Chapter

Modeling of the Small Wind Energy in Saharan Region of Algeria

Harrouz Abdelkader, Fadila Tahiri, Boussaid Brahim and Fatiha Bekraoui

Abstract

In the last century, research for the wind power industry started to gain importance in the field of renewable energies. This research is mainly on the side of big wind power. This wind form, are grouped and connected to the electricity grid. In the other form, the small wind power for production in isolated areas. This wind are applicated for example: telecommunication stations, sailboats and isolated areas. This power is from 100 W to a few tens of kilowatts. They are applied to power installations, for example, telecommunication stations, sailboats, and isolated areas. The use of small wind power in the region of Adrar—the southwest of Algeria—is an economical and durable solution. This chapter will focus on the modeling of the main components of a small wind turbine adapted to Saharan regions. The wind chain consists of a wing coupled directly to a synchronous generator that delivers on a continuous bus via a rectifier; it is the overall structure of the chain that we retain for modeling in this chapter. In order to control the system, the modeling of this study touches all the parts of the system: the turbine, the generator PMSG, and the converter with the load. At the end, simulation results are presented to show the good performance of the choice of control type that is applied to the wind system.

Keywords: wind, modeling, electricity, MPPT

1. Introduction

Wind energy is one of the fastest-growing renewable energy in the world. The wind resource comes from the movement of air masses that is directly related to the sunshine of the earth. By warming certain areas of the planet and cooling others a pressure difference is created and the air masses are in perpetual motion.

Since the use of the windmill, wind sensor technology has been evolving. It was in the early 1940s that real prototype wind turbine blades were successfully used to generate electricity. Several technologies are used to capture wind energy (vertical axis or horizontal axis sensor) and the sensor components, the mechanical characteristics of the wind turbine, and the synchronous and asynchronous machines are efficient [1].

In the region of Adrar (located in the southwest of Algeria), there are isolated sites, where the use of this abundant source of energy, is an economical and durable solution. The permanent magnet synchronous machine is characterized by high volumetric torque, very low inertia and low inductances. All of these features

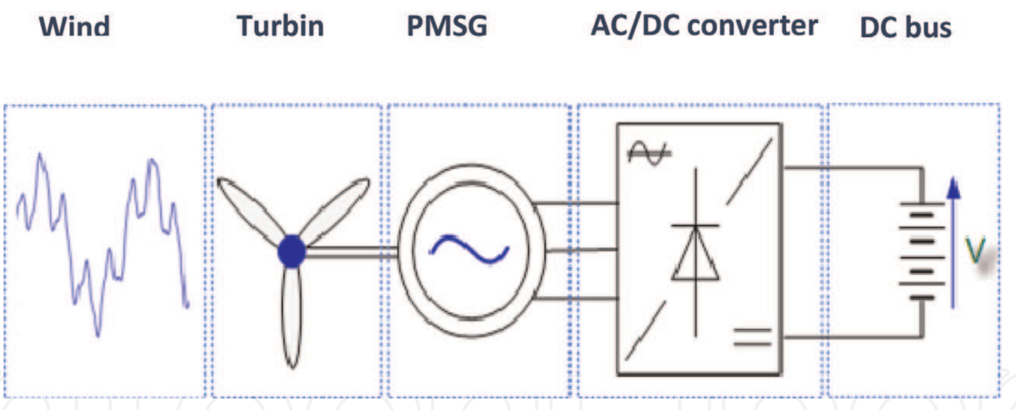

Figure 1.
Schematic diagram of a wind chain.

provide the generator with high performance, high efficiency and better control. This puts this machine in competition with the asynchronous machine [2].

To meet the demand for autonomous electric charge at remote sites, small wind turbines smaller than 5 kW have become a very important system for the production of electricity. Current research will study the functional analysis, control and modeling techniques appropriate for this small turbine system [3].

Modeling of the wind turbine recently published by many authors, Harrouz et al. [4] have modeling of small wind energy based on PMSG in the south of Algeria. Langlois [5] have modeling and study the performances of wind system out the link. Tran [6] has present work of optimal design integrate of wind energy "passive" robustness analysis, experimental validation. Jedli and Hidouri [7] present a power drive scheme for an Isolated pitched wind turbine water pumping system based on DC machine, this work can be a good application of win system in Sahara region. Modeling, simulation, and control of a variable speed wind turbine based on the asynchronous dual-feed generator [8].

