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Modeling of Wind Energy on Isolated Area

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ABSTRACT

In this paper, a model of the wind turbine (WT) with permanent magnet generator (PMSG) and its associated controllers is presented. The increase of wind power penetration in power systems has meant that conventional power plants are gradually being replaced by wind farms. In fact, today wind farms are required to actively participate in power system operation in the same way as conventional power plants. In fact, power system operators have revised the grid connection requirements for wind turbines and wind farms and now demand that these installations be able to carry out more or less the same control tasks as conventional power plants. For dynamic power system simulations, the PMSG wind turbine model includes an aerodynamic rotor model, a lumped mass representation of the drive train system and generator model. In this paper we propose a model with an implementation in MATLAB / Simulink, each of the system components off-grid small wind turbines.

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1. INTRODUCTION

The wind power generation has been developed very quickly in the past few years [1]. With the growing penetration of wind energy generation into power grids, the impact of wind turbine (WT) on power system operations and stability control is of increasing concern.

WT system normally consists of wind turbine, generator and grid interface converters, among which the generator is an very important component in the WT system. During the development of the WT techniques, synchronous generator, induction generator and doubly fed induction generator were employed to convert wind power to electrical power. Wind turbines usually rotate at a speed of 15–20 rev/min, and Generators should rotate at the speed of 1000–1500 rev/min. Hence, a gearbox should be connected between a wind turbine and a generator. The gearbox causes unpleasant noise, increases the loss of the WT system, and also requires regular maintenance. In order to overcome these problems, the WT with permanent magnet synchronous generator (PMSG), where the gearbox was eliminated, was developed [2].

The variable-speed wind turbine is now the one that is most frequently installed. Over recent years, it has become the most popular type of wind turbine. This interest in variable-speed wind turbines is due to the wide range of advantages Offered, such as reduced mechanical stress, increased power capture, Wind energy in Algeria is only used for pumping water; the first experience of pumping water with wind turbine in Africa was conducted in 1957 in Adrar "Ksar Sidi Aissa" for irrigation of 50 hectares [3]. The wind resource in Algeria varies greatly from one location to another. This is mainly due to a very diverse topography and climate. The Adrar region, in South Algeria, presents an excellent wind energy potential as shown by the figure below. The annual mean power density is very interesting recoverable by the wind. Which allows supplying electrical energy to remote areas (Forages, Kessour), where connection to the grid is not possible or economically expensive.

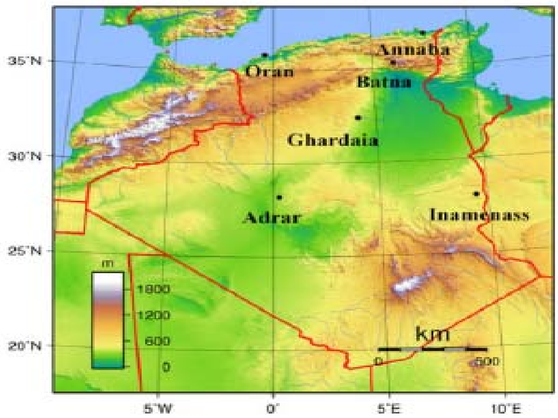

Figure 1. Topographical map of Algeria

Table 1. Average Wind Speed [14]

Station	V (m/s)	k	A (m/s)	Wind power density (W/m^2)
Adrar	6.34	2.15	7.2	283
Béchar	4.15	1.35	4.8	168
Ghardaia	4.69	1.65	5.6	183
In Aménas	4.77	1.86	5.6	155
Tamanrasset	3.37	1.46	4.0	83
Tindouf	5.06	1.98	6.1	187

In this paper we will be interested more specifically to the modeling of the major components of a small wind turbine adapted to regions such as Adrar Sahara.

