An adapted method for a small wind turbine to extract the optimal power

MY ELHOUSSINE ECHCHHIBAT[1],
LHOUCINE BAHATTI[2], ABDELHADI RAIHANI[2], ABDELMOUNIME ELMAGRI[2]

Laboratory of Signals, Intelligence Artificial and Systems Distributed, (SSDIA)
[1]Mechanical Engineering Department
[2]Electrical Engineering Department
ENSET Mohammedia
Hassan II University, Casablanca
MAROCCO
[1]e-mail: echchhibate@ gmail.com

Abstract: - In this paper, the control of the wind energy conversion systems (WECS) is synthesized. The considered WECS includes a two-bladed wind turbine and a permanent magnet synchronous generator (PMSG). First, a model of the whole controlled system is developed in the Park-coordinates and given a state space representation. A multi-loop controller is designed to meet the main control objective, i.e., speed reference optimization in order to extract maximum wind energy whatever the wind speed. For this, a speed-reference optimizer is developed. This approach uses an identification method to determine a mathematical function generating the optimal speed reference (Maximum Power Point Tracking). The speed-reference optimizer and the control law performances are illustrated through numerical simulations. All control objectives are proved to be asymptotically achieved.

Key-Words: - Turbine, modeling, non-linear model, identification, polynomial, simulation.

1 Introduction

Increasing electrical energy consumption and environmental concerns have forced most of researchers to develop an alternative electrical power sources. So, in recent years, the wind conversion systems are widely used to head environmental protection requirements and electricity demand capacity.

In the wind energy conversion system (WECS), the electrical energy is generated from wind using a wind turbine and an electric generator [1-8]. Thus, electrical energy generated is closely related to the wind speed and to the wind turbine characteristics. Among the wind turbines, the Permanent Magnet Synchronous Generator (PMSG) is widely used for small WECS because of its reliability, high efficiency and low cost [9, 10]. So, the use of PMSG in electrical machinery system has several advantages as no electrical energy absorbed by the field excitation system, better dynamic response, Smaller copper losses and smaller acoustic noise. That being said, we must find the best approach to optimize the output electrical power of this wind turbine. In literature, there are many methods for extracting the maximum of this electrical power [11-13]. In [14], some available MPPT algorithms, for extracting maximum power, are reviewed and classified according to the power measurement. So, a comparison of the different MPPT algorithms is highlighted in the terms of complexity, wind speed requirement, speed responses, etc. and also the ability to acquire the maximum energy output. In this way, this work aims at establishing a suitable mathematical model to a two-bladed PMSG [5] [8]. The wind turbine which has been used in this paper is installed at “ENSET- Mohammedia”, Morocco, at 33˚41’23” N, 7˚23’23” W. The wind turbine is characterized by a 3 Kw rated power, two blades, 4.6m in diameter, operating at variable speed. The turbine is located at 21 m above the ground on a tubing tower.

Because of the intermittent solar wind speed characteristics, storage batteries are used to fill the deficit power when the generated power is not enough for the load. There are also used to store the excess power or some portion of power from the WECS. Note that the recovered energy is used locally for the lighting, pumping and heating [5].

The extraction of the maximum electrical power of wind turbines is carried out by several methods, which act directly or indirectly on the parameters of the turbine. In this case, the blades are fixed around their longitudinal axis (constant pitch angle). The WECS is controlled electrically by acting on the rotor's rotation speed of the generator; the literature intends several algorithms that cannot be enumerated in few lines; nevertheless, the MPPT techniques are split into two broad categories:

- Techniques that use known turbine characteristics
- Techniques without knowing turbine characteristics.

However, the optimum rotor speed is calculated instantaneously using the algorithm as a function of the wind speed variation.

In this paper, an approach to extract the maximum power from a given wind speed has been performed for a WECS having battery bank as storage element. This approach uses an identification method to extract the desired mathematical function.

The paper is organized as follows: the system under study (i.e. the permanent magnet synchronous aero-generator) is modeled and given a st ate space representation in Section 2; the Maximum Power Point Tracking method is developed and presented in Section 3; the controller design is proposed in Section 4; And the control law performances are illustrated through numerical simulations in section 5.

2 System modeling

2.1 System structure:

The controlled system is illustrated by Fig. 1 and Fig. 2. It includes a wind turbine - synchronous generator combination and an AC/DC boost rectifier on one hand, and a single phase DC/AC inverter and DC/DC converter on the other hand. The captured energy is used to power a load and a local storage system. The obtained energy is intended for lighting and possibly heating. The wind platform and its characteristics are widely described in [15].

