



## Modelling with Matlab/Simulink of a wind turbine connected to a generator asynchronous dual power (GADP)

**B. Benyachou<sup>1</sup>, S. Men-la-yakhaf<sup>1</sup>, B. Bahrar<sup>2</sup>, M. Tamani<sup>2</sup>**

<sup>1</sup>Team of Modeling and simulation of Mechanical and Energetic, Faculty of sciences, Mohammed V University, Rabat, Morocco.

<sup>2</sup>Team of Fluid Mechanics, Energy & Environment, ENSET Mohammedia, Hassan II University Casablanca, Morocco.

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[bahrarb@yahoo.fr](mailto:bahrarb@yahoo.fr)  
Phone: +212671259317;

### Abstract

The work presented in this article is devoted to a MATLAB / SIMULINK to model a *wind turbine*. It consists to build a model to control a variable velocity wind system based on a dual power asynchronous generator. It is based on mathematical equations and allows describing the operating principle of a wind system using a wind turbine with a horizontal axis and variable velocity plant with a generator asynchronous dual power (GADP). Data of our study are carried out from the wind distribution of the Tangier wind farm in Morocco, using the least squares method. In the developed model, simulations have been carried out and the results obtained are in agreement with those developed in literature.

## 1. Introduction

Energy, and in particular electrical energy, has become increasingly primordial for humanity. Indeed, access to electricity is a prerequisite for the socio-economic development of a country. The industrial revolution of the last few decades has led to enormous planetary needs in electrical energy. Admittedly, this access is far from assured in the emerging and least developed countries. According to estimate by the World Bank and the United Nations (UN), more than 1.2 billion people still do not have access to electricity, almost half of them in sub-Saharan Africa. The production of global electricity has increased on average by 3.1% per year for the last ten years. The most consumed part comes from fossil fuels, such as oil, gas, coal. Encountered with the current rate of electricity consumption, and in order to limit the use of nuclear power plants and the use of fossil energy, several countries have turned to renewable energies. Reducing greenhouse gas emissions and exploiting the resources of renewable energy are now a real global challenge. Among these renewable energies is the wind turbine, which represents supplementary energy complementary to nuclear energy and fossil energies. It is a form of inexhaustible and clean energy extracted indirectly from solar energy, since it is the difference in temperature and pressure induced in the atmosphere by the absorption of solar radiation, which causes the winds to move.

The work presented in this paper is devoted to the modelling of a wind chain using a large turbine tripod with horizontal axis, variable velocity and fixed pitch, which will be connected afterwards with a generator that will be connected to a Generator Asynchronous Dual Power (GADP).

## 2. Modelling the wind system

The wind power generation has experienced strong evolution in the last decade. This results in the development of Conversion Systems Wind Energy (CSWE) at the levels of modelling and Power. Modern wind turbines operate at different wind velocities and are equipped with synchronous or asynchronous generators. Among these generators, the generator Asynchronous Dual Power (GADP) offers several advantages and capabilities of active and reactive power in four quadrants.

## 2.1. Modelling of the wind

The first step required for a wind power project is the geographic location of the site. The wind properties are interesting for the study of the whole wind energy conversion system, since its power, under ideal conditions, is proportional to the cube of the wind velocity. For the properties of a site, it is essential to have measurements of the wind velocity and its direction over a large period of time. Many researchers have worked on wind modelling from white noise to which we'll apply a transfer function to be determined. The parameters of this transfer function depend on the characteristic values of the site and wind. The wind velocity can be modelled as a scalar function that evolves over time [1-2]:

$$V(t) = A + \sum_{k=1}^i a_k \sin(w_k \cdot t)$$

$A$  : Average wind velocity.

$a_k$ : Amplitude of the harmonic of order  $k$ .

$w_k$ : Pulsation of the harmonic of order  $k$ .

