbine, operated predominantly by lift force, is 59.3%, but practically this value is 40% for wind the most powerful and 30% for most often [2]. For the continuation, we will take a turbine of small power which has fixed blades, for that one considered that the pitch angle β does not intervene in our model (pitch angle β= 0). The mechanical angular velocity of the turbine can be obtained by the relation between the electromagnetic torque and the mechanical torque, y included/understood the masses of the generator and the turbine, and be represented by this equation:

$$J\frac{d\omega_t}{dt} = T_{em} - T_m \qquad (5)$$

With,

T_{em} is the electromagnetic torque and T_m is mechanical torque.

III. EXTRACTION OF THE MAXIMUM POWER METHODS (MPPT)

The three-phase asynchronous generator presented in figure 1 is connected to the wind turbine by the intermediary of a speed-increasing gear. Families of chains of conversion exist to fulfill this function. From the structure of a mechanical sensor (speed and position), it is possible of autopilot the electric machine in order to carry out control of speed or in torque. This structure allows various strategies of research of the optimal point of power, in particular that which makes it possible to abstain from the knowledge of the curve characteristic of the airfoil.

A. *Importance of a method MPPT*

The energy produced by the aerogenerator depends mainly on the wind which is an unforeseeable climatic factor, in particular its speed [1]. The wind is modelled here by a sum of sinusoidal functions. Its deterministic model applied to various systems makes it possible to compare them between them. In accordance with the model used by A. Mirecki [4], we adopt like model of the wind the relation (6) below, and figure 2 shows the variation its speed according to time:

$$V(t) = V_0 + \sum_i^4 V_i \sin\left(\frac{2\pi t}{T_i}\right) \qquad (6)$$

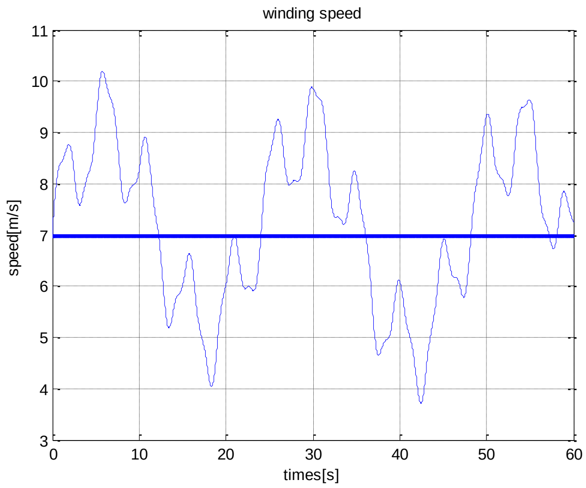

Figure 2: winding speed according to times.

Figure 2 shows us the evolution speed around an average value of 7m/s on a scale of times of 60 S. This profile is obtained by simulating the relation giving the profile of the wind (6) on the Matlab software. The corresponding power is thus given by:

$$P_t = \frac{1}{2} \mathrm{C_p}(\lambda)\rho\pi R^2 v^3 \qquad (7)$$

Thereafter, the maximum power being able to be collected by wind is calculated starting from the limit of Betz:

$$P_t^{\max} = \frac{1}{2}\rho\pi R^2 v^3 C_p^{\max} = 0.593 P_v \qquad (8)$$

In this form, the formula of Betz shows that maximum energy to be extracted by an aerogenerator cannot exceed to in no case 59.3% of the kinetic energy of the mass of air which crosses it a second [5].

Thus, we can define the concept of output aerodynamic of the wind mill by the ratio:

$$\eta_a = \frac{C_p}{C_p^{\max}} = \frac{C_p}{0.593} \qquad (9)$$

In practice, the value of the maximum of power coefficient approaches the value of 0.48 with a three-bladed

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turbine. What gives an aerodynamic output of 81% for the current wind turbines [6]. we find in various of the literature several types of modeling of power coefficient, generally valid for a particular turbine: each turbine having a specific behavior. Thus, everyone is confronted with this problem of modeling a power coefficient according to relative speed figure (3). Nevertheless, the modeling used in this work appears in other references [3].

$$c_p(\lambda) = -0.2121\lambda^3 + 0.0856\lambda^2 + 0.6539\lambda \qquad (10)$$

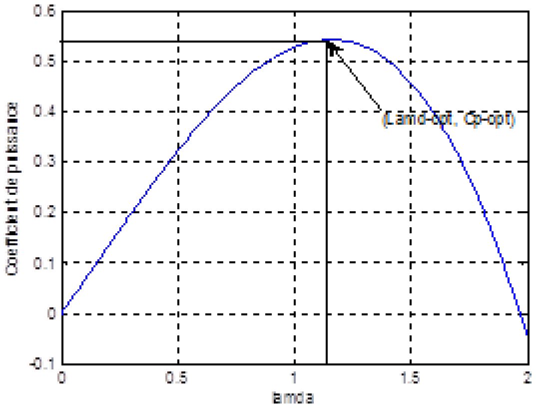

Figure 3 Characteristic of power coefficient according ratio

Figure 3 represents the layout of the characteristic $c_p(\lambda)$ where a maximum is 0.54 for 1.16 of ratio value. he relation (9) and the value of c_p obtained on figure (3) enable us to have an aerodynamic output up to 91%. For better optimizing the conversion of power, it is thus necessary to try to preserve this fallback speed, i.e., to modify the rotation speed when the speed of the wind varies.

