VARIATION AND THE INFLUENCE OF THE PITCH ANGLE OF THE ROTATIONAL SPEED OF THE WIND TURBINE

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Abstract: ***The considerable growth of energy consumption in all its forms with the associated*** **pollution** ***effects is caused by the burning of fossil fuels. They are at the heart of the discussions on the future of the planet. Renewable energy, like wind power, has increased growth, but its mechanical power is highly dependent on wind speed and wind turbine performance characteristics. The variation of the wind speed has a significant influence on the wind flux that acts on the blades and the mechanical power generated. In this article we study the influence of the variation in the pitch angle (β) on the power generated by the induction generator. The simulation results were analyzed proving effective control and flexibility of the system (wind-network) simulated by Matlab based on the control and actual geographical information of the study area. This allowed us to control the speed of rotation of the wind turbine by the corrector PI within the turbine so that the system remains stable and gives good efficiency.***

Key words: *Wind turbine; Wind speed; Pitch angle; Modeling; Control MPPT; DFIG; Simulation ;PI corrector.*

1. Introduction

Wind energy is the most viable renewable energy today and has a strong development in the world, despite the cost of returns which is higher than traditional energy sources. Currently, several solutions are possible in order to reduce this cost, such as the use of advanced control laws, which allow to significantly improving the performance of a wind turbine at [1] variable speed. Control algorithms implemented are aimed to optimize the energy conversion of the system, and reduce mechanical loads experienced by the mechanical structure of the wind turbine in order to lengthen the life of the system [2]. The operation of a wind turbine ' variable speed, breaks down into several areas of operation, depending on the speed of the wind acting on the rotor: for low wind speeds, the main objective is to maximize the energy collected by the turbine, while for high wind speeds [3], the electric power must be limited and regulated to the power rating of the generator [4]. Wind power collected by the turbine depends on how strongly non-linear external input, the wind speed, the speed of rotation of the impeller and the angle of inclination of the blades (pitch angle β) "Fig. 1 ". Therefore, the controller must be adapted by acting on the electromagnetic torque generator and on the pitch actuator, the speed of rotation of the turbine and the angle of the blades to wind acting on the rotor speed. This stochastic quantity very quickly in time-variant is unfortunately not measurable precisely, since it is energy average contained in the flow of air through the rotor, and not the speed of the wind at a point. The best ways to know this quantity is then estimate it ' from the behavior of the turbine.

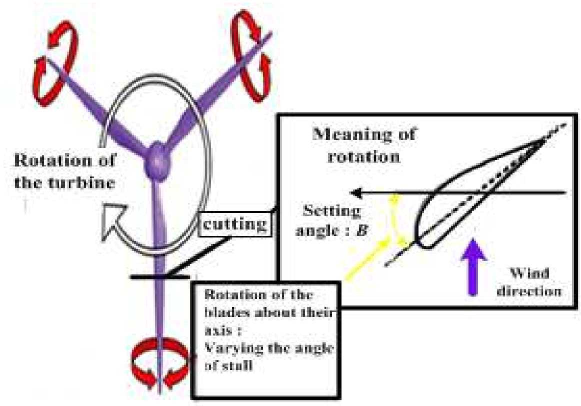

Fig.1. Change the pitch angle of a blade.

A simulation program of the control system was developed under Matlab / simulink7.8 where the results obtained by simulation are presented in this article whose organization is as follows: the introduction is described in section 1, the structure of the system is presented in section 2, the presentation and modeling of the system of the student is presented in section 3, The command is discussed in section 4, the results of the simulation are detailed in section 5, followed by a conclusion.

2. Structure of system

The DFIG wind generation system is shown in Fig. 2, where the wind turbine is connected to the DFIG directly [5].The electrical power generated by the DFIG is transmitted to a power grid via a variable-frequency converter, which consists of a machine-side converter and a grid-side converter connected back to-back via a DC link[7].

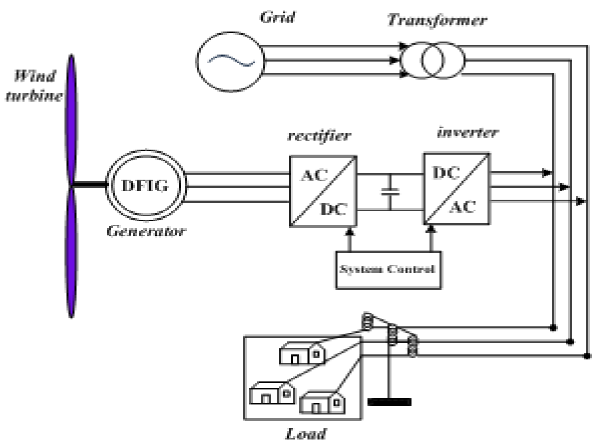

Fig.2. Structure of renewable generation system

We have made a modeling of the different components of the studied system

3. Modeling of the studied system

The wind speed varies according to geographical areas and seasons. In temperate regions, the wind speed is higher in winter than in summer. Figure 3 shows the annual distribution of wind ADRAR region during 2004/2009.