2.1. Model of PMGS

Basically, PMSG is a Permanent Magnet Synchronous Generator; the equivalent circuit is shown in Figure 2. Aligning the direction of the d axis of the d–q reference, the model of the PMGS is given by [4], [5]:

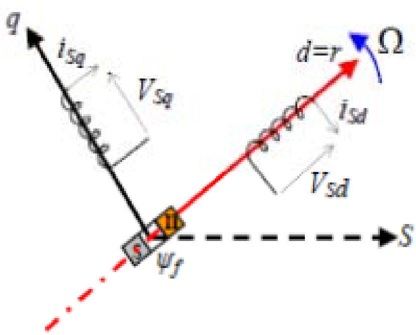

Figure 2. PARK model for PMSG

$$\begin{cases} u_d = -R_s \cdot I_d - L_d \dfrac{d\,I_d}{dt} + L_q\,\omega \cdot I_q \\ u_q = -R_s \cdot I_q - L_q \dfrac{d\,I_q}{dt} - L_d\,\omega \cdot I_d + \phi_f\,\omega \end{cases} \quad (1)$$

Where u_d and u_q are the direct (d) and quadrature (q) axis stator voltage, respectively, I_d and I_q are the d and q axis stator current, respectively, R_s is the resistance of the stator; L_d is the inductance of the stator. ω is the generator electrical speed.

The Power equations are given by:

$$P(t) = \frac{3}{2}[R_S(I_d + I_q) + (I_d \frac{d\phi_d}{dt} + I_q \frac{d\phi_q}{dt}) + \frac{d\theta}{dt}(I_q \varphi_d - I_d \phi_q)] \quad (2)$$

The electromagnetic torque has the expression:

$$Te = kP[(Lq - Ld)\, I_d \,.\, I_q + \phi_f \,.\, I_q)] \quad (3)$$

Where k take the values 1 or 1.5, depending on know the transformation is performed park (In this case, k =1.5). The instantaneous power of the machine is [6]:

$$P(t) = u_d \cdot I_d + u_q \cdot I_q \quad (4)$$

2.2. Model of Converters

The rectifier most frequently used is a diode bridge perfect. This is an electronic device that is placed between the alternator and the battery to turn the three AC voltages at the output of the alternator voltage. The bridge consists of six diodes, as shown in Figure 3. In reality, the voltage at the output of the bridge presents undulations with a frequency 6 times that of the alternator, so often we add a condenser in order to smooth the tension at its output.

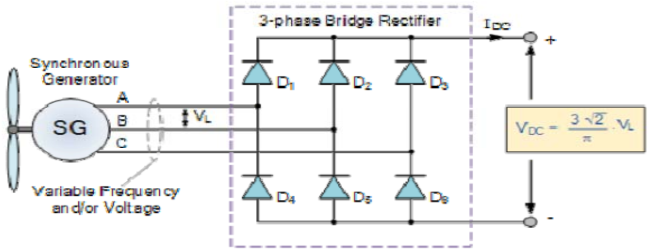

Figure 3. Magnet generator charged to the DC bus

The mean voltage *Vcc* to the output of three-phase bridge rectifier is given by [2]:

$$V_{CC} = \frac{3\sqrt{2}}{\pi} V_L \quad (5)$$

Or V_L effective voltage between two lines of the synchronous generator, for a star connection of the line neutral voltage, the relationship between the voltage to the terminals of the generator and the V_{DC} voltage of the battery is given as follows:

$$V_{DC} = \frac{\pi}{3\sqrt{6}} V_{CC}$$

3. DYNAMIQUE MODEL OF WT WITH PMGS SYSTEM
3.1. Wind Modeling

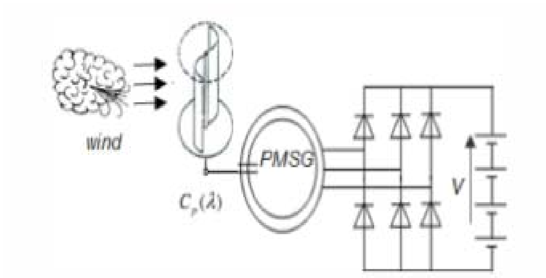

Figure 4. Wind Turbine chain of conversion energy

The PMSG associate with a wind turbine is show in Figure 3. The PMGS and which discharges directly through a three-phase diode bridge, on the DC bus and the DC bus and the electrochemical battery.

