INFLUENCE OF WIND SPEED ON THE CONVERSION SYSTEM OF A LOW POWER WIND TURBINE

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Abstract: *Alongside the substantial market for high power wind generation, small power systems (about 100 W to several kW) are developed mainly for remotely located sites. Energy conversion systems are very different from those of high power; they are often based on using a three phase permanent magnet generator supplying an inverter through a diode rectifier.*
 This study represents a model of the conversion system, and it's simulation concerning the whole mechanical system, electrical and energetic behavior for different speeds and wind profiles.
Energetic comparisons with strong profiles of variable wind speeds were used to evaluate the different structures and drive strategies.

Key words*: wind energy, power electronics, modelling/ simulation control /command.*

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1. Introduction

Among all renewable energy systems which are contributing to the production of electricity, wind energy is currently playing a starring role [1] [2] [3]. Various production lines coexist for generating electricity by wind turbines. They can be quite different depending on whether it is high or low power, operating at fixed speed (or slightly variable) or variable speed. A commonly used solution is to use the cage induction motors with two polar stator winding configurations which provide two-speed and voltage [4]. The work is part of the complete model of a wind generation system. The goal is to have a model of complete system simulation in Matlab / Simulink, the conversion chain is for different profiles and wind speeds. However, several studies [5] [6] have shown that this structure could be effective in terms of energetic if a judicious choice of its parameters (electrical and geometric) is achieved. In other words, this means that removing any order MPPT, one can obtain a recovery of energy from the wind almost optimum. This structure is a concrete example of converting complex energy as it consists of several sub systems from several different natural areas (aerodynamics, mechanics, electrical, thermal......) strongly interacting. The existence of a strong coupling between the different elements of this structure needs to consider the system as a whole, rather than examining the different organs separately. In this context, the interest in modeling the energy conversion is given to the entire system.

2. Principal work of conversion system

The figure below presents the wind conversion system of the case study.
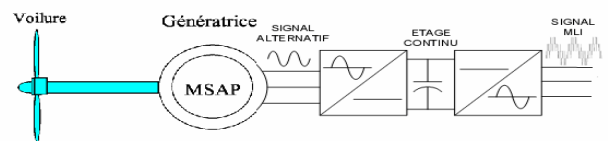

Figure 1. Wind conversion system

3. Modelling

A. Wind Model:

Figure 2 presents the wind card in Algeria established by the energies renewable development center laboratory of wind energy [7]
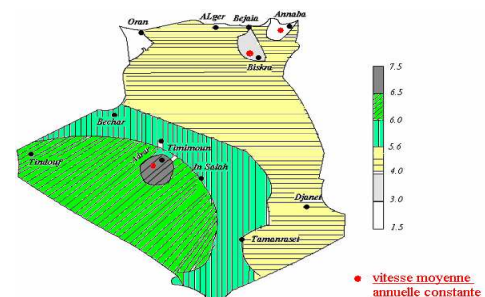

Figure 2: Wind speed cartography in Algeria

To know the wind nature influence on the mechanical, energetic and electric system parameters. Three cases are considered:

- Fixed wind speed value (9 m/s), figure 3.a.

- Variable wind speed (the variation is situated between (9±10 m/s), figure 3.b.
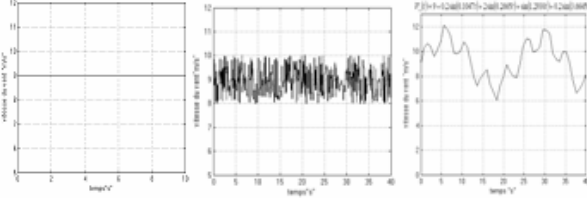
- Real wind profile, figure 3.c.

Figure 3.a.b.c: Wind profiles used in this study

B. Turbine Model:

Equation 1, presents the mechanical power recovered by the wind turbine [5]:

$$P_{eol} = P_m = \frac{1}{2} \pi \rho \, C_p(\lambda) R^2 V_v^3 \qquad (1)$$

Cp is generally given according to λ; report of the turbine peripheral speed brought back to the wind speed

$$\lambda = \frac{R \cdot \Omega}{V_v}$$
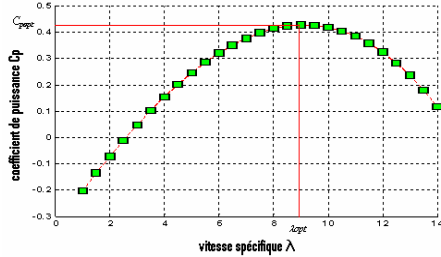
Figure 4, presents the characteristic curve of Cp vs. λ

Figure.4: Cp vs. λ

The three-blade horizontal axis turbine can recover 43% of the wind power.