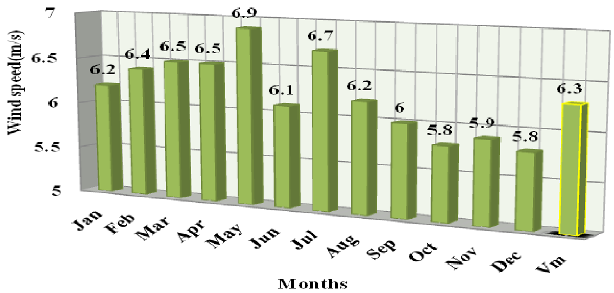

Fig.3. Monthly averages speed of wind of Adrar.[8]

a. Wind turbine model and field oriented control of DFIG

In our article we consider a three-bladed wind turbine associated with a turbine driving an asynchronous generator doubly fed through a shaft and a speed multiplier (see Figure 4).

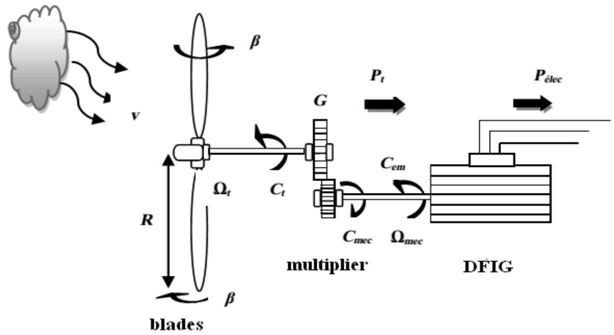

Fig.4. Diagram of the system to be modelled.

Model Wind: The wind speed is usually represented by a scalar function that evolves over time.

$$V_v = f(t) \tag{1}$$

The wind profile can be modeled by a sum of several harmonics, in accordance with [9-11]:

$$V_v = V_{moy} + \sum_{i=1}^{n} a_n.\sin(b_n.W_v.t) \tag{2}$$

With:

V_{moy}: wind speed [m/s]

t : time [s]

Figure.5 shows the wind the block diagram which is used in the simulation according to the equation (2).

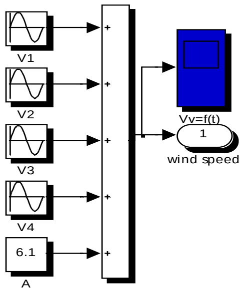

Fig.5. Wind block diagram in Matlab / *Simulink*

Wind energy systems convert the kinetic energy of the wind into the electrical energy. The kinetic energy produced by a moving object is expressed as [12]:

$$E_{kiv} = \frac{1}{2}.m.V^2 \quad (3)$$

In this case, m is the mass of air and V is the wind velocity. The mass m could be derived from[6]:

$$M = \rho(Ad) \quad (4)$$

Where

ρ Air density

A Swept area of the rotor blade

d Distance travelled by the wind.

The mechanical power of the wind turbine (Pw) by defined is the kinetic energy over the time (t), thus Pw is expressed as

$$P_w = \frac{E_{kin}}{t} = \frac{\frac{1}{2}\rho A d v^2}{t} = \frac{1}{2}\rho.A.V^3 \quad (5)$$

The power expressed by Eq. (5) is the ideal power captured by the wind turbine. The actual power of the wind turbine depends on the efficiency of the turbine represented by $C_p(\lambda,\beta)$ which is the function of the tip speed ratio(λ) and pitch angle (β) [12]**.** The power conversion coefficient is a function of the tip-speed ratio (TSR) and the blade pitch angle β (deg.), in which the TSR is defined as[13]:

$$\lambda = \frac{\omega \ . R}{v} \quad (6)$$

Where ω is the turbine angular speed and (R) is the radius of the turbine. Therefore, the actual power captured by the wind turbine is given by Eq. (7)

$$P = \frac{1}{2} Cp(\lambda, \beta)\rho A v^3 \quad (7)$$

Then, the torque of the wind turbine could be expressed as [6]:

$$T = \frac{1}{2} Ct(\lambda,\beta)\rho A R v^2 \quad (8)$$

Where $Ct(\lambda,\beta)=Cp(\lambda,\beta)/\lambda$ is the torque coefficient of the wind turbine.

The turbine power coefficient $Cp(\lambda,\beta)$ is a non linear function and expressed by a generic function

$$Cp(\lambda,\beta) = 0.5176\left(\frac{116}{\lambda i} - 0.4\beta - 5\right)\ell^{\frac{21}{\lambda.i}} + 0.0068\lambda i \quad (9)$$

With:

$$\frac{1}{\lambda i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (10)$$

Figure 5 shows the **Cp-λ** characteristics for the different values of β.

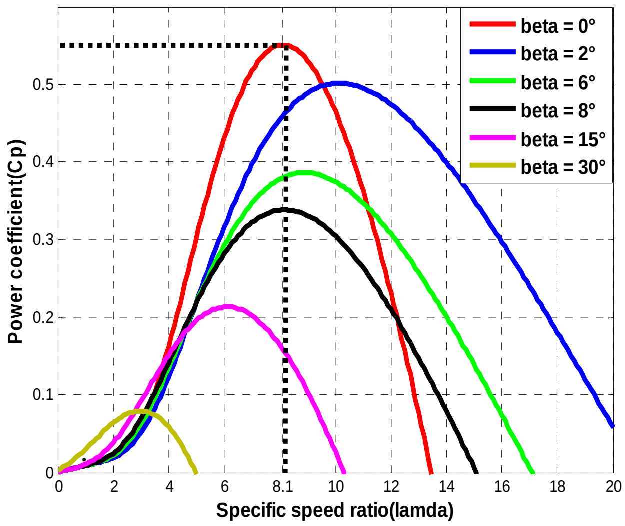

Fig.6. Power conversion coefficient versus tip speed ratio ($Cp - \lambda$) curve for different pitch angle (β°).