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, that is to say; the energy associated with the wind.

A different approach used in the literature to generate a synthetic series of wind in our case, the wind speed is modeled by a sum of several harmonics [3]:

$$V_{wind}(t) = V_0(1 + \sum_k A_k \sin(w_k.T)) \tag{6}$$

Where:

V_0: is a value of wind velocity
A_k: is amplitude of harmonic
W_k: is frequency of harmonic

To produce energy, a wind turbine requires a wind speed of minimum of (6.34 m / s). This is verified from all year in the region of Adrar.

3.2. The Turbine Modeling

The instantaneous power of the wind is given by the following equation [7], [11]-[12]:

$$P_m = \frac{1}{2}\rho \cdot A.C_p.V^3 \tag{7}$$

Where ρ is the air density which is approximately 1.2kg/m3, A is the swept area by the blades. The power coefficient C_p is a function of the tip speed ratio, λ which is the ratio of the linear speed at the tip of blades to the speed of wind, expressed as:

$$\lambda = \frac{\Omega.R}{V} \tag{8}$$

R is the radius, Ω is the mechanical angular velocity, respectively, of the wind turbine rotor. Expression of C_p as a function of λ employed in [8]-[10] are:

$$C_p(\lambda) = -0.2121\ \lambda^3 + 0.0856\,\lambda^2 + 0.2539\,\lambda \tag{9}$$

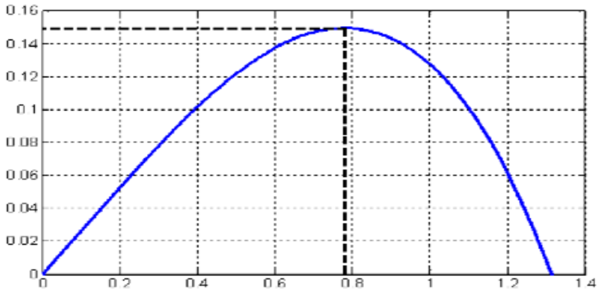

Figure 5. The characteristic used for the test $C_p(\lambda)$

The Figure 5, represents the characteristics power coefficient as a function of λ, the maximum power coefficient ($C_{p\,max}$=0.15) is attained for λ_{max} = 0.78 [14].

The turbine used in the context of our word, is a wind turbine "Savonius" vertical axis is show in Figure 6.

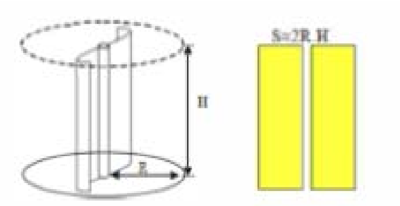

Figure 6. Turbine type "Savonius"

$$J\frac{dw}{dt} = T_e - T_{em} - f_m.w \qquad (10)$$

Where J is the rotation moment of inertia of the rotor and the generator kg.m2, w is the angular velocity of the rotor in red/s, T_e is the mechanical torque applied to the alternator shaft in Nm, T_{em} is the electromagnetic torque developed by the generator in Nm and f_m us the viscous friction coefficient in Nm.

