A Contribution to the Design and the Installation of an Universal Platform of a Wind Emulator using a DC Motor

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Abstract- In the goal to implement an experimental wind energy board we have interest by a survey and development of a wind emulator based on DC-machine. The development of this subject has focused on modeling of a vertical axis wind turbine, a DC motor with independent excitation and its control via a fourth quadrant chopper. To carry out this work, we studied and designed the electrical and mechanical sensors dedicated to the stand and a PWM control using 18F452 microcontroller. The presented emulator permits to test some theoretical algorithm control used in the wind energy control system, such as, system was the SCIG, DFIG or PMSM.

Keywords- Wind turbine, wind turbine simulator, actual speed, estimated speed, actual torque, estimated torque.

1. Introduction

The extent of industrialization, the multiplication of domestic appliances has led to considerable electrical energy needs. Meet this demand; we turned to a new form of energy called "renewable". Renewable energies present now solutions to meet the global energy crisis, to reduce the emission of greenhouse gases by oil and limiting the depletion of fossil fuels and fissile.

Among these energies that may be mentioned solar energy (photovoltaic and thermal), biomass energy and wind energy. This is based on the conversion systems that convert kinetic energy of wind into electricity or other forms of energy.

So many work to be done in order to penetrate this source in future power grids. The development of experimental platforms is essential to the validation of these works.

In this context, the design of a test bench aims to study the energy conversion systems developed in simulation. The test bench provides an opportunity to check the functioning of the turbines. The photo in figure 1 represents the electro-technical part of a test bench consists of an induction motor coupled to a DC- machine which is the basis of the wind emulator. Double-Fed Asynchronous Generator is coupled to the synchronous machine.

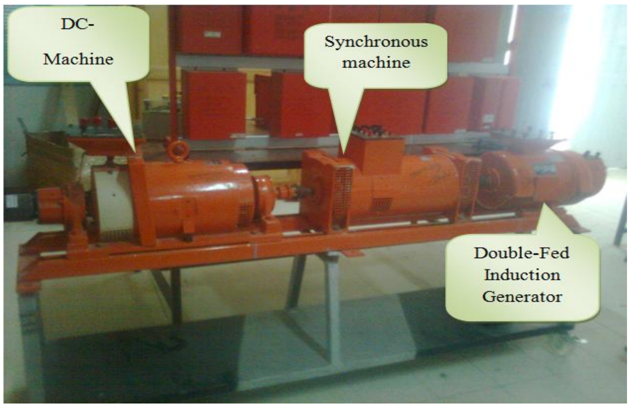


Fig. 1. Experimental platform test bench

This paper is organized as follows: in the second section we present the wind turbine simulator description. In the first part a general wind turbine description is presented, in the second part the global structure of the studied structure is given. The third section is devoted to wind turbine model. In forth different part's, we have treated the wind profile, some power coefficient model, the comparaison between those different curves and the tubine torque respectivelly. Global wind emulator model is studied in section four. In the section we have used Matlab/Simulink platform. Some conclusions and perspectives are given in section five.

2. Wind Turbine Simulator Description

Wind power is the energy produced by the wind. The wind speed is difficult to reproduce on a site. So the solution is a wind turbine simulator: WTS, which is important equipment for the development of converting wind energy systems. WTS provides a controlled test environment which allows the evaluation and improvement of control systems for power generators that are difficult to reach with a real wind turbine as the wind speed varies randomly. Emulator wind consists essentially of an electric motor controlled by a calculator and torque reference torque. This generally reproduces the medium torque of the wind turbine.