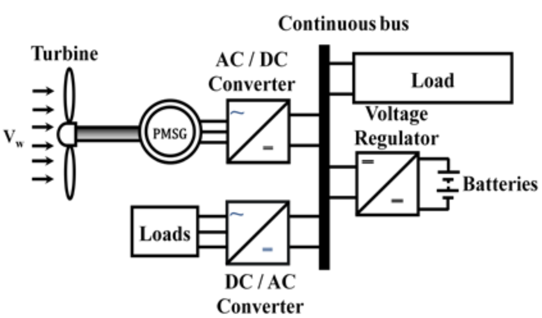

Fig.1, Wind Energy Conversion System (PMSG-WECS)

2.2 Aerodynamics equations:

First, let us clarify notations related to turbine power characteristic of Fig.. 1. The wind power acting on the swept area of blade A is a function of the air density ρ (kg/m3) and the wind velocity V_w (m/s). The transmitted power P(W) is generally deduced from the wind power, using the power coefficient Cp (λ, β), as follows [17][19]:

$$P = \frac{1}{2} C_p(\lambda, \beta).\rho.A.V_w^3 \qquad (1)$$

The torque (T_t), applied to the PMSG rotor,is expressed by the following equation:

$$T_t = \frac{1}{2} \frac{C_p(\lambda, \beta).\rho.A.V_w^3}{\omega_t} \qquad (2)$$

Where, ω_t (rd/s) is the angular velocity of the turbine.

The power coefficient $C_p(\lambda, \beta)$ is a nonlinear function of the tip speed-ratio $\lambda_i = R.\omega_t/V_w$ (with R the turbine radius) which depends on the wind velocity V_w and the rotation speed of the generator rotor ω_t (rd/s); and the pitch angle β. The power coefficient $C_p(\lambda, \beta)$ can be expressed as: [18][23]

$$C_p(\lambda, \beta) = 0.5176 * \left(\frac{116}{\lambda_i} - 0.4 * \beta - 5\right) * e^{\frac{-21}{\lambda_i}} + 0.0068 * \lambda \quad (3)$$

With: $\lambda_i = \frac{1}{\lambda - 0.08 * V} - \frac{0.035}{\beta^3 + 1}$

Fig. 2 represents the nonlinear power coefficient $tC_p(\lambda, \beta)$, described by equation (3), according to the tip speed ratio λ for various values of pitch angle β.

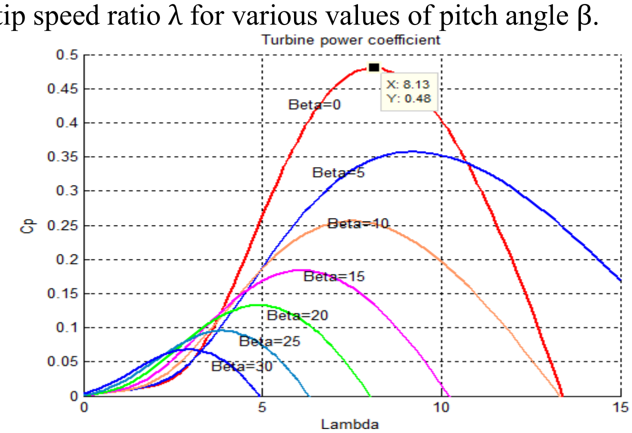

Fig.2, Power coefficient Cp (λ, β)

2.3 Wind turbine and generator rotor model:

Owing to the mechanical equation, it follows applying the fundamental principle of dynamics to the rotor motion.

$$J_t \frac{d\omega_t}{dt} = T_t - f_t.\omega_t - T_{em} \qquad (4)$$

Where T_{em} denotes the electromagnetic torque (developed by PMSG), f_t is the viscous friction coefficient, and J_t the global rotor load inertia.
The electromagnetic torque developed by the machine depends on the inductance and the current vector and can be given the following general expression [13][14][15]:

$$T_{em} = \frac{3}{2}.p.\left(\left(L_d - L_q\right).i_d.i_q - \emptyset_m.i_q\right) \quad (5)$$

where L_d and L_q denote the direct and quadratic axis inductances respectively; i_d and i_q are the direct and quadratic current components in the Park frame respectively; $\emptyset_m$ is the permanent magnet flux norm; and p is the number of poles pairs.

2.4 PMS Generator modeling:

Such a modeling is generally performed in the d–q rotating reference frame (with a rotor position) because the resulting components i_d and i_q turn out to be DC currents. It is shown in many places (e.g. [10-14][24][26-27]) that the synchronous machine model, expressed in the d–q coordinates, can be given the following state space form:

$$\begin{cases} \frac{di_d}{dt} = -\frac{R_s}{L}.i_d + p.i_q.\omega_t - \frac{1}{L}.v_d \\ \frac{di_q}{dt} = -\frac{R_s}{L}.i_q - p.i_d.\omega_t + p\frac{\emptyset_m}{L}.\omega_t - \frac{1}{L}.v_q \end{cases} \quad (6)$$