The Weibull distribution allows a good approximation of the distribution of the wind velocity. Indeed, for periods ranging from a few weeks to a year, the Weibull function reasonably represents the observed velocities. This is a probability density function, expressed as [3-5-16]:

$$f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^k\right)$$

In the above expression,  $exp$  is the exponential function,  $c$  is the Weibull scale factor expressed in  $m \cdot s^{-1}$ ;  $f(v)$  is the velocity probability density  $v$  and  $k$  is a shape factor. Several methods are used to determine parameters  $c$  and  $k$  from wind statistical data. In this work we used the least squares method to determine  $k$  and  $c$  for the Tangier wind farm in northern Morocco [4], and we obtained:

$$c = 6.65834 m \cdot s^{-1} \quad \text{and} \quad k = 2.2424$$

The average wind velocity is given by the relation:

$$A = \sum v_i \cdot f_i(v)$$

From the Annual balance sheet of the distribution of frequencies of the given wind velocity of our site we obtained:

$$A = 6.04 m \cdot s^{-1}$$

During our work, the wind velocity will be modelled in deterministic form of a sum of several harmonics in the below formula:

$$V(t) = 6.04 - 0.2 \sin 0.1047 \cdot t + 2 \sin 0.2665 \cdot t + 0.2 \sin(3.6645 \cdot t)$$

## 2.2. Modelling of the turbine

A wind energy system transforms the energy of the air mass in motion and delivers mechanical power characterized by the rotational velocity and the mechanical torque. The device studied in this work is constituted by a wind turbine with a nominal power of 1.8MW, comprising a radius  $R=40m$  of the blades driving a generator through a multiplier gain  $G=70$ .

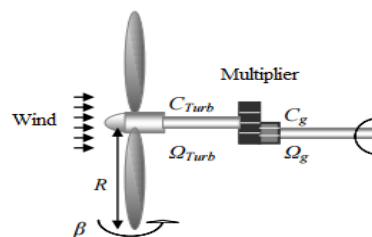


Figure 1: Model of a wind turbine

The aerodynamic model should produce aerodynamic torque from the wind velocity and the rotational velocity of the turbine. This velocity corresponds to the rotation velocity of the mechanical shaft. To perform modelling of aerodynamics, we use the expression of the mechanical power produced by a wind turbine [6-21]:

$$P_{aer} = C_p(\lambda, \beta) \frac{1}{2} \cdot \rho \cdot S \cdot v^3 \quad (1)$$

The power coefficient  $C_p$  is a function of the specific velocity  $\lambda$  and the pitch angle of the blades of the turbine  $\beta$ . This coefficient is different from one turbine to another. Numerical approximations were developed in the collected works to calculate the coefficient  $C_p$  and different expressions have been proposed. In this work we will model this coefficient by the following analytical expression [5-7-11]:

$$C_p(\lambda, \beta) = 0,5176 \left( \frac{116}{\lambda_i} - 0,4 \beta - 5 \right) e^{-\frac{21}{\lambda_i}} + 0,0068 \lambda \quad (2)$$

where:

$$\lambda_i = \left( \frac{1}{\lambda + 0,08 \beta} - \frac{0,035}{\beta^3 + 1} \right)^{-1}$$

The mathematical model of the power coefficient facilitates the execution of simulations dynamically especially when the parameters affecting the power of the turbine changes over time. If we know the velocity of rotation of the turbine, we can express the aerodynamic torque that appears at the turbine rotor by the following expression [8]:

$$T_{aer} = \frac{P_{aer}}{\Omega_t} = C_p(\lambda, \beta) \frac{1}{2 \Omega_t} \cdot \rho \cdot S \cdot v^3 = C_p(\lambda, \beta) \frac{1}{2 \Omega_t} \cdot \rho \cdot v^3 \cdot \pi \cdot R^2 \quad (3)$$

With:  $\lambda = \frac{\Omega_t \cdot R}{v}$

$\Omega_t$  is the wind turbine rotation velocity.