B.1. Parameters which influence on the recovered power of this turbine.

Figure 5 presents the power variation recovered by the turbine according to the wind speed.
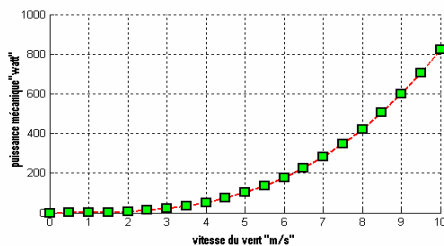

Figure.5: Power variation vs. Wind speed (Cp=0, 43; R=1m)

B.2.wind turbine blocks simulation:

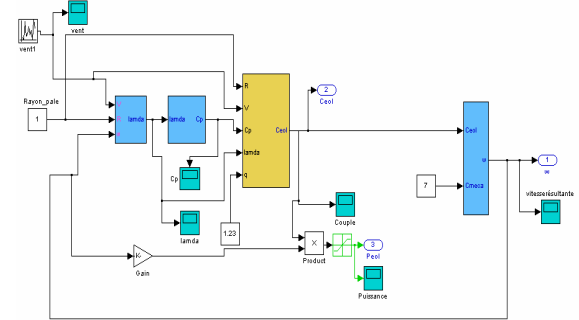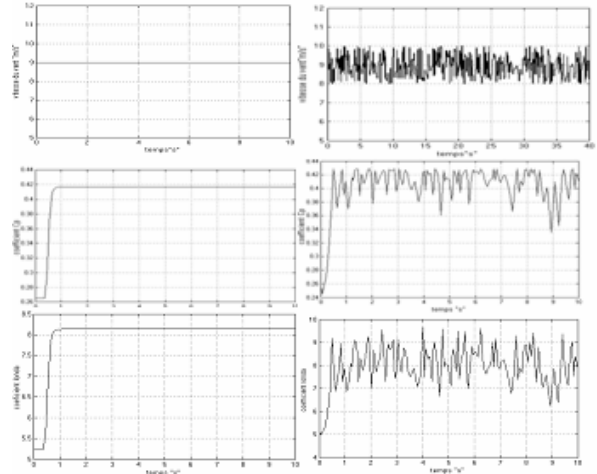*Figure. 6: Wind turbine Block simulation*

Figure. 7: Wind profile influence on Cp and λ

The simulation results show clearly the influence of wind profile on the power coefficient and on the reduced speed of this turbine.

C .Generator model:

The considered machine is conceived especially to be used in a horizontal axis turbine. The whole is a multi pole permanent magnet synchronous machine. Considering the range of wind turnover speed, the number elevated of poles serves to get a sufficient electric frequency without having resort to the mechanical multiplier [9] [10]. The model of the latter is presented by the following equations

C.1 the electric voltages equations:

$$V_d = -R_s i_d - L_d \frac{d}{dt} i_d + \omega L_q i_q$$

$$V_q = -R_s i_q - L_q \frac{d}{dt} i_q - \omega L_d i_d + \omega \psi_f$$

On the other hand, the application of voltages V_d and V_q on the load gives:

$$V_d = -R_s i_d - L_d \frac{d}{dt} i_d + \omega L_q i_q$$

$$V_q = -R_s i_q - L_q \frac{d}{dt} i_q - \omega L_d i_d + \omega \psi_f$$

The currents electric equations

$$P i_d = \frac{1}{L_d + L_{ch}} \left[-(R_s + R_{ch}) i_d + \omega (L_q + L_{ch}) i_q \right]$$

$$P i_q = \frac{1}{L_q + L_{ch}} \left[-(R_s + R_{ch}) i_q - \omega (L_d + L_{ch}) i_d + \omega \psi_f \right]$$

