Modelling and Control of generator PMSG based of Wind Energy Systems

A. Harrouz, A. Benatiallah
Department of Electrical Engineering, Adrar University
Energy and Environment Laboratory Information System
Adrar (01000), Algeria
harrouz.onml@gmail.com, benatiallah@univadrar.org

O. Harrouz
Département de Gestion et Maitrise de l'Eau
Institut des Sciences de la Nature et de
l'Agroalimentaire de Bordeaux (ISNAB) - Bordeaux, France
harrouz@isnab.fr

***Abstract*— Small wind turbines offer a promising alternative for many remote electrical uses where there is a good wind resource. This paper describes a new model to control permanent magnet synchronous generator (PMSG) based of wind energy conversion systems. This model system consists of a rectifying control by the DPC connected to the PMSG which is driven by a turbine vertical axis wind type"Savonius". After, this turbine is used to drive the PMSG in order to feed the isolated (R, L) load. The control study concerns the converter; the method proposed is around two hysteresis controllers that enable to adjustment of active and reactive power. Finally, after using Matlab, the simulation results show a high performance proposed as control.**

***Keywords*— modelling; wind turbine; rectifier; control; Permanent-magnet synchronous generator (PMSG);**

I. INTRODUCTION

Renewable energy comes from natural sources that are constantly and sustainably replenished. Among these sources of energies, we find the wind power energy that occupies a particular place. Wind power is an affordable, efficient and abundant source of domestic electricity [10]. It's pollution-free and cost-competitive with energy from new coal- and gas-fired power plants in many regions. The wind power sector has experienced strong growth in recent years pushed by new environmental and economic imperatives [2].

A. Advantages of wind energy

- Wind energy produces no polluting emissions of any kind, including those that cause global warming [10].
- Wind turbines use a fuel that's free, inexhaustible and immune from the drastic price swings to which fossil fuels are subject.
- With careful sitting and outreach to the local community, wind farms can be built in a fraction of the time it takes to construct coal or natural-gas power plants. A 50-megawatt wind farm can be completed in less than a year.
- In the right location, it takes only three to eight months for a wind energy farm to recoup the energy consumed by its building and installation -- one of the fastest "energy payback times" of any energy technology on the market.
- Although bird and bat safety are ongoing concerns, wind power does not contribute to the plethora of other environmental and public health costs caused by conventional fossil power production: acid rain in lakes, mercury in fish, particulate-matter respiratory illnesses, coal mine slag, nuclear waste fuel storage.
- The growing use of wind energy creates manufacturing and technical jobs, and significantly more jobs per dollar invested compared to non-renewable technology.
- Wind power consumes no water during operation. This will be an increasingly important attribute as the water-energy nexus grows in importance and as water use becomes an increasingly important facet of defining sustainability.

B. Small wind turbines

One of the greatest challenges associated with wind power is the unpredictable character of the wind. Even at the best wind sites, those with steady reasonably high speed wind, there are variations in speed and direction of the wind which affect the ability of the wind turbine to deliver power. Larger wind turbine systems have complex control systems which automatically track changes in wind direction and speed, and adjust turbine orientation, blade pitch, and generator gearing to maintain the desired electrical output [11].

Small turbine systems are typically much less sophisticated, however they generally still have some form of control to improve their longevity and power production. The main purposes of a controller in a wind energy system are (in order of priority):

- Prevent damage to the wind turbine
- Prevent damage to the load
- Maximize power production

We will concern ourselves here with smaller wind turbine systems, figure 1, which we will define somewhat arbitrarily as those systems rated at 1k or less. Such small systems in the past have been predominantly designed for sturdiness, with robust mechanical controls, and relatively modest overall performance. With advances in microcontrollers, and electronic power switching components, however, the level of sophistication of these small wind systems has been steadily improving [11].