When the wind speed changes, the rotor speed and the power captured by the wind turbine will change.According to Eqs. (6), (7), (9), for a certain wind speed, the power will be varied with respect to the rotor speed (ω), and there is a point when the power is maximum, at the optimal rotor speed (ω_{opt}).

Figure 7 illustrates the curves of the wind turbine power versus the rotor speed (ω) for the different wind speeds. From the figure, it is clear that for the different power curves, the maximum powers are achieved at the different rotor speeds [12].

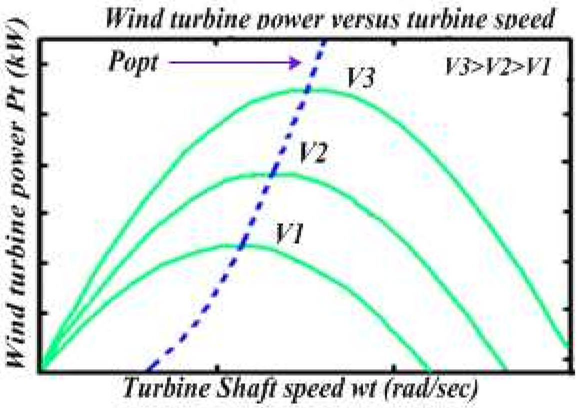

Fig.7. Wind turbine power curves [14].

Model multiplier : The multiplier adapts the (slow) speed of the turbine at the speed of the generator [15]. This multiplier is modeled by the equation:

$$C_{aer} = G * C_g \quad (11)$$

Tree model: The basic equation of dynamics applied to the shaft of the generator determines the evolution of the mechanical speed Ωm from the total mechanical torque C_m [16] :

$$C_m = J\frac{d\Omega_m}{dt} + f.\Omega_m + C_{em} \quad (12)$$

With :

C_m : Mechanical torque on the shaft of the DFIG.

Ω_m : Rotational speed of the DFIG

f : Coefficient due to viscous friction of DFIG

C_{em} : Electromagnetic torque of the DFIG

J : Total inertia that appears on the rotor of the generator:

$$J = \left(\frac{J_t}{G^2}\right) + J_g \quad (13)$$

With:

J_g : Inertia of the generator.

J_t : Inertia of the turbine.

It may be determined that the control target is the electromagnetic torque that should be applied to the machine for rotating the generator at its optimum speed.

Thus, the couple is determined by the controller which is used as a reference torque of the turbine model "Fig.7". Variation of the system of the orientation angle of the blades (variation of the angle of incidence) to change the ratio between the lift and drag. To extract the maximum power (and keep constant), adjusted the angle of the blades to the wind speed [17].

b. Modeling of the DFIG

Generating for the selected conversion of kinetic energy of the wind is a double-fed induction generator [18-19]. The DFIG voltage and flux equations, expressed in Park reference frame [20], are given by (14),(15):

$$\begin{aligned} u_{ds} &= R_s i_{ds} + \frac{d\psi_{ds}}{dt} - w_s \psi_{qs} \\ u_{qs} &= R_s i_{qs} + \frac{d\psi_{qs}}{dt} + w_s \psi_{ds} \\ u_{dr} &= R_r i_{dr} + \frac{d\psi_{dr}}{dt} - w_r \psi_{qr} \\ u_{qr} &= R_r i_{qr} + \frac{d\psi_{qr}}{dt} + w_r \psi_{dr} \end{aligned} \quad (14)$$

$$\begin{aligned} \psi_{ds} &= L_s.i_{ds} + M.i_{dr} \\ \psi_{qs} &= L_s.i_{qs} + M.i_{qr} \\ \psi_{dr} &= L_r.i_{dr} + M.i_{ds} \\ \psi_{qr} &= L_r.i_{qr} + M.i_{qs} \end{aligned} \quad (15)$$

Where R_s and R_r are the stator and rotor phase resistances respectively.ωs, ωr are respectively the synchronous angular speed of the generator and the angular speed of the rotor. L_s, L_r are respectively the stator and rotor inductances and M is the magnetizing inductance[21].

The electromagnetic torque is expressed by[22]

$$Cem = \frac{3}{2} P \frac{M}{L} (i_{qr}\psi_{ds} + i_{dr}\psi_{qs}) \quad (16)$$

The following figure shows the simulation of the dual Generator (DFIG) block power.