Electromagnetic torque

$$C_{em} = \frac{3}{2} P \left[(L_q - L_d) i_d i_q + i_q \psi_f \right]$$

The mechanical equation

$$J \frac{d\Omega}{dt} - f \Omega = C_m - C_{em}$$

$$C_{em} = \frac{3}{2} P \left[(L_q - L_d) i_d i_q + i_q \psi_f \right]$$

D. Generator Block simulation:

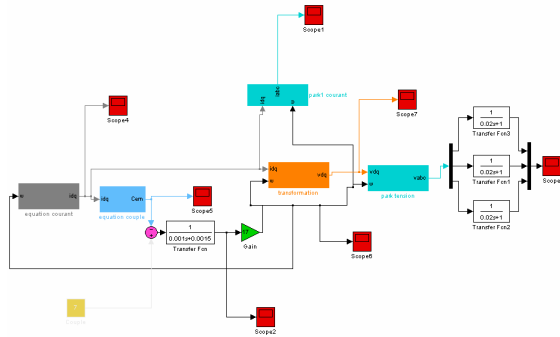For the simulation, it's sufficient to implant the model of the PMSG under the **Matlab/Simulink**.

Figure 8: Generator Block simulation

E. rectifier Model:

The static converters used fluently in the energy conversion systems dedicated to the wind systems, are based on entirely controlled modules that make them expensive therefore penalizing in a small power set. In the cost reduction worry, the bridge of diodes, little costly, seem attractive provided that the performances energetic are not too graduated

The model of this last is presented by the following equations [5]:

The continuous bus voltage is expressed by:

$$V_{bus} = R i_L$$

The current in the inductance is given by:

$$i_L = \frac{1}{2L} \int c (V_a - V_b - R i_L) dt$$

The conduction condition, the diode is conductive (c = 1) if and only; if one of the following conditions is

$$V_L = c.\left[V_a - V_b - V_{bus} \right] \quad \text{verified:}$$

$$V_{ac} - V_{dc} > 0, \quad \text{or} \quad i_L > 0$$

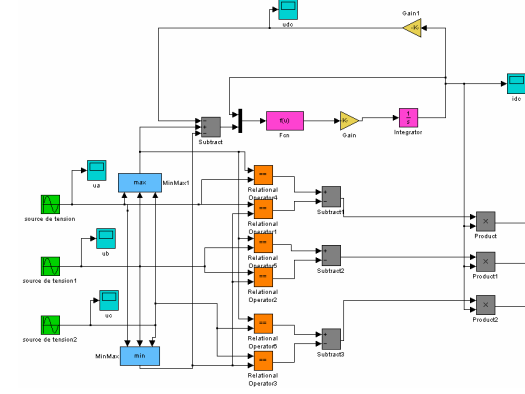This model allows a temporal simulation of the complete diode rectifier's under Matlab / Simulink:

Figure 9: Diodes bridge model simulation

F. inverter MLI Model:

The voltage inverters feed alternative current machines as load from a direct voltage source. They offer to the machine terminals (load) adjustable voltages amplitude and frequency. A voltage inverter with three arms each comprising two switching cells. Every cell is composed of a firing and blocking switch, and an anti-parallel diode. The latter model is presented by the following equation:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{1}{3} U_0 \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix}$$

F.1 Current control by PWM:

The method of current control is done by pulse width modulation (P.W.M) system from a direct voltage source consist in imposing to the machine terminals; a voltages in such a way that the voltage fundamental is to be closer to the sine voltage reference wave.
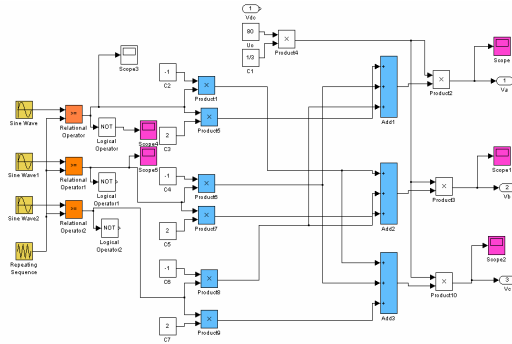
F.2. Voltage inverter block simulation:

Figure 10: Voltage inverter block simulation

G. Modeling and simulation of the complete system:
The wind system studied is a complex system composed of several subsystems belonging to several very different physical domains. The model presented has the objective behavioral simulation of the complete system on the mechanical and electrical energy. Simulations nature 'system' is then presented in this study.