B. Maximization of the power without control speed

There are various ways of proceeding to seek the maximum point of power: either by using the method by fuzzy logic, or on the basis of the curve characteristic of the wind airfoil to control [4]. In this work, one will use methods MPPT knowing the curve characteristic of the airfoil figure 3.

1) Speed control

Figure 3 give a curve Cp (λ) of a turbine. The top of this curve is equivalent to the maximum power "extractable", therefore at the optimal point. It is characterized by the optimal ratio λ_{opt} and the optimal power coefficient C_{p_opt}. While inserting the equation (4) in the expression (7) and by taking account of the optimal value $\left(\lambda_{opt}, C_{p-opt}\right)$, we obtain the power function according to the speed:

$$P_{t\_opt} = \frac{C_{p\_opt}\rho\pi R^5}{2\lambda_{opt}^3}\Omega_t^3 \qquad (11)$$

This equation enables us to calculate the optimal speed of the turbine given by the following relation:

$$\Omega_{opt} = \sqrt[3]{\frac{P_{t\_opt}}{K_{opt}}} \qquad (12)$$

Where:

$$K_{opt} = \frac{C_{p\_opt}\rho\pi R^5}{2\lambda_{opt}^3} \qquad (13)$$

2) Torque Control

Taking into account the difficulty of regulating the speed of a strongly inertial turbine, an order in torque of the generator is applied. This way of proceeding gives an association of modes of "healthy" order more from the physical point of view: a source speed (airfoil unit) is connected to a source of torque (generating controlled in couple). This new way of controlling the system requires an adaptation of the device of research of the point of maximum power MPPT. By using the formula (11) of computation of the power, it is easy to determine the wind torque corresponding:

$$P(\Omega) = T_t\Omega_t \qquad (14)$$

Then:

$$T_{tr\_opt} = \frac{C_{p\_opt}\rho\pi R^5}{2\lambda_{opt}^3}\Omega_t^2 \qquad (15)$$

Maximization of power without control of speed rests on assumption that the speed of the wind varies very little in steady operation in front of the electric time-constants of the wind system, which implies that the couple of acceleration of the turbine can be regarded as null ([4], [7], [8]). In this case, starting from the dynamic equation of the turbine (5), one obtains the static equation describing the steady operation of the turbine:

$$J\frac{d\omega_t}{dt} = T_{em} - T_m = 0 \qquad (16)$$

This equation enables us to write:

$$T_{em} = T_m \qquad (17)$$

The equation (17) means that the electromagnetic torque of adjustment is given starting from an estimate of the wind torque and is defined by:

$$T_{em\_ref} = T_{tr\_opt} \qquad (18)$$

we can then obtain the diagram of following control.

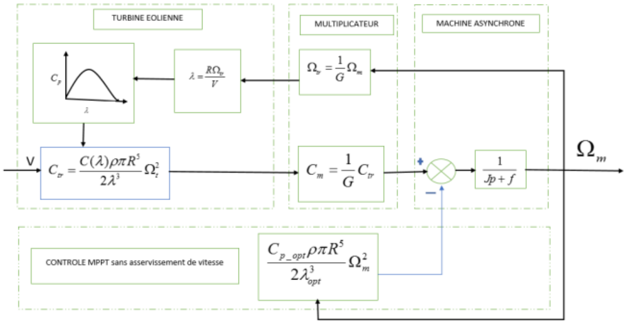

Figure 4: Control MPPT without control speed.

After development of the system in the Matlab environment, we have the following results:

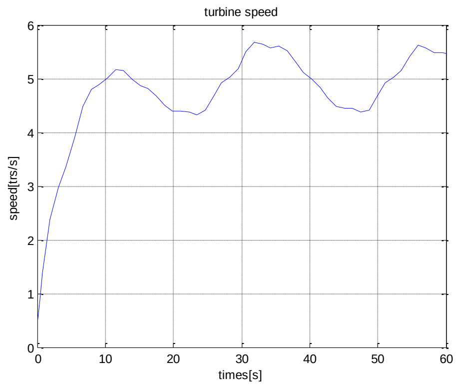

Figure 5 Curve of turbine speed according to time.