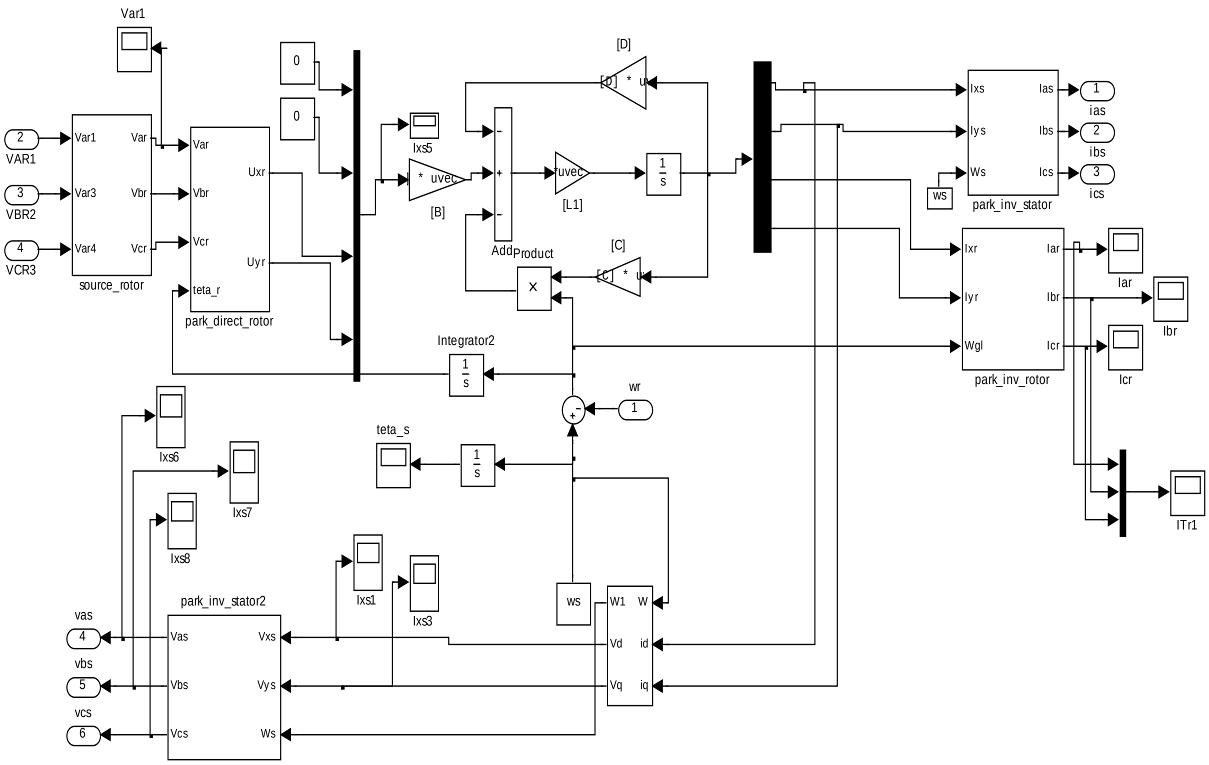

Fig. 8. DFIG standing

c. *Grid Model*

The input is a three phase voltage supply as follows:

$$Va = v_m \sin(wt)$$
$$Vb = v_m \sin(wt - \frac{2\pi}{3}) \qquad (17)$$
$$Vc = v_m \sin(wt + \frac{2\pi}{3})$$

Where Va,Vb and Vc are the output voltages of [24] the grid side converter.

4. MPPT Control and pitch control

In order to track an optimal rotor speed reference, the MPPT algorithm is proposed and based in PI controller .The objective of the MPPT operation mode is to maximize power extraction at low to medium wind speeds by following the maximum value of the wind power .To extract the maximum power, we need to fix the tip speed ratio at λ_{opt}, the maximum power coefficient C_{p-max} and β should be equal to 0° [25].

$$\lambda_{opt} = \frac{\omega_{opt}.R}{v} \qquad (18)$$

Where λ_{opt} and ω_{opt} are the tip speed ratio and the rotor speed optimal respectively.

The aerodynamic power optimal must be set to the following expression:

$$P_{opt} = 0.5C_{p-\max}\rho A\left(\frac{\omega_{opt}.R}{\lambda_{opt}}\right)^3 \qquad (19)$$

The above equations are used to establish the servo block diagram of the turbine speed (see Figure.9).

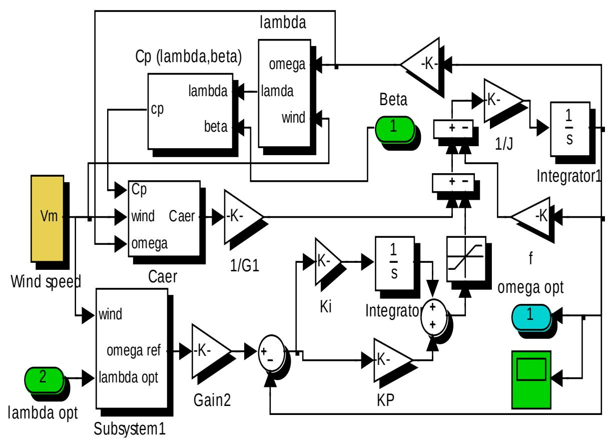

Fig.9. DFIG speed control loop [27].

To capture the maximum power of the incident wind must continuously adjust the rotational speed of the wind turbine. Optimal mechanical turbine speed is λ_{opt} and $\beta = 0°$. The speed of the DFIG is used as a reference for a controller Proportional-Integral type (PI phase lead), [17].