2.1. Overview of Wind Turbine Simulator

Such a simulator designed to reproduce in the laboratory the turbine behavior very close to reality. The development of such a tool saves considerable cost in terms of research, a small footprint, flexibility in terms of the characteristics of the wing and especially full control of the wind speed applied. For this reason, in recent years there have been many studies on wind turbine simulators. N.A. Cutululis and al. in [1] presented a real time wind turbine simulator based on frequency controlled ac servomotor. F. Poitiers in [2] presented the steps to create a physical wind turbine simulator. The simulator was tested with a model of DC machine and validated on a real computer of the laboratory of 10 kW. L. A. C. Lopes and al. in [3] presented the implementation of a wind turbine emulator that accounts for the inertia of the wind turbine as well as the dynamics of the drive train. A. Mirecki in [4] and A. Abdelli in [5] used a permanent magnet synchronous machine the basis of their simulator. All calculations are performed by the DSP card dS1102 through information gathered from various electrical and mechanical sensors. M. Monfared and al. in [6,7] described a new wind turbine simulator for dynamic conditions. This system consists of a 3kW dc motor, which drives a synchronous generator. V. Vongmanee [8] proposed a simple emulator of variable speed wind turbine generator, which consists of two inverters control two squirrel cage induction motors. Z. Yanjie in [9] described a wind turbine simulation system based on switched reluctance motor. Md. Arifujjaman and al. in [10] describe the development of an isolated small wind turbine emulator based on a separately excited DC motor is developed to evaluate the performance of small wind turbine control strategies. Also Md. Arifujjaman and al. in [11] utilized a separately excited DC machine to emulate a small wind turbine emulator. The model describe by T. Hardy and al. [12] of WTS was implemented in a software simulation along with controllers for a DC motor acting as the wind turbine and a dynamometer acting as the generator.

2.2. System Structure of Wind Turbine Simulator

The structure of wind turbine simulator is depicted in figure 2.

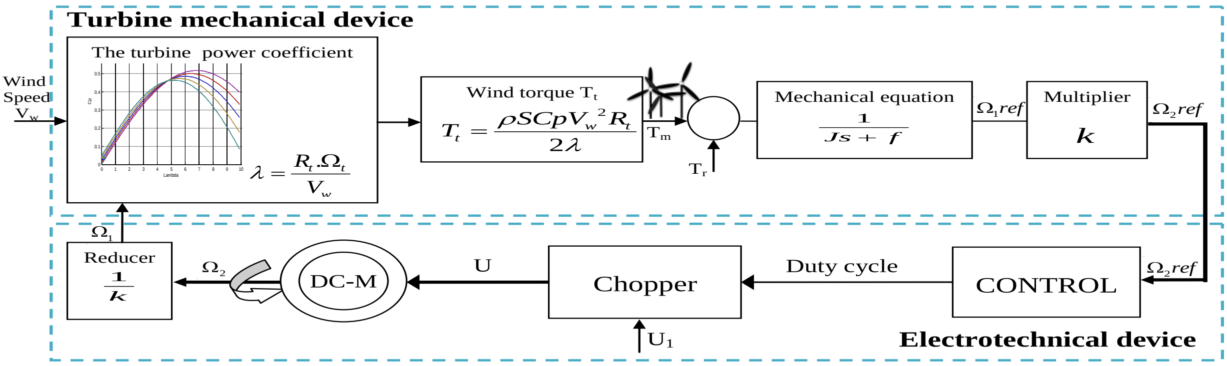


Fig. 2. The principle of wind turbine simulator

The wind turbine emulator is based on DC machine 3 kW, 1500 RPM, fed by a PWM converter. The command of this converter is provided by a microcontroller. A measurement interface composed of a voltage sensor and a current sensor LEM recording is required to control the machine. A measure of speed is achieved thanks to an incremental encoder. Each of these WTS part will be discussed in details in the following sections.

3. Wind turbine model

Discuss the implementation of a wind emulator cannot do without taking into account a range of factors related to the wind turbine.

3.1. Wind profile

In the literature, some consider the wind as a stochastic quantity. These studies decompose the wind speed into a mean component and high frequency fluctuations. Other research model the wind speed as a sum of deterministic harmonic number defined by the following expression:

$$\begin{aligned} V_w &= V_0 + C_1 * \sin x + C_2 * \sin 3x + C_3 * \sin 5x \\ &+ C_4 * \sin 10x + C_5 * \sin 30x + C_6 * \sin 50x \\ &+ C_7 * \sin 100x (m/s) \end{aligned} \quad (1)$$

The temporal evolution of wind is plotted in the following figure.