Where R_s and $L = L_d = L_q$ are the stator resistor and inductance; v_d, v_q (and i_d, i_q) denote the stator voltage (and current, respectively) in d-q coordinate (Park's transformation of the triphase stator voltages).
The state space equations obtained ((4) and (6)) up to now are put together to get a state-space model of the whole system including the turbine combined with the permanent magnet synchronous generator. The state variables i_d, i_q and ω_t. For convenience, the whole model is rewritten here for future reference:

$$\begin{cases} \frac{di_d}{dt} = -\frac{R_s}{L}.i_d + p.i_q.\omega_t - \frac{1}{L}.v_d \\ \frac{di_q}{dt} = -\frac{R_s}{L}.i_q - p.i_d.\omega_t + p\frac{\emptyset_m}{L}.\omega_t - \frac{1}{L}.v_q \\ \frac{d\omega_t}{dt} = \frac{T_t}{J_t} - \frac{f_t}{J_t}\omega_t - \frac{3}{2}p\frac{\emptyset_m}{J_t}i_q \end{cases} \quad (7)$$

The expressions of active and reactive power in the PARK reference [17][21] are given by the following equation.

$$\begin{cases} P_a = \frac{3}{2}(V_q I_q + V_d V_q) \\ P_r = \frac{3}{2}(V_q I_d - V_d I_q) \end{cases} \quad (8)$$

3 Maximum Power Point Tracking Method:

3.1 Considered wind speeds history

In this study we are limited to the case of the Mohammedia city in Morocco. Measures have been taken, every 15 m in, during January, February and March 2015. The distribution of maximum winds speed per day is shown in Fig. 3 and will be used to establish an adequate and appropriate control for our case. The wind speed at the site did not exceed 14m/s and is measured twice during the three months.

The wind speed is measured at a height of 8m. The blades have a height of 21m, a correction coefficient is therefore indispensable [21].

$$\frac{V_w(z)}{V_w(z_0)} = \left(\frac{z}{z_0}\right)^{\alpha} \quad (9)$$

Where $V_w(z_0)$ is the wind speed measured at anemometer height z_0, $V_w(z)$ is the wind speed at the height z, α is the power law exponent depending on the surface roughness. It is empirically obtained.

In our case, $z = 21m$, $z_0 = 8m$ and $\alpha = 0.3$.

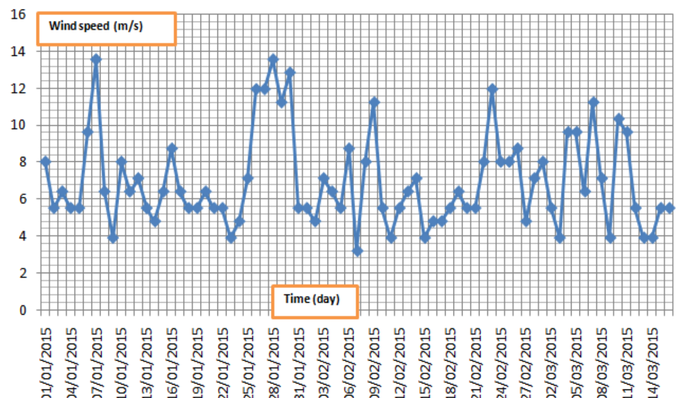

Fig.3, wind speed variation in the considered site

3.2 Maximum power point characteristic

Our objective is to control the wind turbine WHISPER 175, which have a rated power of 3kW, to have optimum output electric power.

To ensure maximum generator power extraction, the rotor speed must track the optimum speed reference. For this, a speed-reference optimizer is developed for MPPT achievement. First, a characteristic (optimal power-wind speed) must be identified. Consequently, a variable load is connected to the aero-generator system that operates in open loop Fig. 4.

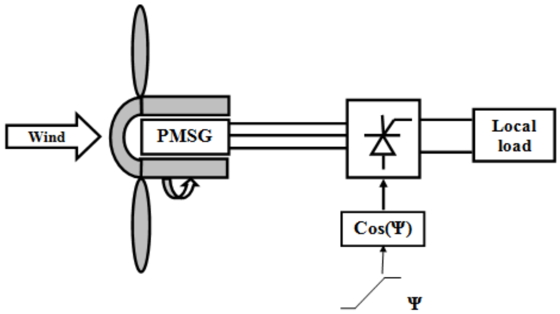

Fig.4, Experimental setup of the conversion system

The global system described by Fig. 4, including the wind energy conversion (WEC) system and the resistive load, is implemented using Matlab/Simulink resources (V. R2015a), operating under Windows 10. Table 1 provides the maximum power for a given wind speed and the resistor load values are also presented.

TABLE 1, OBTAINED RESULTS

Pmax(watt)	Eff_R(Ohm)	Vw(m/s)
0	0	2 ,500
138,581	2,753	3,500
288,509	2,027	4,500
508,808	1,581	5,500
644,934	1,419	6,000
959,869	1,172	7,000
1306,122	0,995	8,000
1643,724	0,886	9,000
1966,111	0,910	10,000
2299,293	0,959	11,000
2642,395	1,010	12,000
3097,925	1,083	13,300
3345,761	1,125	14,000
4057,934	1,251	16,000
4773,274	1,383	18,000
5474,537	1,532	20,000
6136,588	1,705	22,000
6774,824	1,889	24,000

This result may be presented differently as in the following Fig. 5.