G.1. Complete system bloc simulation: The five components of wind conversion chain were involved and it led to a complete model for the small power conversion chain.
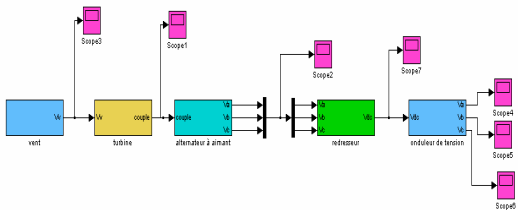

Figure 11: Complete system bloc simulation

G.2 Results of the complete system simulation:
The aim of the simulation is to know the influence of

the wind nature on the mechanical, energetic and electric system parameters, while using the three wind profiles.

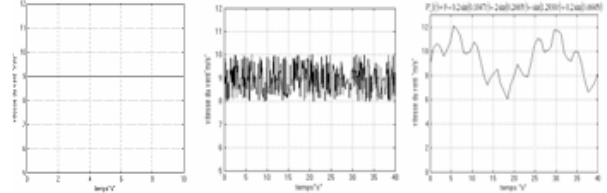*G.3. Wind profile Influence on the system mechanical Parameters:*
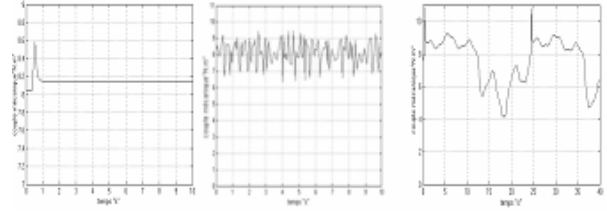

Figure 12.a: Wind profiles vs. Time
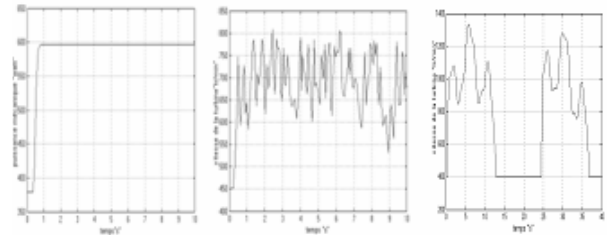

Figure.12.b: Mechanical torque vs. time

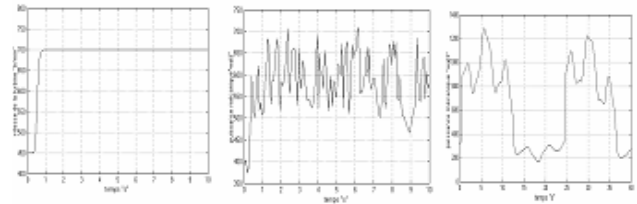*Figure.12.c: Speed turbine vs. time*

Figure 12.d: Mechanical power vs. Time

Figures (12.b), (12.c) and (12.d) respectively show the evolution of mechanical torque; turbine speed and mechanical power against time. It is clear that the wind profile affects greatly the mechanical turbine torque; for a constant wind speed; torque and mechanical power are constant. The system function in an optimal point after which all magnitudes are constant For variable wind speed (9 ± 10 m/s); the torque speed and mechanical power vary slightly; and the

torque limited between (9 and 7N.m), the turbine rotational speed is limited between (600 and 800tr/min), and mechanical power is limited between (500 and 700Watt) these changes do not affect much the other system parameters, speed and voltage will not be altered too. For a real wind profile; values ranging between 6 and 12m /s; cause a change in the mechanical torque (4 and 10N.m); and cause a variation in the turbine rotational speed (400 and 1300tr/min) where a change in the mechanical power of turbine (200 and 1300Watt) gap deviates completely from the chain's operating point and leads it into a random operation, degrading the quality of energy supplied by the system.

So the wind profile influences directly the mechanical parameters (the speed, the mechanical torque and turbine power). For a constant wind speed value, the power coefficient reaches an optimal value and entails the stabilization of the mechanical and electric parameters of the system. Consequently, we register a maximal energy. For a variable wind value (9±10 m/s) the mechanical parameters system varies feebly, this variation doesn't influence many on the other parameters of the system, the speed and voltage won't be altered too much. For a real wind profile that varies of (6 to 12m/s); it drags a variation in the mechanical parameters this variation deviates the system of its optimal point working completely and drags it in an uncertain working.