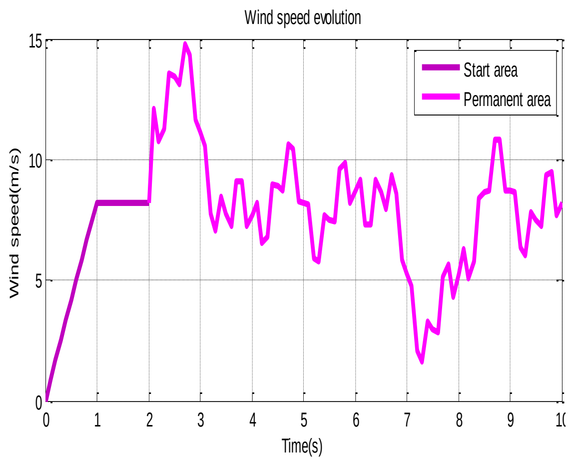


Fig. 3. The wind speed-analytic model

The evolution of the wind speed as a function of time is modeled by an analytical function or generated by a statistical law from the measured data for a given site.

3.2. Power Coefficient

Wind energy is the kinetic energy recovered from the air that passes through a certain surface. Power is proportional to the cube of the wind speed wich is expressed in equation (1)

where ρ is the density of air in kg/m^{-3} and S is the area swept in m^2.

$$P_{wind} = \frac{1}{2} \rho S V_w{}^3 \quad (2)$$

This power cannot be entirely recuperated by the turbine, the coefficient C_P is introduced in determining the mechanical power extracted.

$$P_t = \frac{1}{2} C_p \rho S V_w{}^3 \quad (3)$$

This coefficient represents the aerodynamic turbine efficiency. It depends on the characteristic of the turbine. It can be defined as the ratio:

$$C_P = \frac{P_t}{P_{wind}} \quad (4)$$

The power coefficient C_p was introduced by the theory of Betz. The Betz limit shows that for the best machines: two-bladed or three-bladed, horizontal axis, it does not pick up that 59% of the energy from wind, which means that C_{pmax} (theoretical) is approximately equal to 0,59. For a wind turbine of real power, it is in the order of 0.3 to 0.4 or less.

The variation coefficient is often represented as a function of the specific speed also called a reduced speed noted λ.

The specific speed is calculated by dividing the linear speed of blade by the wind speed as follows where R_t is the radius of the blade:

$$\lambda = \frac{R_t . \Omega_t}{V_w}$$

(5)

Some numerical approximations have been developed in the literature to calculate the coefficient Cp and different expressions have been proposed. We present, in the table 1, different form expressions for approximation used in different scientific papers to determine the power coefficient.

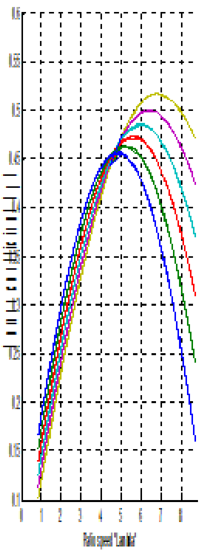
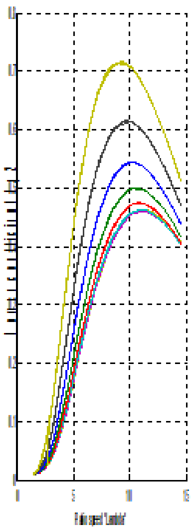
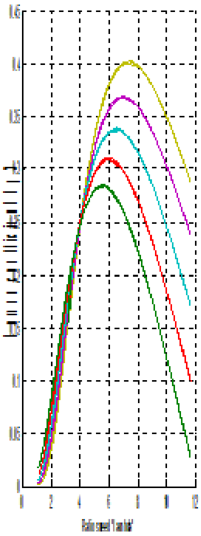
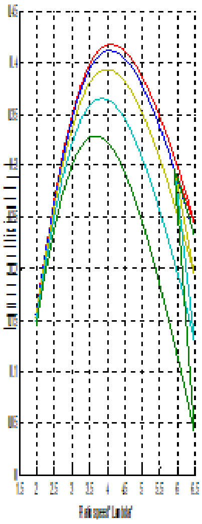
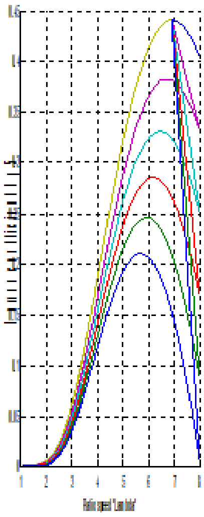
Table 1. Different Cp form expressions.