The multiplier is the connection between the turbine and the generator to adapt the turbine velocity to a generator and it is modelled by the following two equations:

$$\Omega_{mec} = G \Omega_t \quad (4)$$

$$T_{mec} = G T_t \quad (5)$$

Where:

$\Omega_{mec}$  is the angular rotation velocity of the generator (rad/sec) or (r/min) and G is the multiplication ration. The fundamental equation of dynamics to determine the evolution of the mechanical velocity from the total mechanical torque applied to the rotor is [8-10-13]:

$$J \frac{d\Omega_{mec}}{dt} + f \Omega_{mec} = T_T = T_{mec} - T_{em}$$

The viscous friction torque is:  $T_{vis} = f \Omega_{mec}$

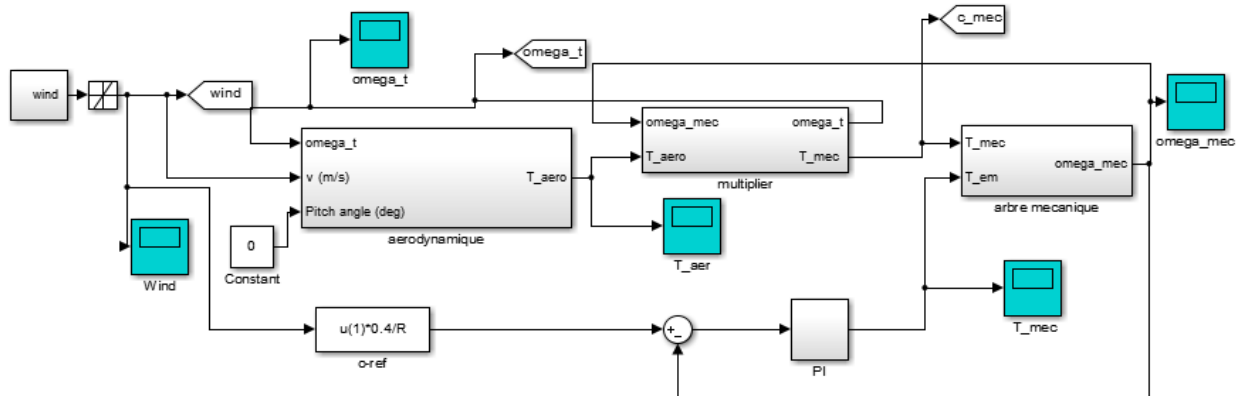
f: friction coefficient.

J: the total inertia that appears on the generator rotor.

The total torque of the wind turbine is given by:  $T_T = T_{mec} - T_{em}$

$T_{em}$ : Electromagnetic torque.

The block diagram illustrated in figure 2 represents the model of the whole kinematic chain of the turbine. It is obtained by modelling and regrouping with MATLAB / SIMULINK the mathematical equations presented previously.



**Figure 2:** bloc schema of a wind turbine with maximization of the extracted power using a velocity control.

In this work we will limit to studying the variable velocity user's control, using the Maximum Power Point Tracking (MPPT) technique in order to ensure energy efficiency. For this, we propose a control strategy by controlling the velocity of rotation allows maintaining the ratio between the extracted power and the wind power to its maximum value. In other way, it is necessary to maintain the power coefficient  $C_p$  at its maximum value. This command requires the use of a cruise control [9-19]. To generate the reference electromagnetic torque, by using a PI controller, it is necessary to calculate the corresponding velocity at  $c_p \max$ . The optimum value of the specific velocity  $\lambda_{opt}$  and the maximum power coefficient  $c_p \max$  makes it possible to obtain the reference velocity of the turbine  $\Omega_T$ . On the basis of the control diagram in figure 2, the reference electromagnetic torque is

obtained by the action of a PI-type controller which influences the difference between the reference velocity and the rotational velocity [14]. The transfer function describing this action is given by:

$$T_{em-ref}(s) = (I + Ps)(\Omega_{T-ref}(s) - \Omega_{mec}(s)) \quad (6)$$

Where

I : the integral gain

P : the proportional gain

The block diagram of the velocity control is given by:

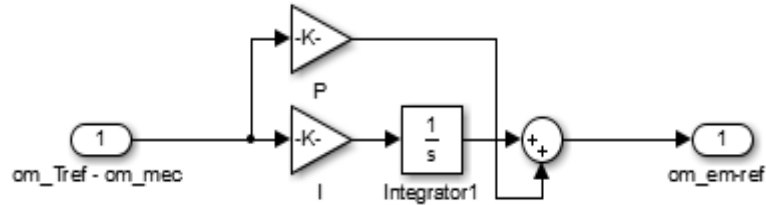


Figure 3: Block diagram of the servo control using a PI regulator

The choice of the eigenvalue pulsation  $w_n$  and the damping factor  $\xi_n$  makes it possible to calculate the coefficients of the PI regulators [12-13].

$$I = \frac{(w_n)^2 \cdot J}{P}$$

$$P = (2 \cdot \xi_n \cdot w_n \cdot J) - f$$

### 2.3. Modelling of the generator

The GADP is a machine that has given excellent performance with its vector control. It is often used in the wind turbine industry for variable wind turbines velocity for various reasons, such as reducing stresses on mechanical parts, reducing noise and the possibility of control for active and reactive powers.

The electrical equations of GADA in a three-phase reference (abc) are as follows [12-15-17]:

$$\begin{cases} [U_s]_3 = [R_s] \cdot [I_s]_3 + \frac{d}{dt} [\Phi_s]_3 \\ [U_r]_3 = [R_r] \cdot [I_r]_3 + \frac{d}{dt} [\Phi_r]_3 \end{cases} \quad (7)$$

The magnetic equations in the three-phase reference (abc) are expressed as a function of the currents by intervening the various inductances:

$$\begin{cases} [\Phi_s]_3 = [L_s] \cdot [I_s]_3 + [M_s] \cdot [I_r]_3 \\ [\Phi_r]_3 = [L_r] \cdot [I_r]_3 + [M_r] \cdot [I_s]_3 \end{cases} \quad (8)$$

In expressions (8),  $L_r, L_s$  are rotor and stator inductances and  $R_r, R_s$  are rotor and stator resistances. By applying the Park transformation [13], this transformation allows the passage from a three-phase reference (abc) to a two-phase rotating reference ( $\alpha\beta$ ) and therefore a reduction in the number of equations, on the fluxes and voltages of the equations of GADA, we obtain the following electrical equations:

$$\begin{cases} V_{\alpha(s,r)} = R_{(s,r)} \cdot I_{\alpha(s,r)} + \frac{d}{dt} \Phi_{\alpha(s,r)} - \Phi_{\beta(s,r)} \frac{d\theta_{(s,r)}}{dt} \\ V_{\beta(s,r)} = R_{(s,r)} \cdot I_{\beta(s,r)} + \frac{d}{dt} \Phi_{\beta(s,r)} + \Phi_{\alpha(s,r)} \frac{d\theta_{(s,r)}}{dt} \end{cases} \quad (9)$$

$\theta_s, \theta_r$  are the park angles of the stator and rotor.

The magnetic equations in the two-phase reference ( $\alpha\beta$ ):

Flux side rotor:

$$\begin{cases} \Phi_{\alpha r} = L_r \cdot I_{\alpha r} + M \cdot I_{\alpha s} \\ \Phi_{\beta r} = L_r \cdot I_{\beta r} + M \cdot I_{\beta s} \end{cases} \quad (10)$$

Flux side stator:

$$\begin{cases} \Phi_{\alpha s} = L_s \cdot I_{\alpha s} + M \cdot I_{\alpha r} \\ \Phi_{\beta s} = L_s \cdot I_{\beta s} + M \cdot I_{\beta r} \end{cases} \quad (11)$$

Where  $M$ , is magnetizing inductance between stator and rotor.