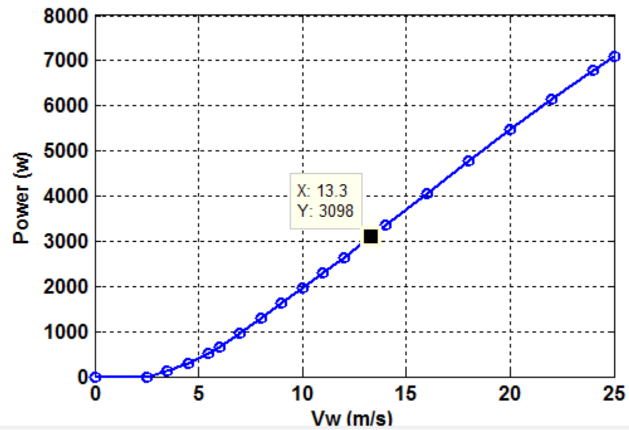

Fig.5, The maximum turbine power characteristics (pitch angle beta=0 degree).

3.3 The speed-reference optimizer

A number of such couples (P_{opt}, V_w) have been collected from Table 1 and interpolated to get a polynomial function $P^* = F(V_w)$. To this end, firstly, let us briefly recall the identification process adopted in this work.

From the points (y_i, x_i) i=1...N, let the obtained polynomial be denoted:

$$F(x, a) = a_0 + a_1\varphi_1(x) + a_2\varphi_2(x) \dots + a_n\varphi_n(x) \quad (10)$$

The values of the degree n and coefficients a_i $(i = 1,2, \dots, n)$ corresponding to the equation (10) should be determined. Typically the number of parameters, n, is much smaller than the number of data points, N. The objective is to find values for the parameters a_i which minimizes the sum of squares of the r_i.

$$\sum_{i=1}^{N} r_i^2 = \sum_{i=1}^{N} (y_i - F(x, a))^2 \quad (11)$$

Where, the error r_i denote the distance between the data point (y_i, x_i) and the graph of $F(x, a)$.

Least squares problems are classified as linear or nonlinear, depending on whether or not the function $F(x, a)$ depends linearly or nonlinearly on the parameters a_i $(i = 1,2, \dots, n)$.

By observing the curve of the Fig. 5, it is clear that the choice of the polynomial linear model is justified. Saying that the function $F(x, a)$depends linearly on the parameters a_i means that it can be written as a linear combination of some basis functions $x, x^1, \dots, x^n$:

$$F(x, a) = a_0 + a_1 x + \dots + a_n x^n \quad (12)$$

Note that the sum (11) is over the data points, and once the data and basic functions are given, the sum of squares $E = \sum_{i=1}^{N} r_i^2$ is a function of the parameters

a_i $(i = 1,2,\ldots,n)$ only. The individual term r_i can be written:

$$r_i = y_i - (a_0 + a_1 x + \cdots + a_n x^n) \quad (13)$$

Like interpolation our aim is to find the coefficientsa_i $(i = 1,2,\ldots,n)$, this time to minimize the sum of squares of the r_i. Note that when we have the same number of parameters a_i as data points, the problem reduces to an interpolation problem. In this case we could find values for the parameters so that all the r_i are zero. And, when the degree n of the polynomial is increased, the residuals r_i are increasingly smaller. When $n > N$ then the system of equations will not, in general, have a solution.

However, the objective is to try to find a vector $[a_0 \ldots a_n]$ for which the residual $E = \sum_{i=1}^{N} r_i^2$ is as small as possible. Then, to find the coefficients a_i, one solves the equation:

$$\left.\frac{\partial E}{\partial a_q}\right|_{q=0,\ldots,n} = 2 * \sum_{i=1}^{N}\left\{-\left(y_i - \sum_{p=0}^{n} a_p * x_i^p\right) * x_i^q\right\} = 0 \quad (15)$$

According to equation (15), it's clear that:

$$\sum_{i=1}^{N}\left\{\left(y_i - \sum_{p=0}^{n} a_p * x_i^p\right) * x_i^q\right\} = 0 \quad (16)$$

$$\left(\sum_{i=1}^{N} y_i * x_i^q\right) = \sum_{p=0}^{n}\left\{a_p * \left(\sum_{i=1}^{N} x_i^{p+q}\right)\right\} \quad (17$$