C_p expressions	The affected constants
$C_{p1}(\lambda,\beta) = [0.5 + 0.167(\beta - 2)] \sin\left[\frac{\pi(\lambda + 0.1)}{18.5 - 0.3(\beta - 2)}\right] - 0.00184(\lambda - 3)(\beta - 2)$	$\lambda : Reduced - speed$ $\beta : Pitch - angle$
$C_{p2}(\lambda,\beta) = C_1(C_2(\frac{1}{\lambda + 0.08\beta} - \frac{0.0035}{\beta^3 + 1}) - C_3\beta - C_4)e^{-C_5(\frac{0.0035}{(\lambda + 0.08.\beta).(\beta^3 + 1)})} + C_6.\lambda$	$C_1 = 0.5109, C_4 = 5$ $C_2 = 116, C_5 = 21$ $C_3 = 0.4, C_6 = 0.0068$
$C_{p3}(\lambda,\beta) = 0.22(\frac{116}{\lambda'} - 0.4 * \beta - 5)e^{\frac{-12.5}{\lambda'}}$	$\frac{1}{\lambda'} = \frac{1}{\lambda + 0.08.\beta} - \frac{0.035}{\beta^3 + 1}$
$C_{p4}(\gamma,\beta) = (\gamma - 0.22\beta^3 - 5.6)e^{-0.17.\gamma}$	$\gamma = \left(\frac{9}{4}\right)\frac{V_w}{\Omega_t}$
$C_{p5}(\lambda,\beta) = 0.73(\frac{151}{\lambda'} - 0.58\beta - 0.002\beta^{2.14} - 13,2)e^{\frac{-18.4}{\lambda'}}$	$\frac{1}{\lambda'} = \frac{1}{\lambda - 0.02.\beta} - \frac{0.003}{\beta^3 + 1}$

3.3. Comparative Study of Different C_p

In the literature different C_p are presented by graphs. The power coefficient is different from one another turbine.In fact the curves of the power coefficient of wind turbine commercial are given in the documentation provided by the manufacturer and can be used to define a mathematical approximation of the power curve using numerical optimization method. In the following table we present thedifferent curves obtained for the different C_p expressions presented in table 1.

Table 2. Different curves of C_p

Form of C_p	C_{p1}	C_{p2}	C_{p3}	C_{p4}	C_{p5}
The curve associate					

Analyzing the curves obtained from the simulations of the different forms of the power coefficient expression in table 2, it is judged not necessary to develop different approximations for all wind turbines types, since the differences between the curves of different forms of approximation of C_p are generally low and can be neglected in many frequently applications.

In that direction that we specify the power curves of wind turbines which we will focus in our application can be approximated by C_{p1}.

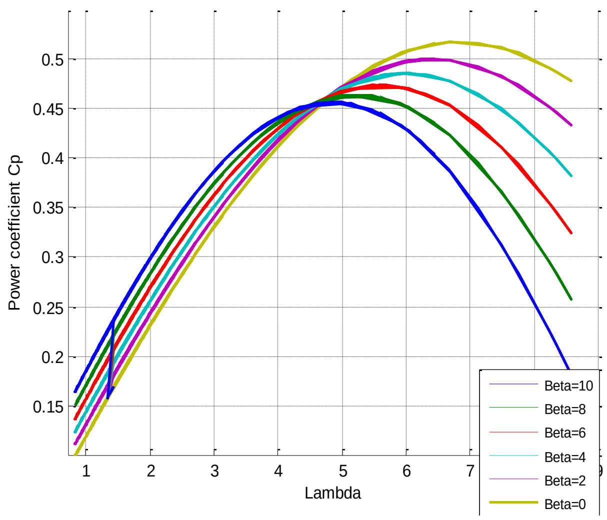


Fig. 4. The Cp - λ characteristic of wind turbine

We can interpret this network twofold, firstly as mentioned by the forward energy cannot be fully captured by the wind which is explained by the German physicist *Betz* theorem. In fact so far this limit is not reached. Only 60-70% of the theoretical maximum power can be exploited by the more advanced gear. On the other hand, the figure also illustrates the variation of this coefficient for different pitch angle values.