The equations of the electromagnetic torque can be written in the next form:

$$C_{em} = -p(\Phi_{\alpha r} I_{\beta r} - \Phi_{\beta r} I_{\alpha r}) = p(\Phi_{\alpha s} I_{\beta s} - \Phi_{\beta s} I_{\alpha s}) \quad (12)$$

Where  $p$  is the number of machine poles.

The active and reactive powers of the rotor and stator of the GADP in a two-phase reference (d q) are given by:

$$\begin{cases} P_r = U_{\alpha r} I_{\alpha r} + V_{\beta r} I_{\beta r} \\ Q_r = U_{\beta r} I_{\alpha r} - U_{\alpha r} I_{\beta r} \end{cases} \begin{cases} P_s = U_{\alpha s} I_{\alpha s} + U_{\beta s} I_{\beta s} \\ Q_s = U_{\beta s} I_{\alpha s} - U_{\alpha s} I_{\beta s} \end{cases} \quad (13)$$

The vector control refers to the set of commands that takes into account the equations of the system carries out in real time. The relations obtained from this command are more complex than those of the scalar commands. They make it possible to obtain better performances during the transient regimes. Indeed, each AC machine can have vector commands.

The choice of the Park reference ( $\alpha\beta$ ) with orientation of the stator flux or with orientation of the rotor flux allows us to create a natural decoupling of the quantities d and q. This allows us to consider the asynchronous machine as the mechanical association of two DC motors [12-13-15]. In this work, we will only use the method of vector control by the stator flux orientation. The field is then rotated and oriented according to the direct axis stator flux [18-20-22]. So we have:

$$\Phi_{\alpha s} = \Phi_s \quad \text{and} \quad \Phi_{\beta s} = 0$$

The flux equations then, become:

$$0 = L_s I_{\beta s} + M I_{\beta r}$$

$$\Phi_s = L_s I_{\alpha s} + M I_{\alpha r}$$

$$\Phi_{\alpha r} = \sigma L_r I_{\alpha r} + \frac{M}{L_s} \Phi_{\alpha s} = \left( L_r - \frac{M^2}{L_s} \right) I_{\alpha r} + \frac{M}{L_s} \Phi_s$$

$$\Phi_{\beta r} = \sigma L_r I_{\beta r} = \left( L_r - \frac{M^2}{L_s} \right) I_{\beta r}$$

The dispersion coefficient is:  $\sigma = 1 - \frac{M^2}{L_s L_r}$

Assuming that the stator resistance is negligible and that the regime is permanent, we obtain:

$$U_{\alpha s} = R_s I_{\alpha s} + \frac{d\Phi_{\alpha s}}{dt} \approx 0$$

$$U_{\beta s} = R_s I_{\beta s} + \omega_s \Phi_{\alpha s} = v_s \approx \omega_s \Phi_s$$

The rotor voltages can be expressed as a function of the rotor currents:

$$\begin{cases} U_{\alpha r} = R_r I_{\alpha r} + \left( L_r - \frac{M^2}{L_s} \right) \frac{dI_{\alpha r}}{dt} + \left( L_r - \frac{M^2}{L_s} \right) \omega_r I_{\beta r} \\ U_{\beta r} = R_r I_{\beta r} + \left( L_r - \frac{M^2}{L_s} \right) \frac{dI_{\beta r}}{dt} - \left( L_r - \frac{M^2}{L_s} \right) \omega_r I_{\alpha r} + \omega_r \frac{M}{L_s} \Phi_s \end{cases}$$

The adaptation of the preceding active and reactive equations to the chosen reference point and to the simplifying hypotheses performed gives:

$$\begin{cases} P_s = -U_s \frac{M}{L_s} I_{\beta r} \\ Q_s = U_s \frac{\Phi_s}{L_s} - U_s \frac{M}{L_s} I_{\alpha r} \end{cases}$$