The wind energy conversion chain is schematized as shown in **Figure 1**.

This consists of a wing coupled directly to a synchronous generator that delivers on a DC bus via a diode rectifier; it is the structure that we retain for this work.

The control strategies of this system and their possible load connection interfaces must make it possible to capture as much energy as possible over the widest possible range of wind speeds, with the aim of improving the profitability of wind turbine installations.

The section after will focus on the modeling of the main components of a small wind turbine adapted to saharan regions such as Adrar.

2. Modeling of the small wind

2.1 Modeling the wind

The wind is highly variable, both geographically and over time. It varies from one place to another, from 1 day to another, and from 1 s to the next. It is the energy input vector of a wind chain, determining for the calculation of electricity production, therefore for profitability [2].

The dynamic properties of the wind are crucial for the study of the whole system of energy conversion because the wind power, in the optimal conditions, is at the cube of the wind speed (see formula (2)) These fluctuations are influenced by the displacement of air masses at altitude, but also by the relief, the type of soil cover and the thermal stability of the atmosphere. The wind varies in direction and intensity, but for the purposes of the model, it is limited to the variation of the wind in intensity, in a single direction in order to determine a valid and representative sequence of real winds [2–8].

Different approaches used in the literature for the generation of a synthetic series of wind, in our case, the wind speed will be modeled by a sum of several harmonics [2, 4, 9]

$$V_{vent}(t) = A + \sum_{k=1}^{i} a_k \sin(\omega_k . t) \tag{1}$$

where a_k: amplitude of the harmonics; ω_k: frequency of harmonics.

The wind speed is represented by the function:

$$V(t) = 10 + 0.2 \sin(0.1047t) + 2 \sin(0.2665t) + \sin(1.2930t) + 0.2 \sin(3.6645t) \tag{2}$$

It should be noted that this particular wind profile corresponds to [9–12].

2.2 Modeling of turbine

A wind turbine is a machine that, by definition, transforms wind energy into mechanical energy. To begin, it is necessary to quantify the energy source available, i.e., the energy associated with the wind. If the wind has a certain speed "*V*" at a given moment and crosses a certain area "*A*," the instantaneous wind power is given by the following relation

$$P_m = \frac{1}{2} C_p \rho A V^3 \tag{3}$$

where ρ is the density of the air, which is approximately 1.2 kg/m^3; A is the area swept by the turbine in m^2; and V is the wind speed in m/s. C_p (power coefficient).

The turbine used in our work is a "Savonius" wind turbine with a vertical axis (see **Figure 2**).

Surface "*A*" given by the following formula:

$$A = 2R.H \tag{4}$$

where R represents the radius of the wing (m) and H its height (m).

The output power is given by the following equation that we will normalize in pu:

$$P_m = C_p(\lambda).\rho.H.R.V^3 \tag{5}$$

where C_p is a coefficient that expresses the efficiency of the wing in the transformation of the kinetic energy of the wind into mechanical energy, which is in fact often

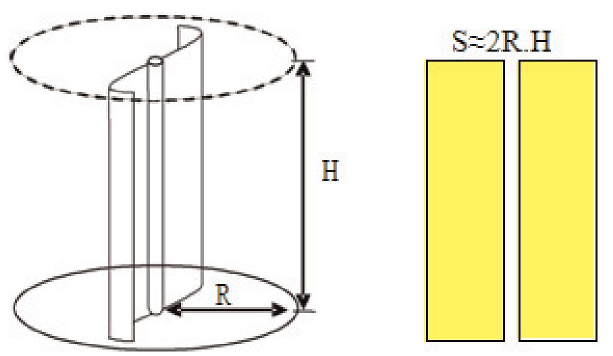

Figure 2.
Wind vertical axis of Savonius type [7].

given as a function of the reduced speed (the specific speed λ), which is the ratio of the linear speed at the end of turbine blades reduced to wind speed, defined by:

$$\lambda = (R.\Omega)/V \tag{6}$$

where Ω the angular rotation speed of the blades in rad/s.