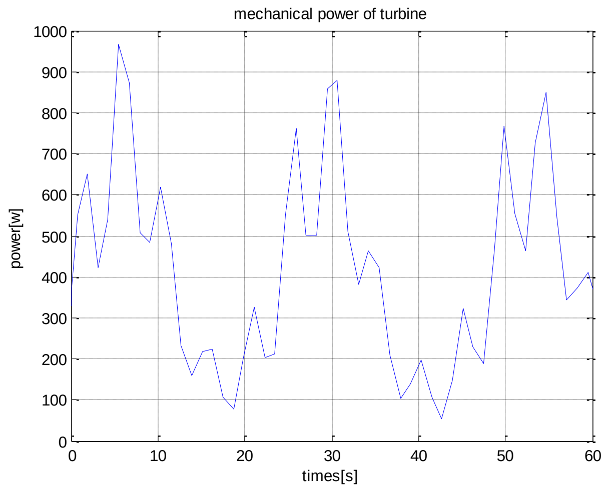

Figure 6 Curve of power for control MPPT without control speed.

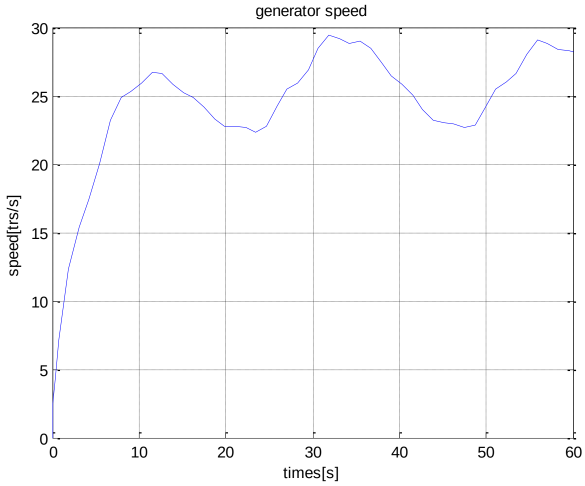

Figure 7: Curve of speed generator for control MPPT without control speed.

Figure 5 shows the variation number of revolutions of the turbine. It is seen well that the number of revolutions is quasi adapted at the speed of the wind of figure 2, which entrain a very significant increase in the power (see Figure 6). On figure 7, we have the pace number of revolutions of the generator. It is noted that this pace has the same profile as that the number of revolutions of the turbine, but with amplitude five times of higher.

C. Maximization of the power with control speed

If it is supposed that the generator is ideal, therefore whatever the generated power, the developed electromagnetic torque T_{em} is at any moment equal to its value of reference (i.e., $T_{em\_ref} = T_{em}$) ([9], [7]).

The method of extraction of the maximum of power (MPPT) consists in determining the speed of the turbine Ω_t which makes it possible to obtain the maximum of generated power. Thus, we must regulate the electromagnetic torque on the shaft so as to fix the number of revolutions of this one at a speed of reference. To carry out this, a control number of revolutions of the machine must be carried out, as Figure 8 shows it [4], [7], [8], [9]. Then, the electromagnetic torque of reference T_{em_ref} making it possible to obtain a speed rotation of turbine Ω_t equal to its value of reference Ω_{tr_ref} is obtained on the outlet side of the speed regulator and is determined by the relation [7], [8]:

$$T_{em\_ref} = K_{PI}.\left(\Omega_{mref} - \Omega_{tr}\right) \qquad (19)$$

Where:

K_{PI} : is the speed regulator of the type PI.

This speed of reference Ω_{mref} depends on the speed of the turbine to fix Ω_{tr_ref} to maximize the extracted power.

The reference the speed of the turbine corresponds to that of the optimal value of the ratio speed λ_{opt} making it possible to obtain the maximum value of $C_p^{\max}$. Then, we ca write:

$$\Omega_{tr\_ref} = \frac{\lambda_{opt} V}{R} \qquad (20)$$

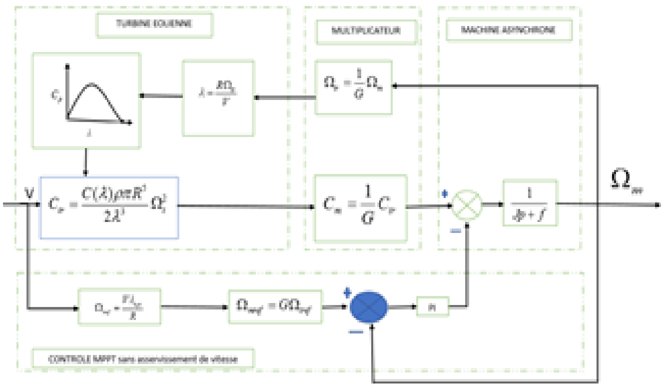

Figure 8: Control MPPT with control speed.