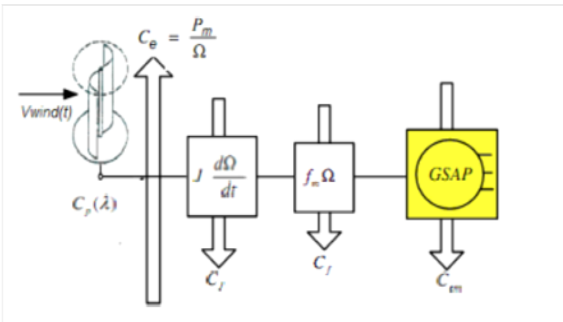

Figure 7. Torque of wind turbine

4. SIMULATION RESULTS

The results of simulation on the matlab-simulink Environment of all associated block diagrams. As shown in Figure (8-11). Of the wind torque, the wind power and the electromagnetic torque PMSG is registered, and has follows the variation of reference wind speed.

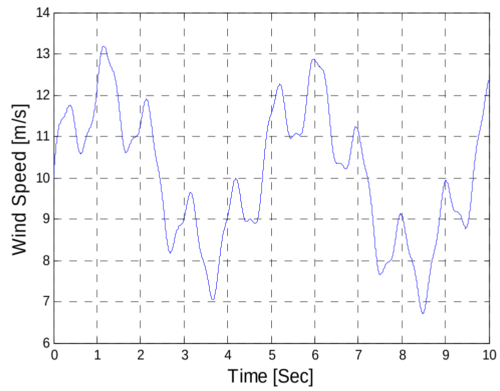

Figure 8. Wind profil

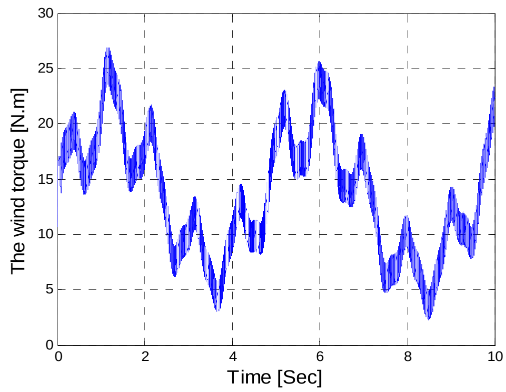

Figure 9. The wind torque

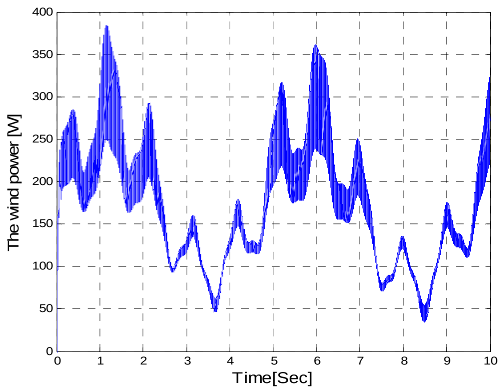

Figure 10. The wind power

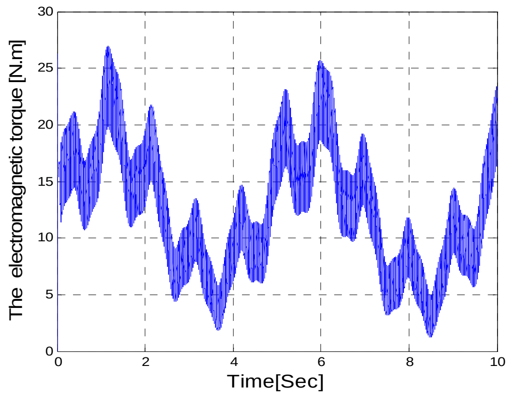

Figure 11. The electromagnetic torque PMSG

5. CONCLUSION

This article has described the modeling of PMSG and modeling of each major system components: wind, turbine and permanent magnet synchronous generator.

The simulations described in this paper demonstrate that the wind torque, the wind power and the electromagnetic torque PMSG is registered, and has follows the variation of reference wind speed.

Pumping water from boreholes for wind power and remote areas inhabited or remote agricultural areas can be the basis of experimental studies to validate the model. This option will allow water managers do not have the energy source as a constraint [13] especially in a region where the only water resource is groundwater.

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