The evaluation of the power coefficient is a data specific to each wind turbine. From the readings taken on a wind turbine, the expression of the power coefficient has been approximated, for this turbine [13, 14], by the analytical equation as a function of λ (resulting from the interpolation) according to:

$$C_p(\lambda) = -0.12992\ \lambda^3 - 0.11681\lambda^2 + 0.45406\,\lambda \tag{7}$$

Figure 3 represents the characteristics of power coefficient as a function of λ, it presents a maximum power factor C_{pmax} = 0.19 for $\lambda_{\max}$ = 0.55.

The wind torque noted C_e is obtained from Eq. (5) and using the expression (6) of the reduced speed (**Figure 4**):

$$C_e = \frac{P_m}{\Omega} = \frac{Cp(\lambda).\rho.R^2.H.V^2}{\lambda} \tag{8}$$

The Model of the wind torque under Simulink presented in **Figure 4**. The **Figure 5** shows the characteristic of the turbine through the wind power extraction of the turbine as a function of the wind speed.

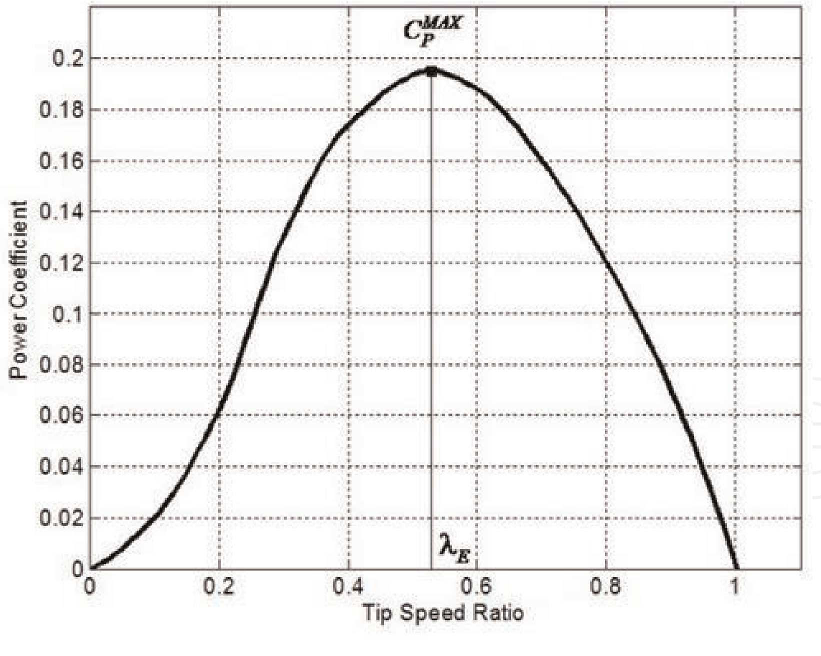

Figure 3.
Power coefficient C_p as a function of λ for Savonius wind turbine.

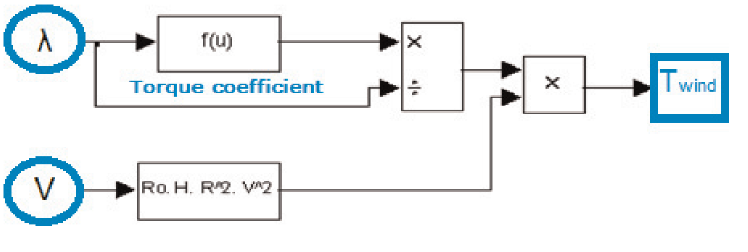

Figure 4.
Model of the wind under Simulink.