The last equation can be rewritten as:

$$B = M.A \quad (18)$$

Where,

$$A = [a_0 \quad \ldots \quad a_n]^T$$

$$B = \begin{Bmatrix} b_0 \\ \vdots \\ b_n \end{Bmatrix} \text{ with } b_j = \sum_{i=1}^{N} y_i x_i^j$$

$$M = \begin{Bmatrix} m_{00} & m_{01} & \cdots & m_{0n} \\ m_{10} & m_{11} & \cdots & m_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n0} & m_{n1} & \cdots & m_{nn} \end{Bmatrix}$$

With, $m_{pq} = m_{pq} = \sum_{i=1}^{N} x_i^{p+q}$

Then we want to find the coefficients a_i (vector A) which minimize the equation:

$$E = \sum_{i=1}^{N} r_i^2$$

The solution is:

$$A = M^{-1}.B \quad (19)$$

The calculation is very heavy by hand; using MATLAB or SCILAB we easily calculate the coefficients a_i.

The residual of the regression is given by (20):

$$R = \sqrt{\sum_{i=1}^{N} r_i^2} \quad (20)$$

Applying this result to our case, the optimal power reference has the following form:

$$P^* = a_0 + a_1 * V_w + a_2 * V_w^2 + \cdots + a_n * V_w^n \quad (21)$$

In order to optimize the equations, it is important to divide the wind distribution into several areas.

The proposed zones division takes into consideration the distribution trend of the cloud points and the studied system limits. Following these criteria, five areas have been identified:

- Area1: very low wind speed less than 2.5m/s,
- Area2: Wind speed between 2.5m/s and 8m/s
- Area3: Wind speed between 8m/s and 13.3 m/s.
- Area4:Wind speed between 13.3m/s and 20.3m/s
- Area5: Wind speed more than 20.3m/s

Area 1:$V_w \leq 2.5\ m/s$

In this area, the power remains at zero ($P_1^* = 0$). The aero-turbine starts from a wind speed of $2.5 m/s$.

Area 2 *:* $2.5\ m/s \leq V_w \leq 8\ m/s$

The identification algorithm established the most optimal order 3 polynomial. However, great precision is not required, because it is an intermediate zone without risk. Therefore, a quadratic model is sufficient but the continuity at the left and right of the limit points (2.5, 0) and (8, 1310) is not guaranteed. A polynomial of order 3 meets our requirements.

The optimal power reference can be expressed as:

$$P_2^* = 0.48601\, V_w^3 + 19.046\, V_w^2 - 6.4437\, V_w - 105.85 \quad (22)$$

The curve Fig. 6 shows the plot of the measured data which corresponds with the polynomial model found.

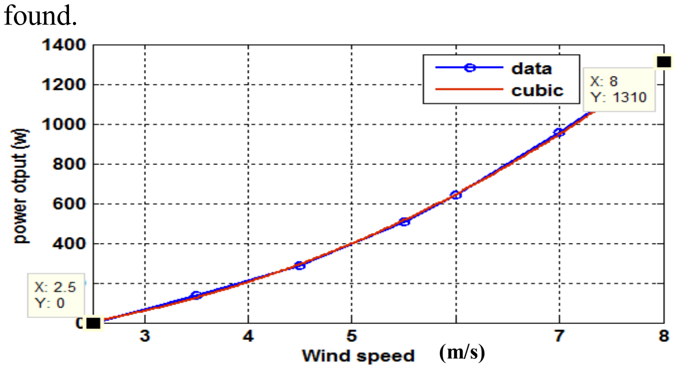

Fig.6, Zone 2 : $2.5\ m/s \leq V_w \leq 8\ m/s$

Fig.6 shows the polynomial approximation (22) of the characteristic of Fig. 5, where the chosen order is 3. The corresponding polynomial coefficients a_i $(i = 0,1,2,3)$, have the numerical values: $a_0 = -105.85$;

$a_1 = -6.4437$; $a_2 = 19.046$; $a_3 = 0.48601$. It is seen that wind speed varies between 2.5m/s and 8m/s.

Area 3: $8\,m/s \le V_w \le 13.3\,m/s$

Concerning the speeds from 8m/s to 13.3m/s, the power can be modeled by a linear polynomial. The continuity at (8, 1310) and (13.3, 3098) limits is not ensured. So we opt for a following quadratic equation:

$$P_3^* = 2.6995 * V_w^2 + 279.42 * V_w - 1097.6 \qquad (23)$$

It is seen, from Fig. 7, that the polynomial approximation (23) remains (almost) all wind speed ($8\,m/s \le V_w \le 13.3\,m/s$) equals to optimal power of the wind energy extraction system. The numerical values of polynomial coefficients a_i ($i = 0,1,2$) are: $a_0 = -1097.6$; $a_1 = 279.42$; $a_2 = 2.6995$.