For each C_p curves, we can observe specific λ_{opt} optimal speed corresponding to the maximum aerodynamic performance (C_{pmax}).

3.4. Turbine Torque

The torque applied by the wind on the turbine is the ratio between the mechanical power derived from the wind turbine P_t and the rotational speed Ω_t.

$$T_t = \frac{P_t}{\Omega_t} \tag{6}$$

Introducing the ratio of the rate λ in the above equation, the expression of the torque becomes:

$$T_t = \frac{\rho S C p V_w^2 R_t}{2\lambda} \quad (7)$$

If we define the torque coefficient C_T, such as:

$$C_T = \frac{C_p}{\lambda} \quad (8)$$

The electromagnetic torque can be written as follows:

$$T_{em} = \frac{1}{2}\rho\pi R_t^3 C_m V_w^2 \quad (9)$$

The torque coefficient is illustrated by figure 5.

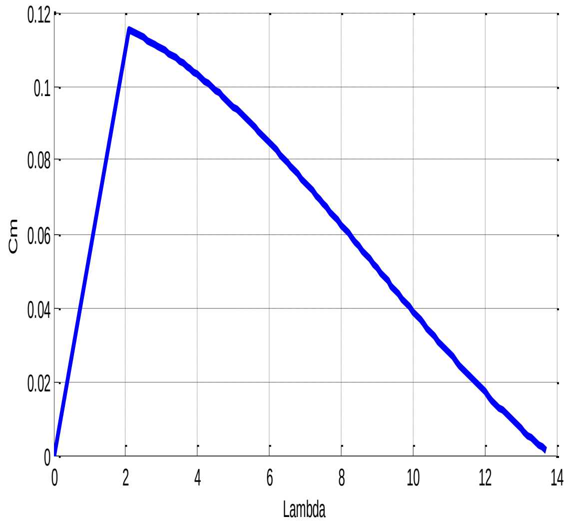


Fig. 5. The torque coefficient

The torque developed by DC-machine is given via the simulink diagram presented by figure 6.

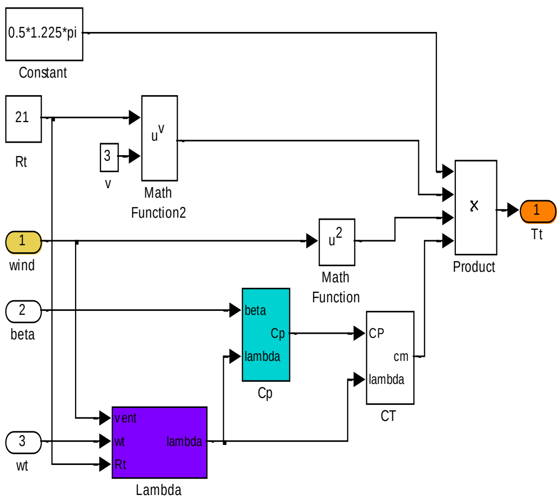


Fig. 6. Block diagram implemented in simulink

The variation of the torque versus time is given by figure 7.

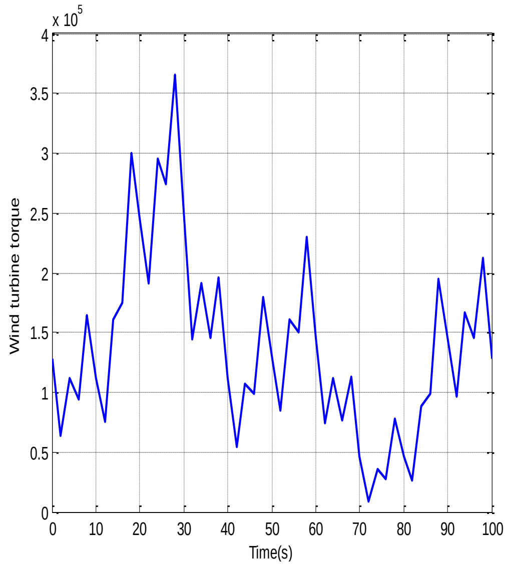


Fig. 7. The evolution of torque's wind turbine

The figure 8 shows the evolution of DC-Machine- speed, under a reference torque illustrated by figure 7.