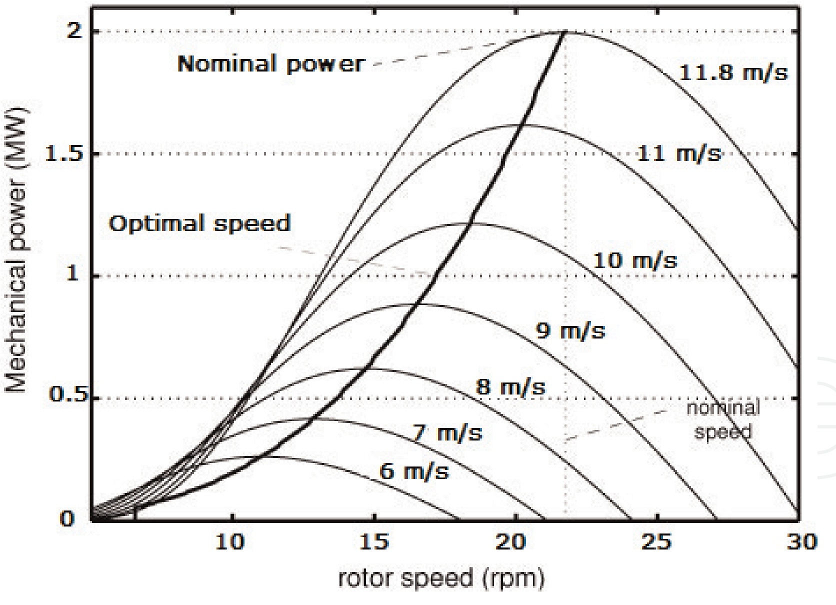

Figure 5.
The output power for different values of wind speed (m/s).

It can be seen from **Figure 5** that the electric power varies with the variation of the mechanical angle of the turbine. The shape of the electric power as a function of the mechanical angle is seems to be that of the Cp as a function of λ. We also note that the higher the wind speed, the greater the power delivered because the power is expressed by the cubic wind speed.

2.3 Mechanical modeling of the turbine-generator coupling

The dynamic (mechanical) behavior of the turbine and generator assembly can be represented by the following relation:

$$J\frac{d\Omega}{dt} = C_e - C_{em} - C_f \tag{9}$$

where Ω the speed on the generator shaft, C_f the friction torque, C_{em} the electromagnetic torque developed by the generator, C_e the mechanical torque applied to the alternator shaft and J is the total moment of inertia, calculated with:

$$J = J_{gen} + \frac{J_t}{i^2} \tag{10}$$

We take note that:

$$C_f = f_m.\Omega \tag{11}$$

where f_m is the coefficient of viscous friction in N.m.

The wind torque provided by the turbine, drives the generator. Taking into account the torque drops caused by the friction and the inertia of the turbine, we can establish the electromechanical model of **Figure 6**.

2.4 Model of the GSAP

According to Chapter, the Permanent Magnet Synchronous Generator (PMSG) is classically modeled in the Park coordinate system, giving rise to the following equation:

$$\begin{cases} V_d = -R_s.I_d - L_d\dfrac{dI_d}{dt} + L_q\omega.I_q \\ V_q = -R_s.I_q - L_q\dfrac{dI_q}{dt} - L_d\omega.I_d + \varphi_f\omega \\ J\dfrac{d\Omega}{dt} = C_m - C_{em} - F.\Omega \\ C_{em} = \dfrac{3}{2}P\left[(Lq - Ld)I_d.I_q + \varphi_f.I_q\right] \end{cases} \tag{12}$$

where: θ is the angle between a reference axis of the stator and an axis of the north pole of the rotor, p-the number of pairs of poles, R_s the resistance of a stator phase.

Also, φ_f is the excitation flux produced by the permanent magnets, L_d and L_q are the equivalent inductances on the d axes, respectively q.

C_{em} is the electromagnetic torque, C_m is the motor torque applied to the generator with F the coefficient of friction, J: moment of inertia and p the number of pairs of poles.

In order to know the dynamic characteristics of the various state variables of the machine and to validate the mathematical model, we proceed to a simulation of the machine using the Runge–Kutta algorithm of order 4.

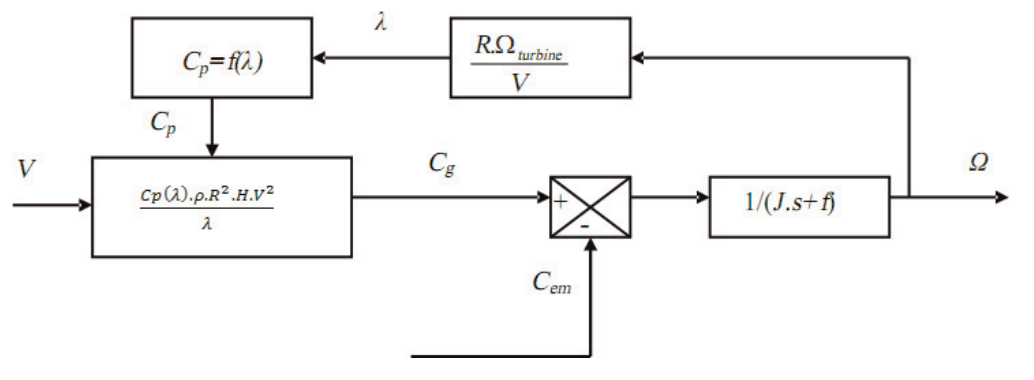

Figure 6.
Model of wind turbine torque.