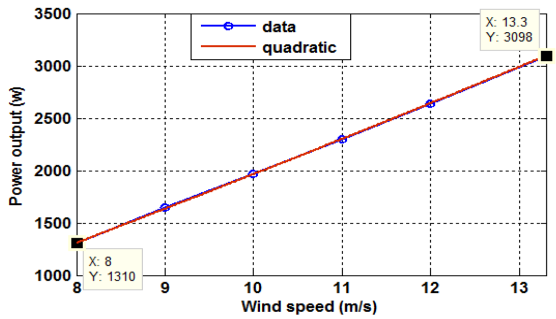

Fig.7, Zone 3 : $8m/s \le V_w \le 13.3m/s$

Area 4: $13.3\,m/s \le V_w \le 20.3\,m/s$

In this part, the power is saturated at the maximum power supported by the generator (23):

$$P_4^* = 3098W \qquad (24)$$

Area 5 : $V_w \ge 20.3\,m/s$

For a speed greater than 20.3 m/s, we have two possible solutions. The first and the adopted one, WEC system is automatically broken and the reference power is $P_5^* = 0$. The second case, the system is controlled and stabilized at its maximum extracted power which is $P_5^* = P_4^* = 3098$ W.

The curve Fig. 8 shows the right choice of the adopted technique to extract a mathematical model which is very close to the points that are representing the maximum power. Taking into account, the limits of the production system, the power is saturated at 3098Watt.

The MPPT optimizer generates the optimal power reference shown in Fig. 8 (red curve) with respect the wind speed. Referring to the turbine power characteristics Fig. 9 (blue curve), and if the power is regulated at this generated value, the extracted active power is optimal for each involved wind speed value.

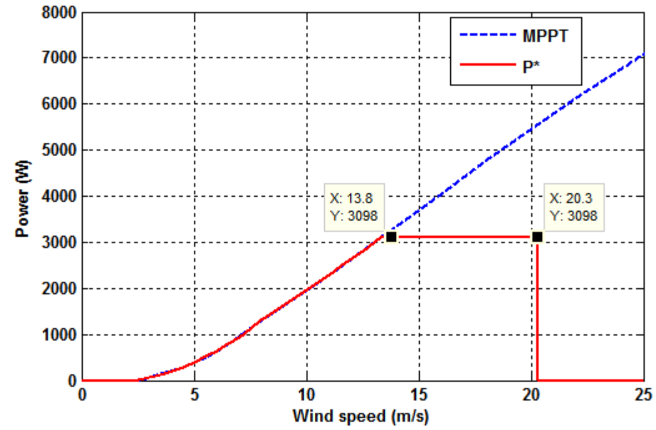

Fig.8, Static WEC system caracteristic (dotted) $P_{max} = f(V_w)$ and power generated by optimiser (line) $P^* = F(V_w)$

3.4 Generation algorithm of power reference:

The algorithm, presented in Fig. 9, retrieves wind speed; a test is performed according to one of the five areas. Then, the corresponding reference power is calculated, the system acquires a new value of the wind speed according to a sampling period and the new set point is calculated.

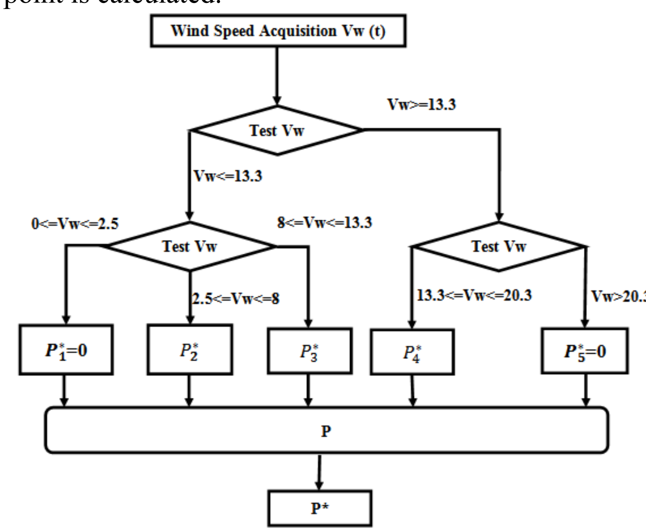

Fig.9, Algorithm for calculating the reference power

4 Power Control Strategy

Our goal is to control the system to extract the desired power based on the power reference optimizer curve Fig. 8 (red curve). As mentioned above, the set is divided into five zones. The synchronous aero-generator model (6) is nonlinear and strongly coupled. The regulator design is based on this Eq. (6) where the input signals v_d and v_q stand as the actual inputs, in order to guarantee active and reactive powers references tracking. To achieve these objectives, a state feedback controller will be designed. It includes speed, active and reactive powers loops.