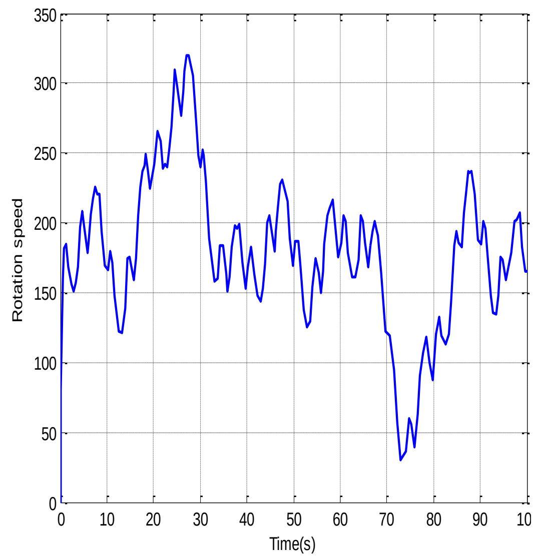


Fig. 8. The evolution of rotation- speed

4. DC- machine: Modeling and Control

Since the emulator is the basis of a DC-Machine feeding via a PWM converter (chopper). In this section we will look at the study of the DC-machine and its control [13, 14].

4.1. DC- Machine Model

The functioning of DC machine is used in a very wide range of application. This orientation is partly related to the simplicity of its structure and the facility of equations model and secondly the existence of natural decoupling between the quantities that create the torque and flux.

Usually, separately excited DC motor can be used to reproduce the static and dynamic characteristics of real wind turbines.

The model of the machine is represented by the simulink block diagram of figure 9.

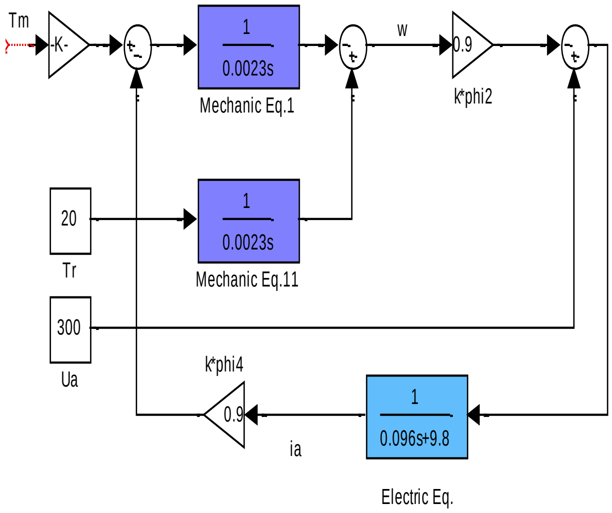


Fig. 9. The block diagram of the DC Machine

This model is a block diagram of the Dc machine in open loop.

4.2. The Control of the DC-Machine Model

Based on the principle of the linear regulation with multiple cascaded loops, the procedure of the machine control is essentially based on two loops: the first is an inner loop that controls the current; the second is an external loop controlling the speed.

The control structure in the motor speed is based on the use of: two sensors (the first sensor is used to the speed and the other to sensedthe current). the complete modele of control of a separately exited DC-machine represented by the figure 10.