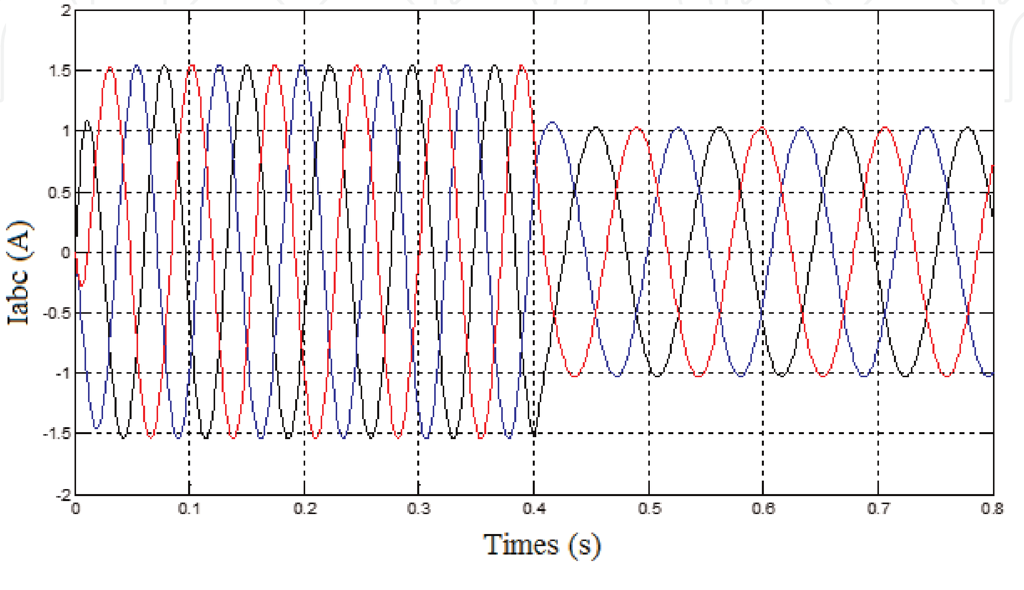

Figure 7.
Stator current I_{abc} of PMSG after simulation.

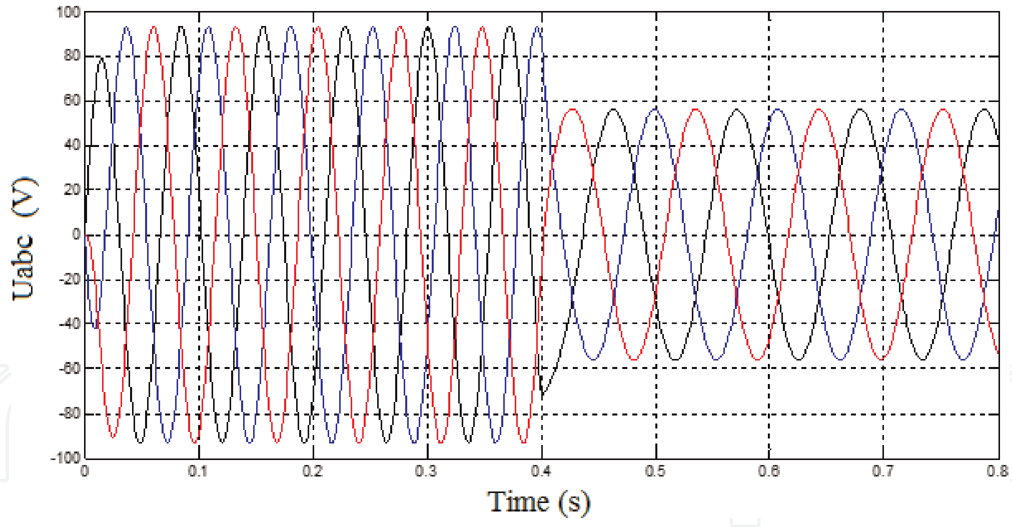

Figure 8.
Stator voltage of PMSG after simulation.