To ensure decoupling and address the nonlinearities, define two new input variables V_d^* and V_q^* [21][23]:

$$\begin{cases} V_d^* = -V_d + L.i_q.p.\omega_{gen} \\ V_q^* = -V_q - L.i_d.p.\omega_{gen} + \emptyset_m.p.\omega_{gen} \end{cases} \quad (25)$$

By substituting (25) in the WECS model (6), the linearized model can be rewritten as:

$$\begin{cases} \frac{di_d}{dt} = -\frac{R_s}{L}.i_d + \frac{V_d^*}{L} \\ \frac{di_q}{dt} = -\frac{R_s}{L}.i_q + \frac{V_q^*}{L} \end{cases} \quad (26)$$

As the latter system model can be processed as two subsystems. Each one is a first order and it can be (globally asymptotically) stabilized using a simple known integral proportional control law. The proposed transfer function of the all correctors is:

$$C(s) = K_p.\frac{1 + T_i.s}{T_i.s} \quad (27)$$

With K_p and T_i are there al positive design parameters.

We used the same type of controller for the rotor speed, active and reactive power.

The WHISPER 175 is composed a permanent magnet synchronous generator. Regulating the current i_d to a reference value i_d^*, preferably equal to zero in order to guarantee the absence of d-axis stator current, implying thus no reluctance torque. Doing so, only the q-axis reactance is involved in producing the final voltage, i.e., there is no direct magnetization or demagnetization of d-axis, only the field winding contributes to producing the flux along this direction. Accordantly to dynamics of the rotor speed ω_t(equation 7), one can see easily that controlling the speed can made by control of the $i_q$current component. The machine speed ω_t must track, as closely as possible, a given reference signal ω_t^*. This reference has been obtained from power regulator. The power reference is generated by the power optimizer used in order to achieve optimal speed ratio working conditions of the wind turbine to capture the maximum energy from the wind.

The experimental setup shown in Fig. 10 summarizes the implementation command of this strategy [22][25].

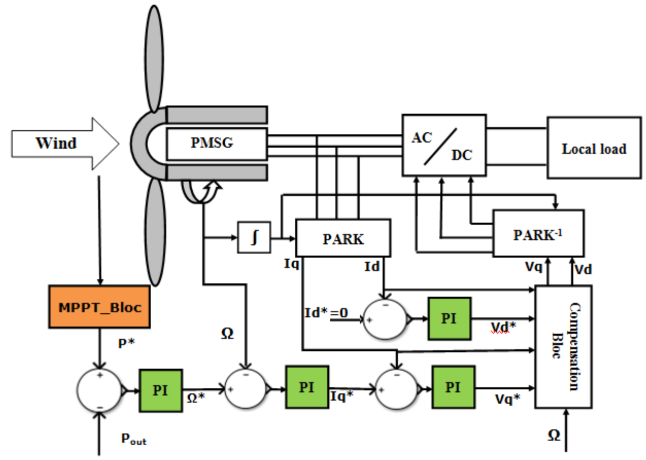

Fig.10, Control system including AC/DC/AC converters and a PMSG.

4.1 Simulation Results

The experimental setup is described by Fig. 10 and simulated, within the Matlab/Simulink environment, using the electro-mechanical characteristics of Table 2.

Table 2, System characteristics.

WHISPER 175		
Pn	Rated power of the PMSG.	3000 W
Rt	Radius of the turbine.	0.27Ω
L	Stator Inductance.	2.3 10^{-3} H
Rs	Stator resistance.	2.3 10^{-3} H
$\emptyset_m$	Magnetic flux	0.14 Wb
p	Number of pole pairs.	8
λ	Optimal tip speed ratio	λ_{opt}=8.3
Cp	Maximal power coefficient	$C_{pmax=}$ 0.48
J	Total inertia moment.	0.1Kg.m^2
f	Friction Coefficient.	1.79 10^{-3}
R	Radius of the turbine.	2.25m
W	weight	30Kg
H	height	21m
ρ	Density of air	1.22Kg/m3

The simulations are presented below confirm the validity of the method proposed in this work:

- The response to a wind speed scale Fig. 11 show:
  - the dynamic response;
  - the stationary regime;
  - the regulator efficiency;

The wind speed chosen in this simulation is 10m/s.

- The chosen wind speed is taken from real measurements and corresponds to an unfavorable situation. This speed is taken from the database of the laboratory which corresponds to the profile Fig. 12. The real sampling frequency of the wind speed is 15 minutes. The sampling period in the simulation is 5s in order to reduce the simulation time.
- Rotor speed properly follows the reference angular velocity imposed by the desired power. A PI controller is dimensioned to achieve these results Fig. 13.
- All the energy produced by the wind turbine is consumed or stored; consequently, the production depends on the wind speed. The output electric power of the system follows the imposed order by the MPPT algorithm, (Fig. 14).
- The curve shape of the power coefficient Fig. 15 shows the compliance of the applied control. The machine yield is near its maximum. The adopted approach is effective and deserves a judicious monitoring.
- The curve of the power coefficient Cp shows that the generator PMSG provides maximum power. Cp is very close to its optimal value which is 0.48.