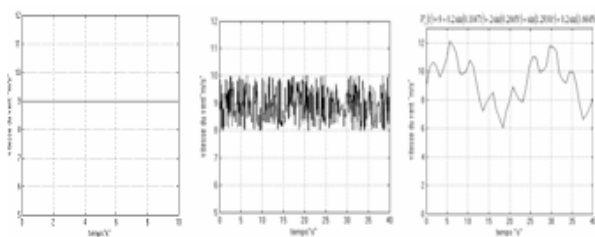*G.4. wind profile Influence on the system electrical parameter:*
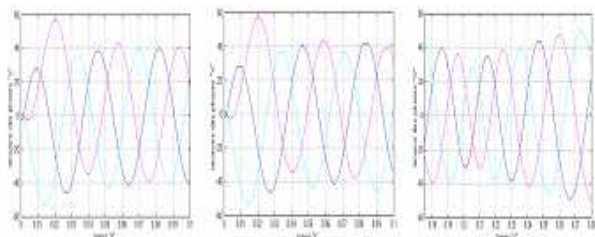

Figure 13.a: Wind profiles vs. time

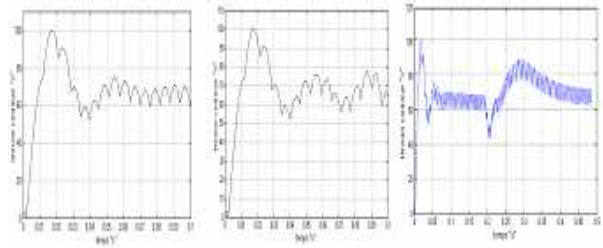*Figure.13.b*: *Voltage phases evolution va, vb, vc (V) vs. Time*

Figure 13.c: Direct voltage evolution of the diode bridge output vs .time
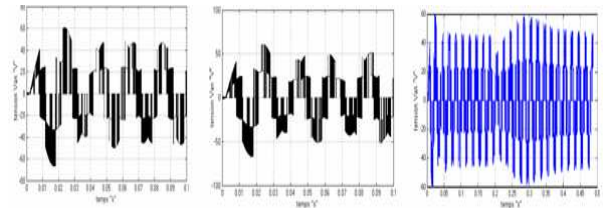

Figure 13.d: PWM voltage evolution of the inverter output vs. .time

Figures (13c), (13.c) and (13.d) show the evolution of the phase voltages value, the output rectifier voltage, and the Van voltage at the output of the inverter vs. time.

For a constant wind; the generator delivers a voltage amplitude and constant frequency, so the rectifier delivers a constant amplitude voltage, or the P.W.M voltage with constant amplitude at the output of the inverter. For variable wind speed (9 ± 10 m/s) the phase voltages amplitude and frequency varies feebly, leading to changes in (± 5V) of the voltage amplitude at the output of the rectifier where the variation in the voltage amplitude at the output of the inverter in a band (± 5V) of the amplitude variation do not affect much the load that feeds the system. For a real wind profile; values ranging between "6 and 12m/s" results in considerable variation in the amplitude (± 10V) and voltage phase frequency , which causes considerable variation (± 20V) in the voltage amplitude at the output of the rectifier which generates a variation of amplitude (± 20V) the output voltage of the inverter which greatly affects the load system.

The results show clearly that the wind profile influences a lot on the amplitude and on the frequency phases voltages, as well as on the direct voltage rectifier's output and the P.W.M voltage inverter's output; for a fixed value of wind all the parameters are steady for a profiles variable wind; record a feeble

variation of the parameters of it; but with the uncertain character wind; the parameters vary strongly

4. CONCLUSION

The multidisciplinary field of wind turbines involves many disciplines, from mechanics of fluid mechanics, through the genius electrical and power electronics. The results obtained in various simulations of different components of the conversion line wind show that the transient is very short for some as the inverter and the rectifier, by cons for the generator and turbine response time is much more important. Before making a choice on the wind conversion system, a necessary data must be known, are the wind profile and its variability. If wind presents a big gap between its maximal and minimal value; a control device whether mechanical or electronic (MPPT) or otherwise, is necessary to have a good power quality.

If wind doesn't present a big gap between its maximum and minimum bidder (±10%) chains completely passive ensures good quality energy. a natural commutation system may therefore be obtained, very reliable and minimum cost.

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