The response to an empty speed step is very fast. The torque peaks at startup and is proportional to the stator current. At full speed, the speed decreases while the torque increases to drive the load (**Figures 7** and **8**).

To see the efficiency of our model, the next part will be the subject of test on matlab/simulink with real parameters of the wind turbine and the wind speed.

3. Simulation of model PMSG with wind system

The wind will be modeled in deterministic form by a sum of several harmonics:

$$V(t) = 10 + 0.2\sin(0.1047t) + 2\sin(0.2665t) + \sin(1.2930t) + 0.2\sin(3.6645t) \quad (13)$$

The simulation results of the permanent magnet synchronous generator associated with the wind turbine and with the wind speed simulated by Eq. (13) are given by **Figure 9**:

We notice that the results take the form of the wind, the coefficient of power is 0.13 (it is the maximum value to have a maximum of power extracted from the wind). The active power is of the order of 400 W.

But this system presents fluctuations due to the variation of the speed of the wind for that the system needs a command to maintain this power at its nominal value. The next partie present the proposed control of system.

4. Command of wind system

The wind system studied is a complex system composed of several subsystems belonging to several different physical domains, namely, traditional mechanics, electrical engineering and electrochemistry. Energy from the wind passes through the wind turbine that is coupled to the GSAP generator and allows the transformation of mechanical energy into electrical energy. The electrical components such as the static converter disposed downstream of the generator, have a role of active adaptation of the characteristics of the electrical energy between the generator and the final load.