The wind turbine is sized to grow on the tree called a rated output power "P_n" which is obtained from a wind speed "V_n", as the rated speed. Knowing that when the wind speed exceeds the rated speed, the wind turbine [3] must change its settings to avoid mechanical destruction, so that its speed remains practically constant .Near the rated speed V_n which will help us to specify the necessary parameters:

- Startup speed V_d, from which the turbine starts supplying power.

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The speed V_n, V_m and Vd define four zones in the diagram as a function of the effective wind speed power " Fig.10":

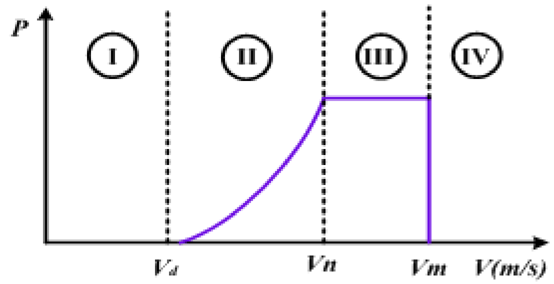

Fig.10. Diagram of the output power on the shaft depending on the wind speed.

- Zone I, where P = 0, the turbine is not operating.
- Zone II, where in the power supplied to the shaft depends on the wind speed V.
- Zone III, where the rotational speed is maintained constant and the power P supplied remains equal to P_n.
- Zone IV, in which the system dependability stops the transfer of energy [26].

a. *Model of the inverter PWM*

The voltage inverter is a static converter composed of switching cells typically transistors or GTO thyristors. It consists of three arms, two switches for each .To ensure continuity in each current switch is connected in anti-parallel with a freewheeling diode. (See Figure.11)

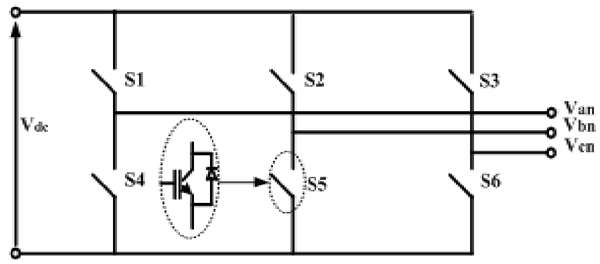

Fig. 11. Equivalent model of the two-level inverter.

The switches (S1, S4), (S2, S5), (S3, S6) are complementarily controlled to avoid short circuit the source [19], [18] (see Table.1).

Table1. Excitation of switches

S1	**S4**	**S2**	**S5**	**S3**	**S6**
S_a		**S_b**		**S_c**	
OFF	ON	OFF	ON	OFF	ON
ON	OFF	ON	OFF	ON	OFF

Where Vabc is the vector of voltages to the inverter output, they are given by:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} * \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \qquad (20)$$

Figure 12 represents the Simulink model of the sinus triangle PWM control and figure 22 shows the simulation of the inverter switches states S_a, S_b, S_c as well as the output voltages v_{an}, v_{bn}, v_{cn} , when the input are three-phase sinusoidal voltages with a frequency of 50 Hz and an amplitude of 230V.

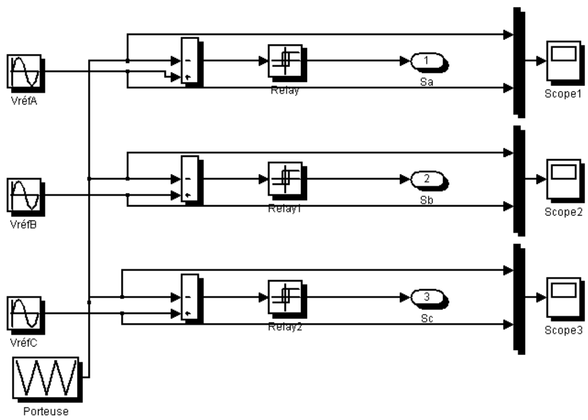

Fig. 12. Model under SIMULINK of the sinus-triangle PWM control

5. Simulation results and discussion

To simulate the System (wind / network), we made the simulation scheme of Figure 2 in the Matlab-*Simulink* software [23].

When simulated the case of a double-fed asynchronous machine this generator is driven by a wind turbine with a mean wind speed of around (6.1 m / s). The simulation results are shown in the following figures:

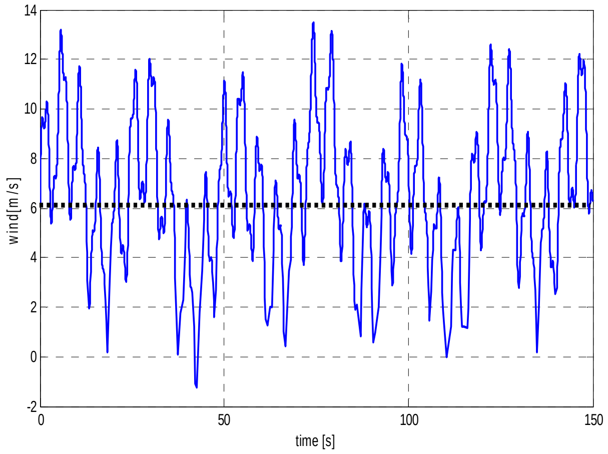

Fig.13. Speed of the wind applied (m/s)