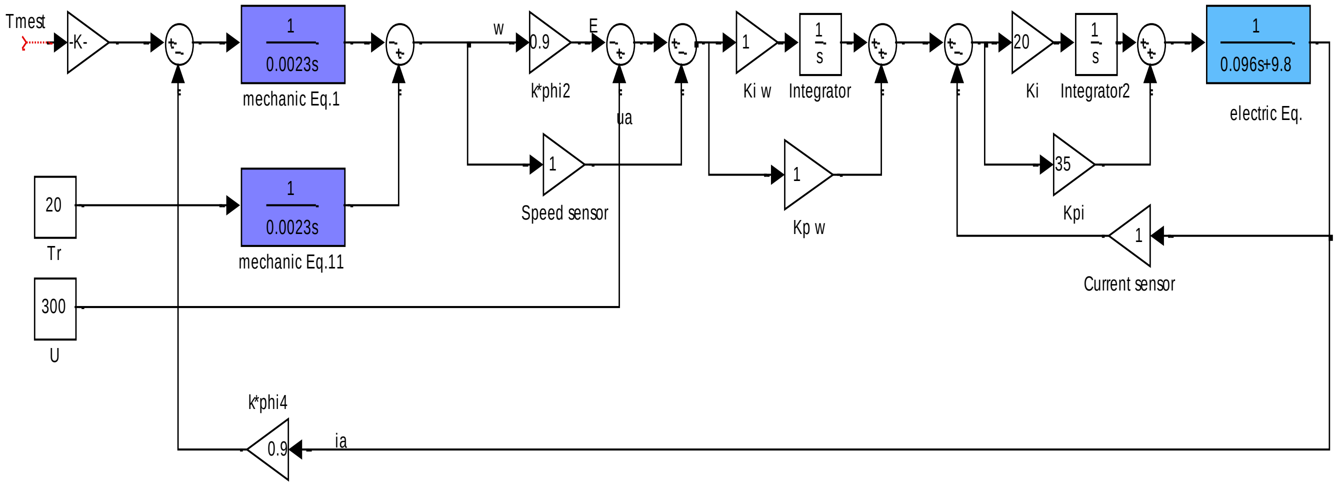


Fig. 10. Controller structure of the separately excited DC machine

4.3. Wind Turbine Simulator Model

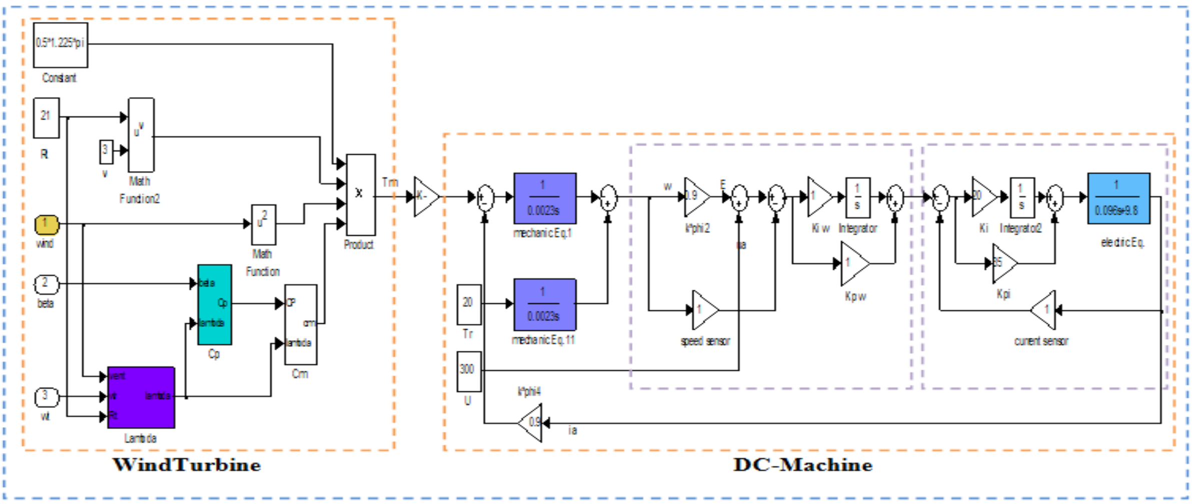


Fig. 11. Global wind turbine simulator model implemented in matlab / simulink

4.4. Simulation Results

4.4.1. Overview of Wind Turbine Simulator Simulation

In this section we tried, as a first step to resolve the problem acquisition given by the realization of an adapter board for electrical sensors based Hall Effect and mechanical quantities by way of an incremental encoder as well as the work of design and construction. Then we study the control of DC motor which is provided by a microcontroller family microchip.