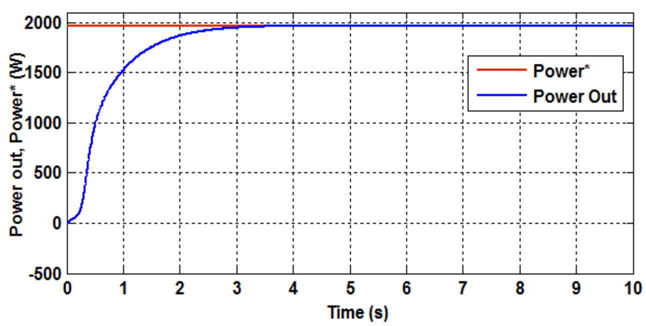

Fig.11, Power Output and Power ref

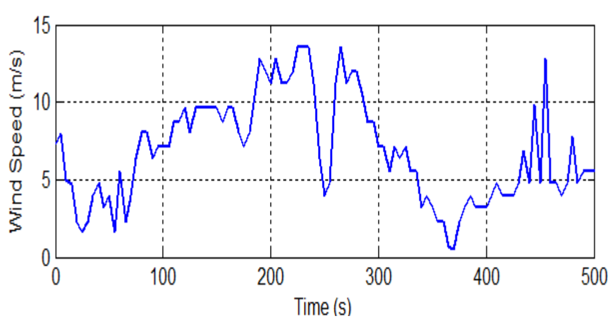

Fig.12, Wind speed profile

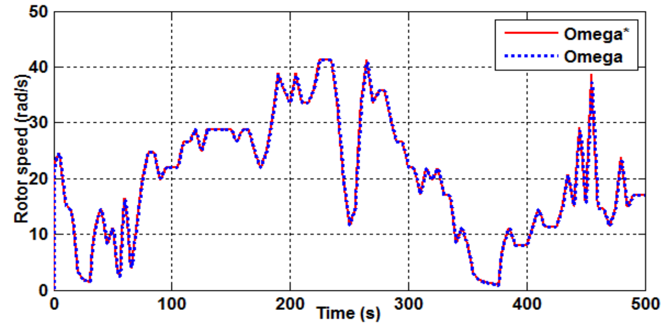

Fig.13, Rotor Speed

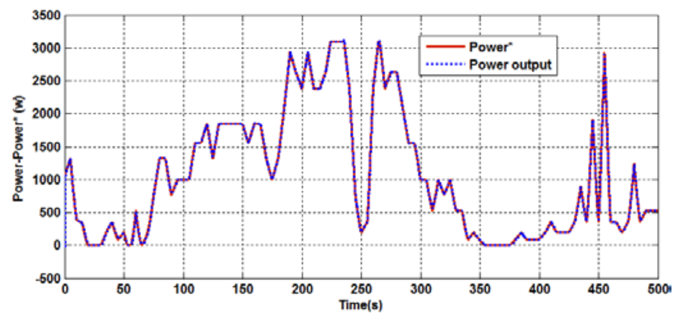

Fig.14, Power Output and Power ref

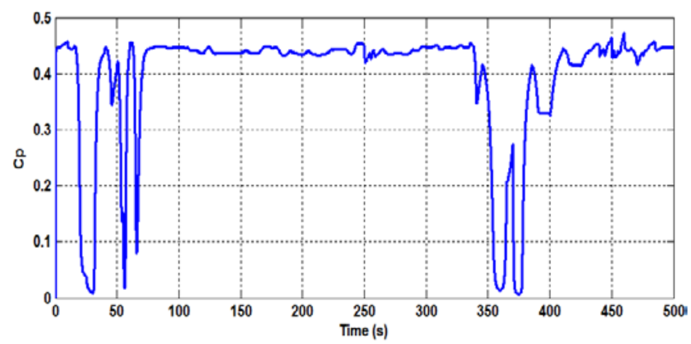

Fig.15, Power coefficient

5 Conclusion and Perspectives

We have addressed the problem of control of the wind energy conversion system. Maximum wind energy extraction is achieved by running the wind turbine generator invariable-speed mode. The controlled system is an association including wind turbine, permanent magnet synchronous aero-generator. We highlight an optimal identification methodology of the system according to operation zones. The controller has been designed to satisfactory power reference tracking for extracting maximum power; tight regulation of the reactive power by controlling the stator d-axis current; these results have been confirmed by a simulation study.

The study was very satisfying; the results found (e.g. 9m/s, ~1700W) are very close to those provided by the original equipment supplier (9m/s, 2000W) of the air turbine. The difference noted is certainly due to the aging of the machine. Thus, the reliability of the conversion system must be timely follow-up. The technical data are actual measurements. The wear of the components is the main cause of the power diminution.

Although the obtained results are interesting and encouraging, some aspects may be developed in future works. So, as perspective, we intend to investigate the possibility to inject the extra power in the public networks to let the system operate in the established optimal conditions.

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