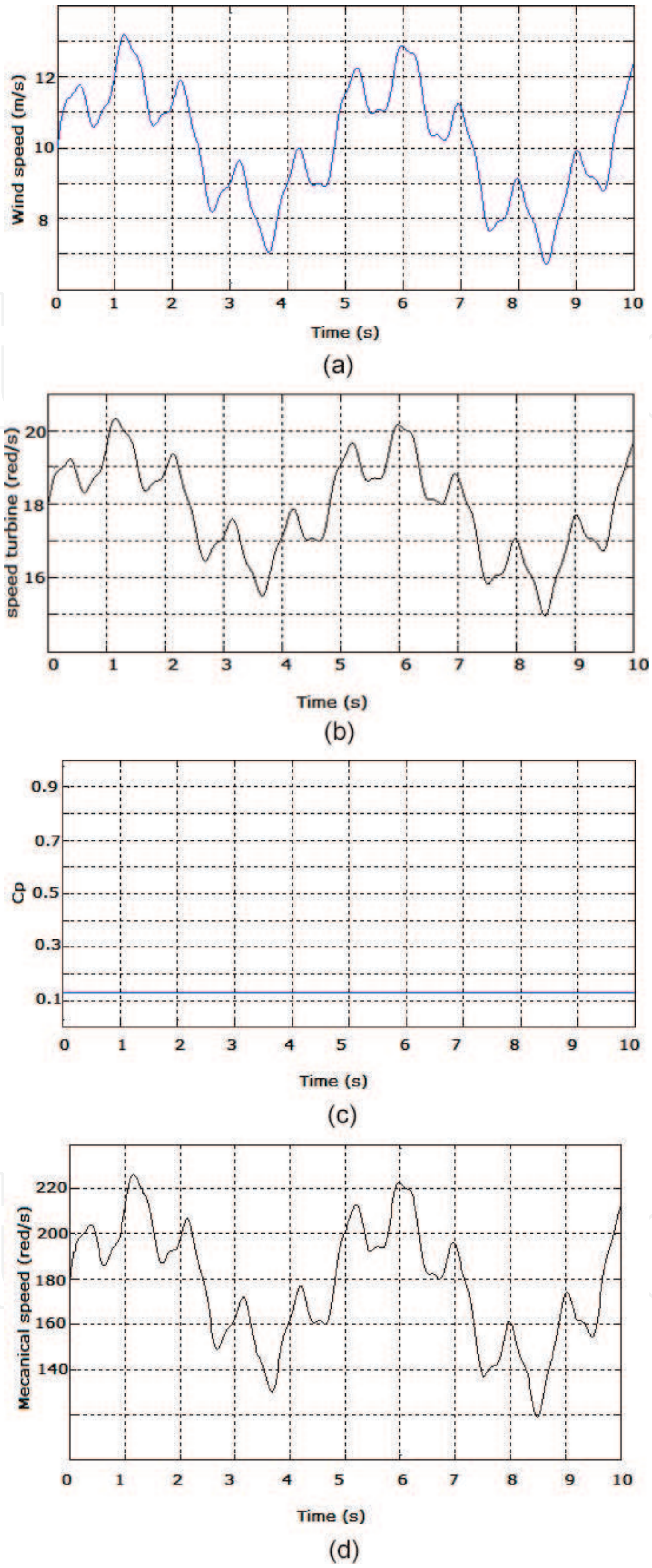

Figure 9.
The results of the wind turbine simulation. (a) The wind speed as a function of time. (b) The speed of the turbine as a function of time. (c) Power factor. (d) The electrical speed of the GSAP as a function of time.

The PWM rectifier was studied by simulation under MATLAB/SIMULINK according to the diagram of **Figure 10**, the current was controlled in the reference frame abc by hysteresis regulators, the reference of the voltage at the output of the

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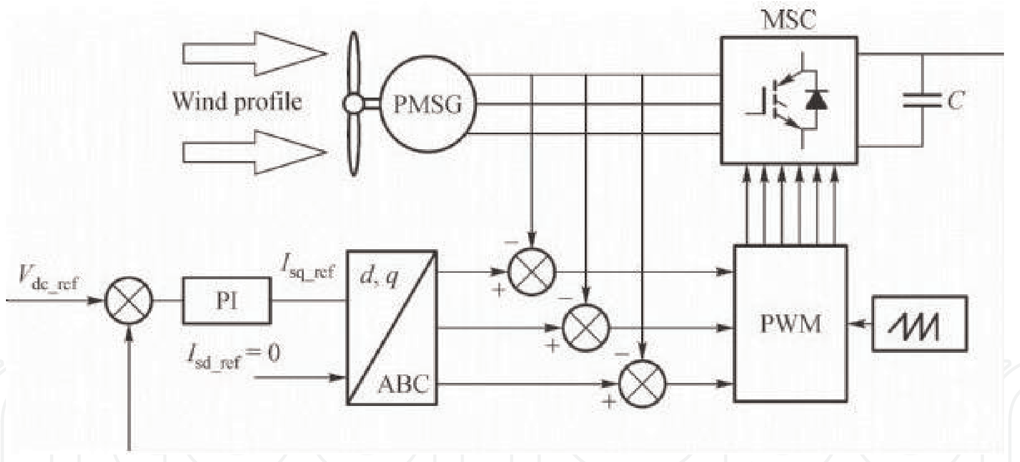

Figure 10.
Structure of control the wind system.

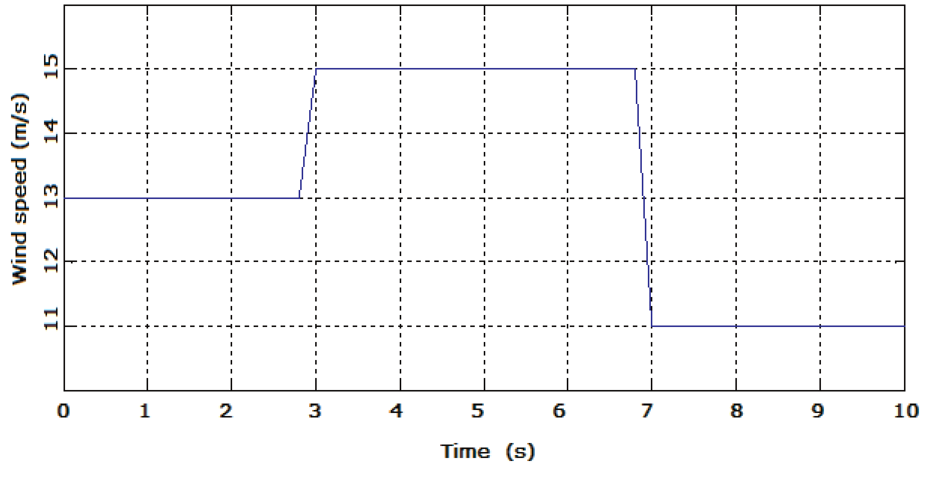

Figure 11.
Wind speed (m/s).