The generation of the PWM signal and PI control are implemented by the microcontroller 18452.

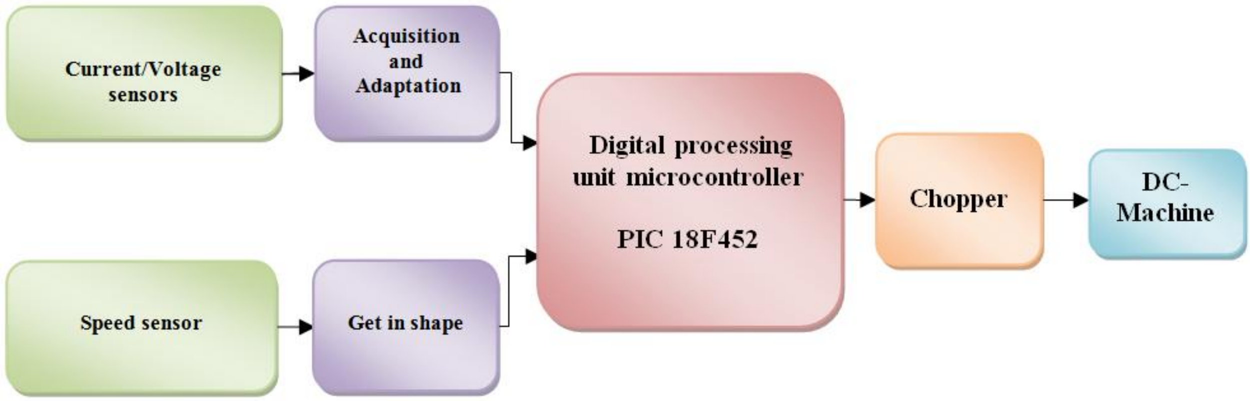


Fig. 12. Diagram explaining the design WTS

4.4.2. Wind turbine simulator controller simulation

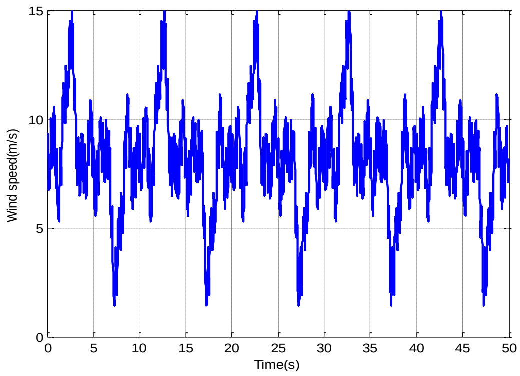


Fig. 13. Generated wind profile

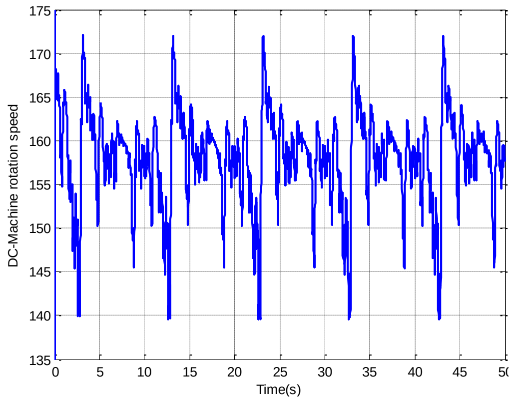


Fig. 14. Rotation speed of DC-Machine

The previous figure shows the changes in the speed of the DC- machine.

5. Conclusion

This paper described the different parts of a wind turbine simulator; the working principles, structures, and test results. In our study, the emulation of the wind turbine is made by association: machine- converter: DC-Machine-four quadrants chopper.

In fact, we are interested in modeling the different components of the wind system. The simulation results show that WTS effectively reproduces the turbine behavior. It can be used to control different types of generators; synchronous generator, the double-fed asynchronous generator and the induction squirrel cage one.

The continued development of this platform will be to connect the different parts of a test bench, and to consider their simultaneous operation.

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