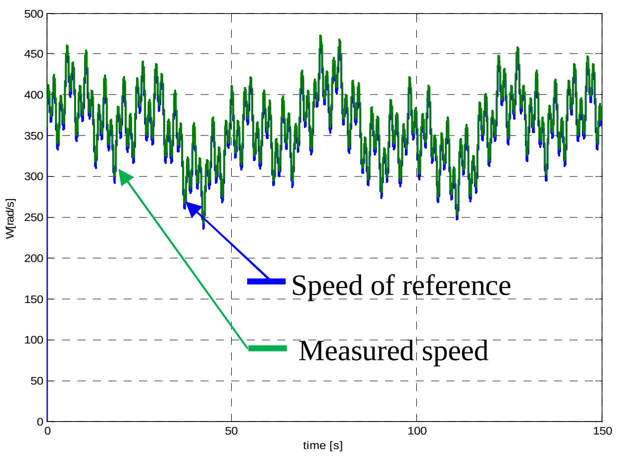

Fig. 14. Rotation and reference speed (rad/s).

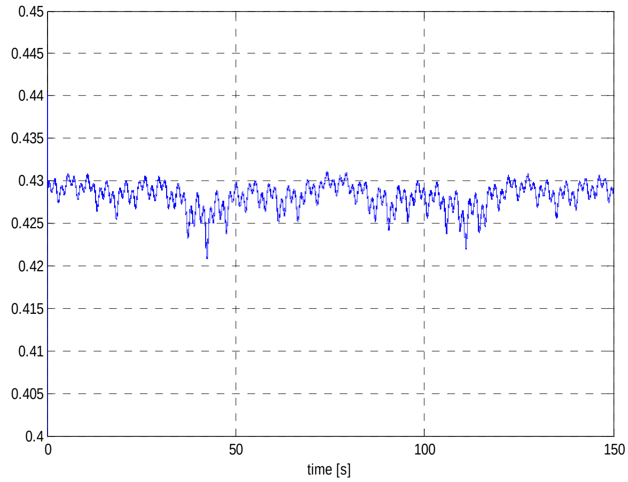

Fig.15. Coefficient of power conversion.

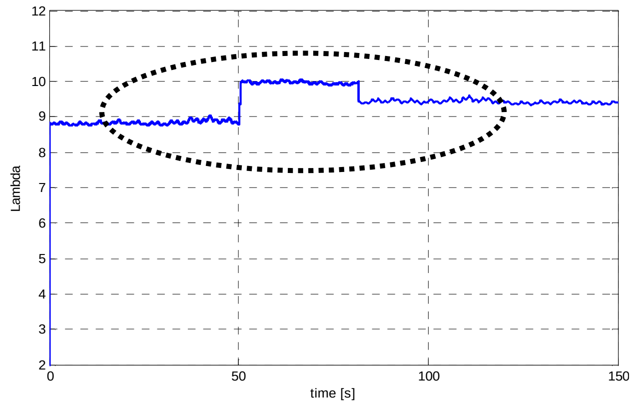

Fig.16. Speed ratio.

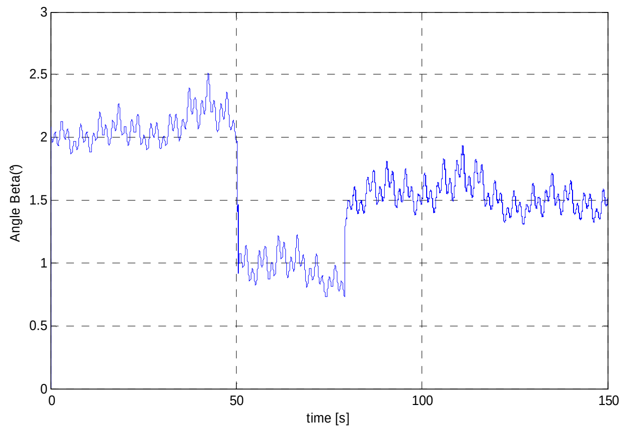

Fig.17. Angle Beta β.

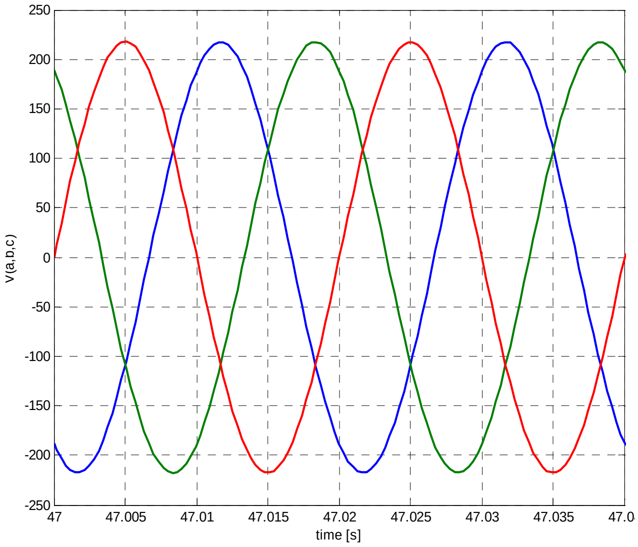

Fig.18. Three phase voltage generated by DFIG.