After the development of the system in the Matlab/Simulink environment, one leads to the following results:

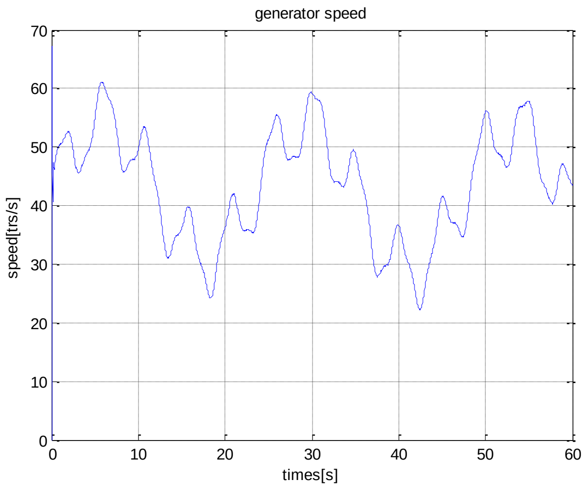

Figure 9: Curve of speed generator for control MPPT with control speed.

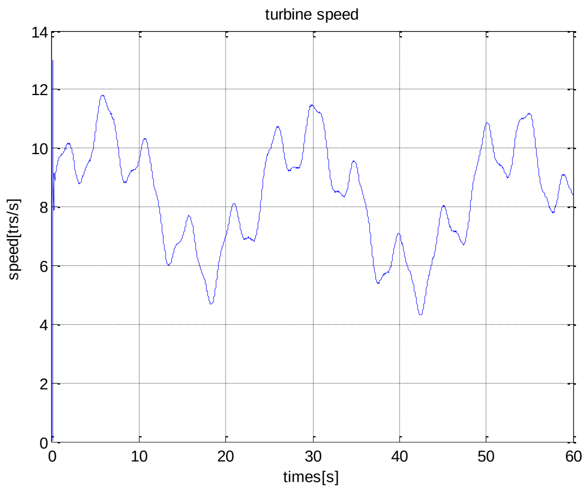

Figure 10: Curve of turbine speed for control MPPT with control speed

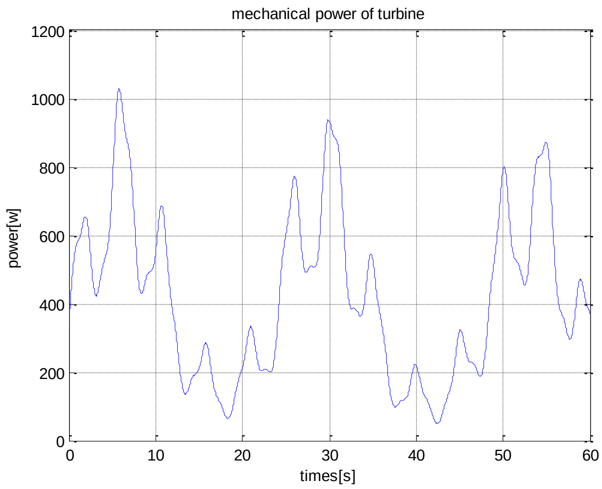

Figure 11 Curve of power for control MPPT with control speed.

Figure 9 shows curve of speed the generator. It is noticed well that this speed is adapted much at the speed of the wind than in the case of the preceding method. Moreover, the number of revolutions exceeds the speed of the synchronism of the asynchronous machine (approximately 3600 tr/min maximum value), this supports the machine to be functioned in two modes, namely in hypo synchronous mode (the machine absorbs the power of the network) and in hypersynchronous mode (the machine provides the power to the network).

This method is simple. However, it strongly depends on the velocity measurement of wind, it be a statement of the quality of the image of the wind provided by the anemometer. Moreover, the reliability of the method holds of the accuracy of the programmed curve of the place of the maximum power according to the speed of the wind (given manufacturer) [7].

IV. CONCLUSION

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In this article, we worked out the mathematical models of the components of the conversion system of wind power (models of the airfoil, of the turbine). The control MPPT by the knowledge of the curve airfoil was developed. The results of various simulations carried out were commented on and one could note that the pace number of revolutions of the turbine with order MPPT without control speed is adapted compared to that which with the control speed.

APPENDIX

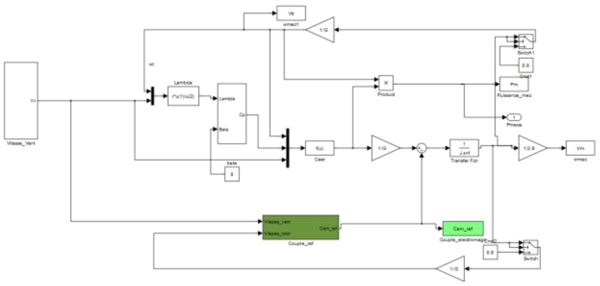

Figure 12: control MPPT in matlab with control speed.

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