The equation of the electromagnetic torque then becomes:

$$C_{em} = p(\Phi_{\alpha s} I_{\beta s} - \Phi_{\beta s} I_{\alpha s}) = -p \Phi_{\alpha s} \frac{M}{L_s} I_{\beta r}$$

The previous equations lead to establish the block diagram of the electrical system realized with Matlab / Simulink and which is presented in the following figure:

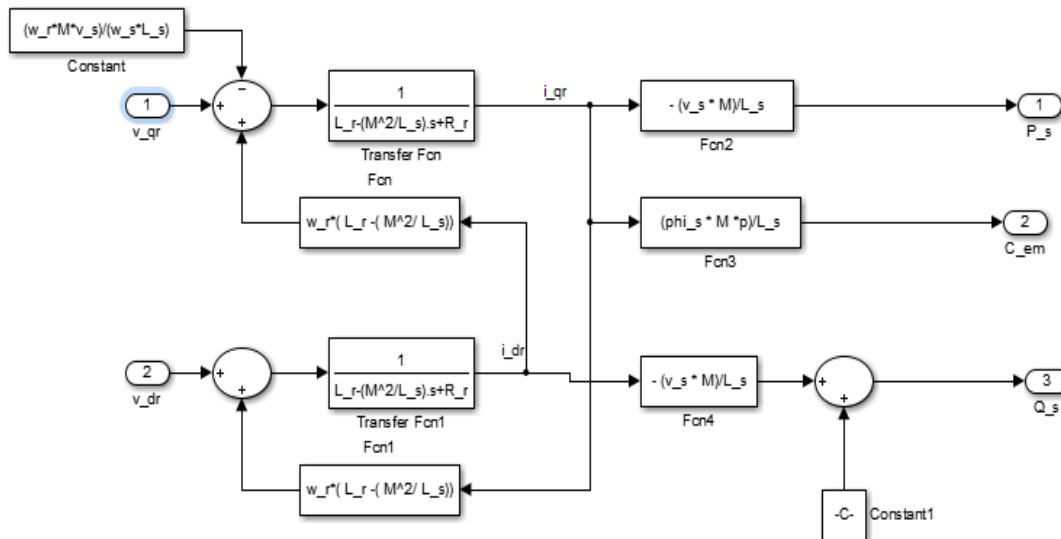


Figure 4: bloc schema of a GADP

### 3. Results and simulation

Figure 4 shows the variation of the wind velocity as a function of time (60 s) for an average wind velocity of  $6.04 \text{ m} \cdot \text{s}^{-1}$  and a zero pitch angle:

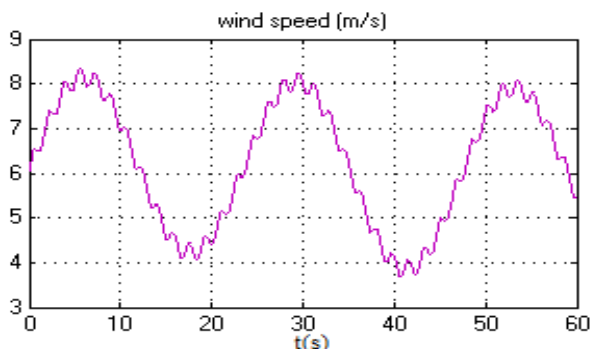


Figure 5: wind velocity ( $\text{m} \cdot \text{s}^{-1}$ )