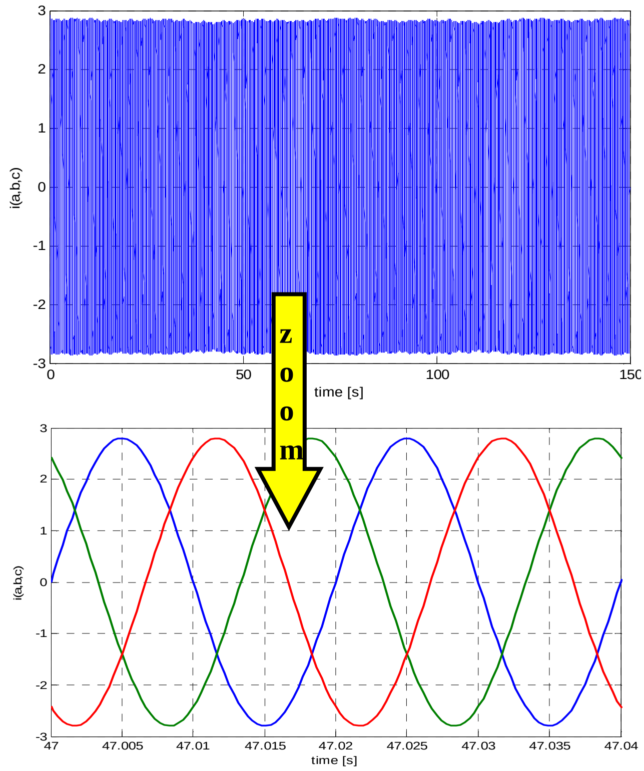

Fig.19. Three phase current generated by DFIG.

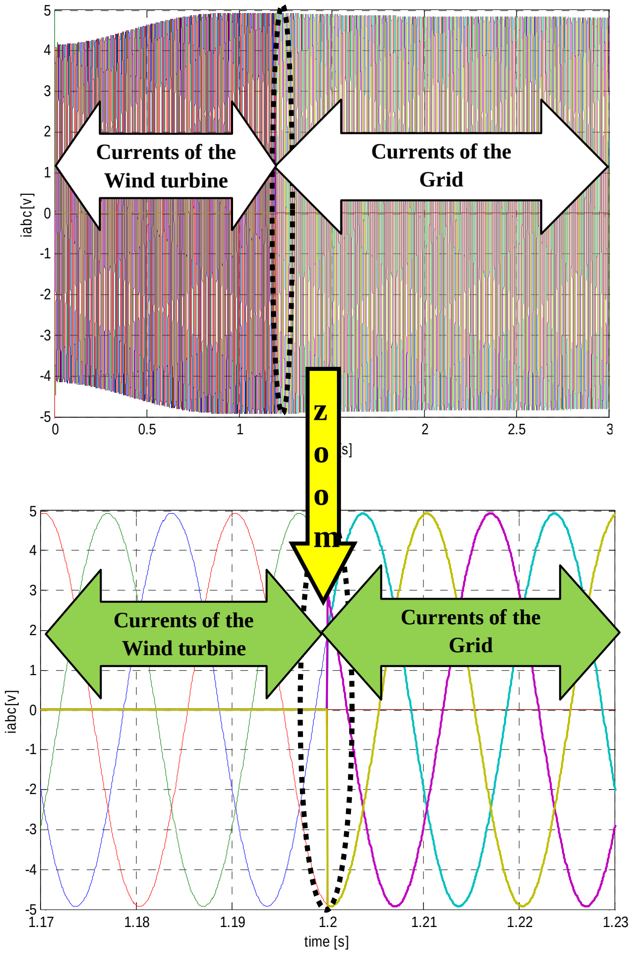

Fig.20. Simple currents produced by (Wind/Grid) with regulation of the phases.

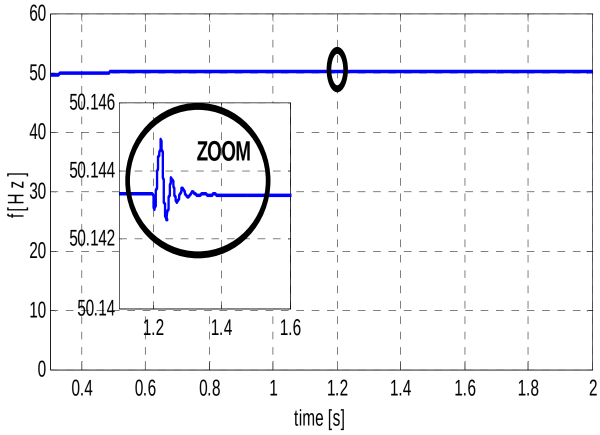

Fig.21. Overview of frequency.

At; **t = 1.2s** time coupling between two sources, wind/network, the shape of the current phase of two sources for the coupling is shown in figure 20. It is sinusoidal with amplitude of ± 4.9 A, with a 20 ms period (50 Hz).