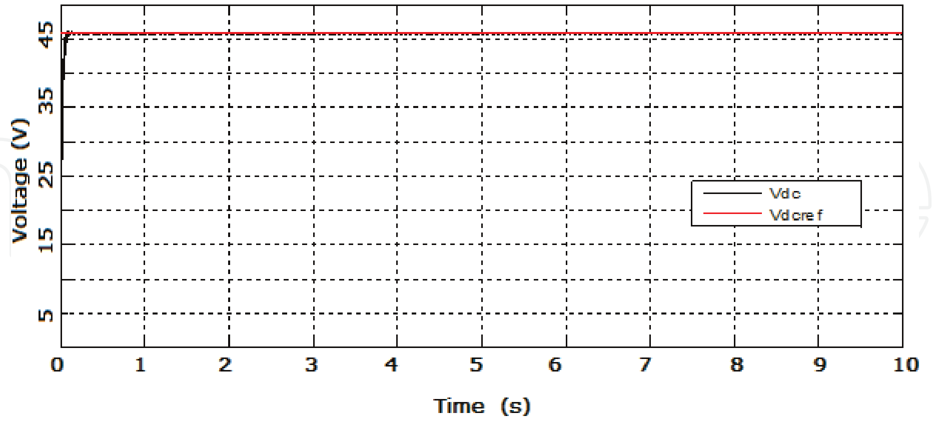

Figure 12.
Voltage rectified.

rectifier is taken equal to 45.8 V, We simulated the model of wind profile is given by **Figure 11**. **Figure 12** shows the DC voltage at the output of the rectifier with its proposed reference, it is observed that the DC bus voltage remains on average equal to 45.8 V. **Figure 13** shows the zoom of the rectified voltage.

According to the simulation results obtained, we conclude that the response of the voltage at the rectifier output (rectified) to a speed variation is relatively fast and does not exceed 2% of the reference value, during disturbances.

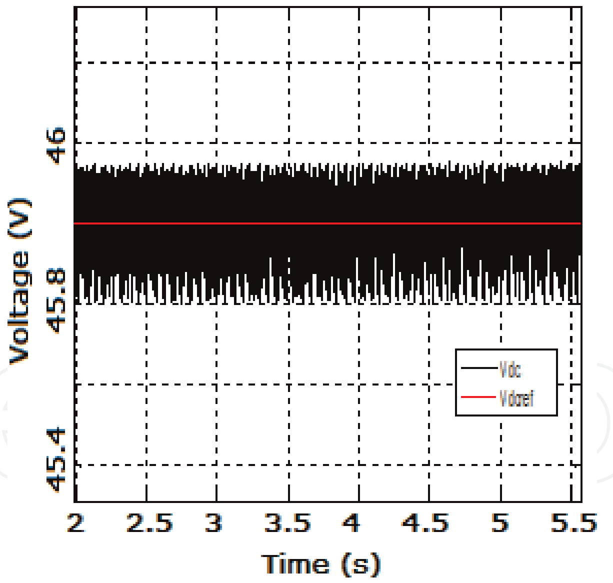

Figure 13.
Zoom of voltage rectified.

In spite of the increase or the decrease of the wind speed, the shape of the voltage of the continuous bus is established with 45.8 V with a time of response which depends on the control of the rectifier, of the order of 0.5 s in the example treated.

5. Conclusion

This chapter has established a global model of the wind energy conversion chain which consists of a GSAP permanent magnet synchronous machine associated with a wind turbine. The turbine used is the vertical axis Savonius type. They presented the simulation results of the complete wind energy production chain. The end of this chapter presents the application of the control of this wind energy production system. This control shows that the response of the voltage at the rectifier output (rectified) to a speed variation is relatively fast. In spite of the increase or decrease in wind speed, the speed of the continuous voltage is established with a response time which depends on the control of the rectifier.

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