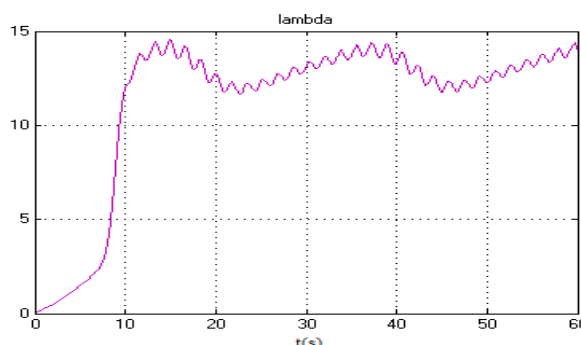


Figure 6: The specific velocity  $\lambda$

Figure 6 shows the evolution of the coefficient  $\lambda$  in terms of time, for a variable wind velocity; The shape of the curve always adopts an increasing shape during the start-up time and then oscillates around the value ( $\lambda = 13$ ), which clearly shows the influence of the wind profile on the turbine  $\lambda$  coefficient. Figures 7, 8 and 9 show the evolution of the power coefficient  $C_p$ , the mechanical torque and the mechanical power of the turbine in terms of time, for a variable wind velocity, these gaps always take on an increasing form during the time Then they demines and begin to oscillate afterwards, which clearly shows the influence of the wind profile on the performance of the turbine.

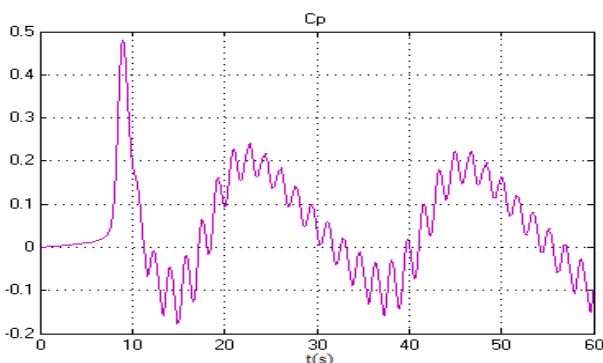


Figure 7: The power coefficient  $C_p$

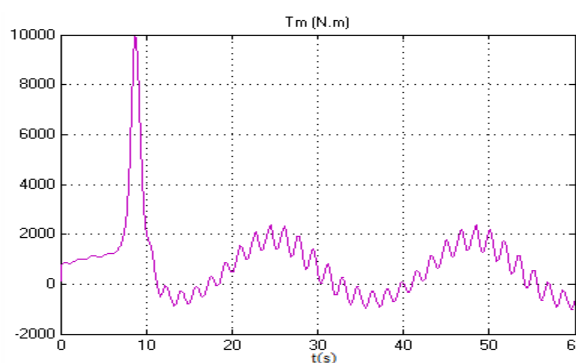


Figure 8: The mechanical torque ( $\text{N} \cdot \text{m}$ )

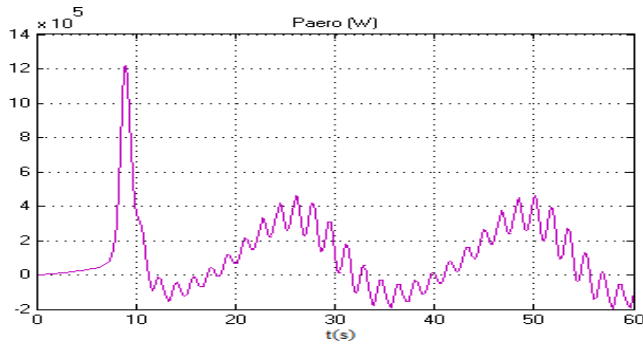


Figure 9: the mechanical power of the turbine (W)

Figures 10 and 11 show the change in the velocity of rotation of the turbine and of the generator in terms of time, for a variable wind velocity; The shape of the curve always takes on an increasing form during the start-up time, which clearly shows the disturbance caused by the wind profile during the rotation of the turbine which modifies the frequency of the voltage and the flux produced by the generator.