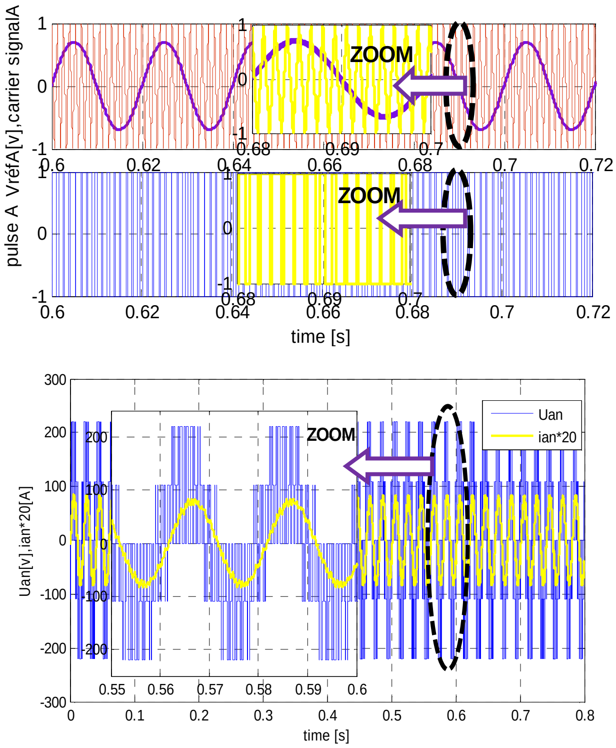

Fig.22. Voltage and simple current of phase "A" generated by DC/AC inverter.

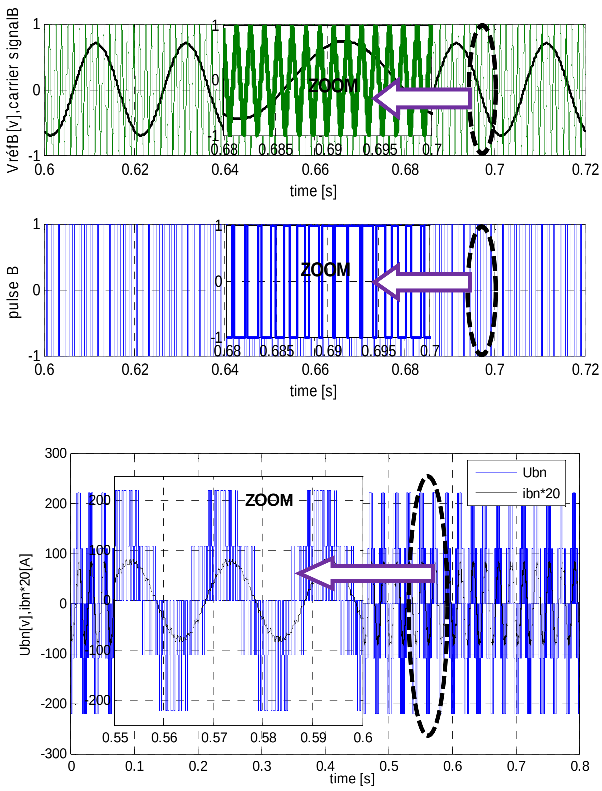

Fig.23.Voltage and simple current of phase "B" generated by DC/AC inverter.

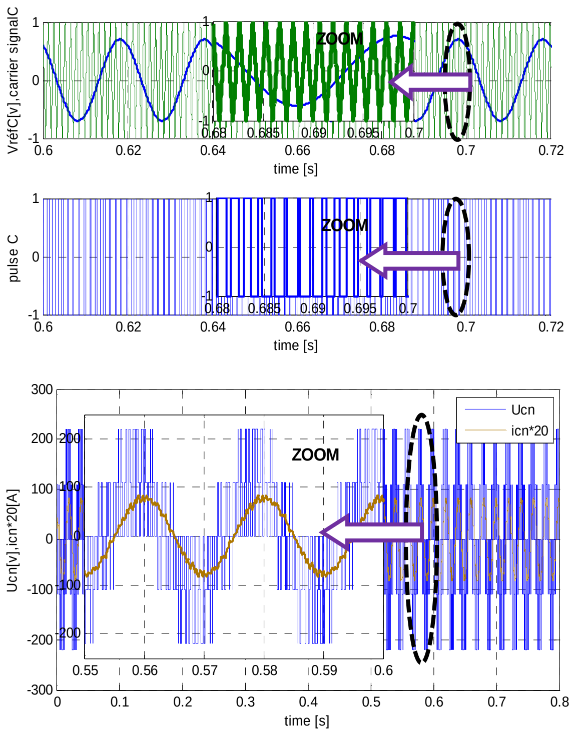

Fig.24.Voltage and simple current of phase "C" generated by DC/AC inverter.

6. Conclusion

In this paper, a structure of a control operation of a wind turbine at variable speed.The control synthesis technique with PI corrector ensures optimum system behavior around an operating point with respect to a compromise which is presented between several control objectives. The evaluation of the proposed control strategy showed a better behavior of the system in each operating region compared to a conventional controller, and good transitions between operating areas.

The simulation results show that the system performance is very encouraging in that modern turbines, which are equipped with a "control variable pitch blade" whose function is to change the pitch angle of the blades to allow the turbine extracts the maximum amount of kinetic power, or decreases the speed of the rotor too in such case.

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