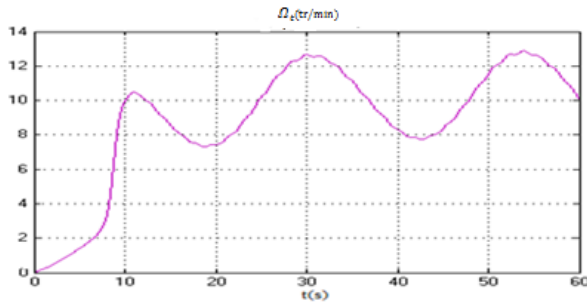


Figure 10: the velocity of rotation of the turbine

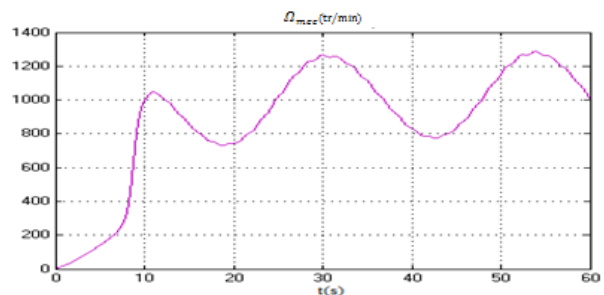


Figure 11: the velocity of rotation of the generator (tr/min)(tr/min)

Figures 12, 13 and 14 show the shape of the electromagnetic torque and the reactive and active power provided by the GADP. For the paces of electromagnetic torque and reactive power, both curves reach their maximum values and then they begin to oscillate around its nominal values. As for the active power, it decreases and reaches its nominal value.

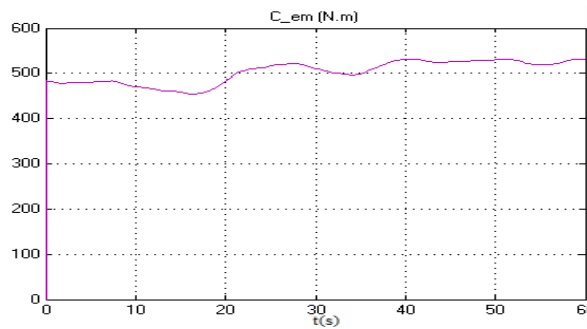


Figure 12: The electromagnetic torque (N.m)

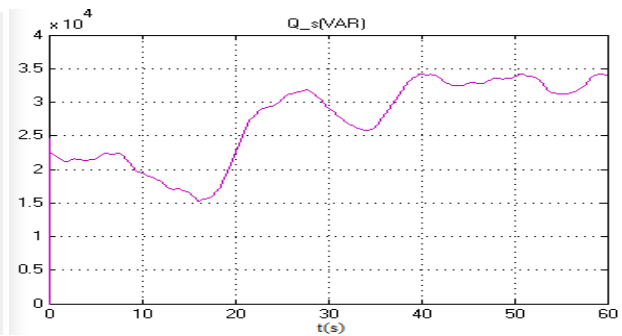


Figure 13: The reactive power (VAR)

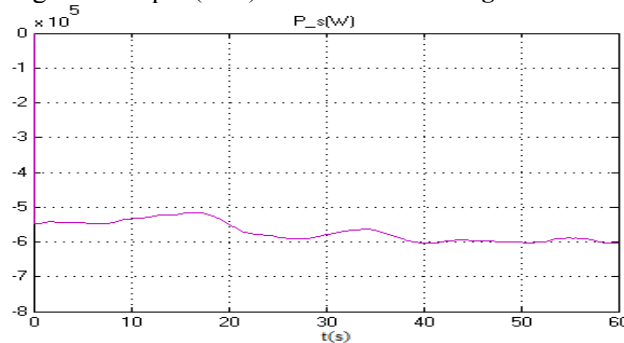


Figure 14: The active power (W)

## Conclusion

In this paper, we treated the modelling and control of a variable velocity wind system based on a dual power asynchronous generator. A conventional controller PI was used to control the angular velocity of the wind turbine. We are interested in modelling the different constituents of the wind system in order to optimise and to develop the aerodynamic, mechanical and electrical models of the system.

In order to validate the modelling and the control of the wind turbine, we carried out simulations to our system. The results of our model are promising and are in agreement with those found in the literature.

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