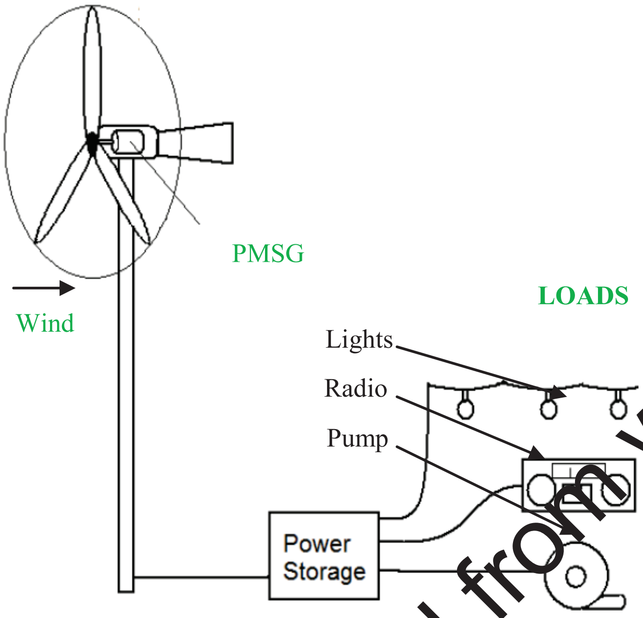

Figure 1. Schematic diagram of a typical small wind turbine power

In this paper we will investigate the controls associated with small wind turbine systems, culminating in a detailed description of the direct power control DPC, including all the system by developing the technique for estimating the various quantities needed to control the converter.

The active and reactive power is used as the pulse width modulated control variables instead of the three-phase line currents usually used. Moreover, line voltage sensors are replaced by a virtual flux estimator and utilizing a microcontroller running an impedance matching DC-DC converter between the turbine and the load.

II. MODELLING OF SYSTEM

A. *Wind profil*

A different approach used to generate a synthetic series of wind in our case, the wind speed is modeled by a sum of several harmonics [1, 2, 7, and 9]:

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

Where:

V_0 -is a value of wind velocity.
A_K - is amplitude of harmonic.
W_k - is frequency of harmonic

B. *Turbine Model*

The wind's kinetic energy can be harnessed by a wind turbine. The wind moves the turbine's blades, which transfer energy through a central hub to a generator. The generator converts this mechanical energy into electrical energy that is then delivered to the power grid. That is to say, the energy associated with the wind. If the wind has a certain speed "V" at some point and passes through a certain area "A", the instantaneous power of the wind is given by the following equation:

$$P_m = \frac{1}{2}\rho . A . V^3 \qquad (2)$$

Or ρ is the density of air, which are approximately 1.2 kg / m³. The model of the turbine is based on the characteristics of the power of the turbine. The output power of a wind turbine is function of wind velocity cubed. It can be described mathematically by:

$$P_m = \frac{1}{2} Cp(\lambda) . \rho . A . V^3 \qquad (3)$$

The specific speed λ which is the report of the linear speed at the end of the turbine blades reduced to wind speed or:

$$\lambda = \frac{R . \Omega}{V} \qquad (4)$$

Where *Ω*: is the angular speed of rotation of the blades. From surveys conducted on a wind turbine, the expression of the power coefficient has been approached to this turbine [2, 4], the following equation:

$$C_p(\lambda) = -0,2121\,\lambda^3 + 0,0856\,\lambda^2 + 0,2535\,\lambda \qquad (5)$$

C. Modeling Of The PMSG

The permanent magnet synchronous generator (PMSG) is modeled in the Park mark, giving rise to the following equation:

$$\begin{cases} V_d = -R_s \,.\, I_d - L_d \dfrac{d\,I_d}{dt} + L_q \;\omega \,.\, I_q \\ V_q = -R_s \,.\, I_q - L_q \dfrac{d\,I_q}{dt} - L_d \;\omega \,.\, I_d + \phi_f \;\omega \\ J \dfrac{dw}{dt} = T_w - T_{em} - B.w \\ T_{em} = \dfrac{3}{2} P \;[(Lq - Ld)\, I_d \,.\, I_q + \phi_f \;.\, I_q] \end{cases} \tag{6}$$

where: θ is the angle between a reference axis of the stator and an axis of the north pole of the rotor, the p-number of pole pairs, the resistance R_s of a phase stator, V_d, V_q and I_d, I_q are components on the axes d and q of the voltage, respectively of the stator current. J is the rotational moment of inertia of the rotor and generator [kg.m²], ω is the rotor angular velocity in [reds / s], T_w is the mechanical torque applied to the alternator shaft in Nm, T_{em} is the electromagnetic torque developed by the alternator in Nm and B is the coefficient of viscous friction in Nm.

D. Battery Charging

Even the small amount of energy (~1 kWh) that these batteries store can sufficiently improve the quality of life for such areas, giving people access to electrical lighting, TV/radio, and other household conveniences. It is a common practice for rural inhabitants in developing countries to acquire electrical service by charging 12-volt, 50–100 amp-hour batteries from diesel powered grids. The major advantage of a centralized battery-charging station is that it can bring electric service to a very low-income segment of the population. The use of wind-electric battery charging stations represents an alternative to conventional diesel-powered stations in many developing countries of the world. To date, there have been only a few examples of renewable- based battery charging stations, mostly using photovoltaic's (PV) [12].

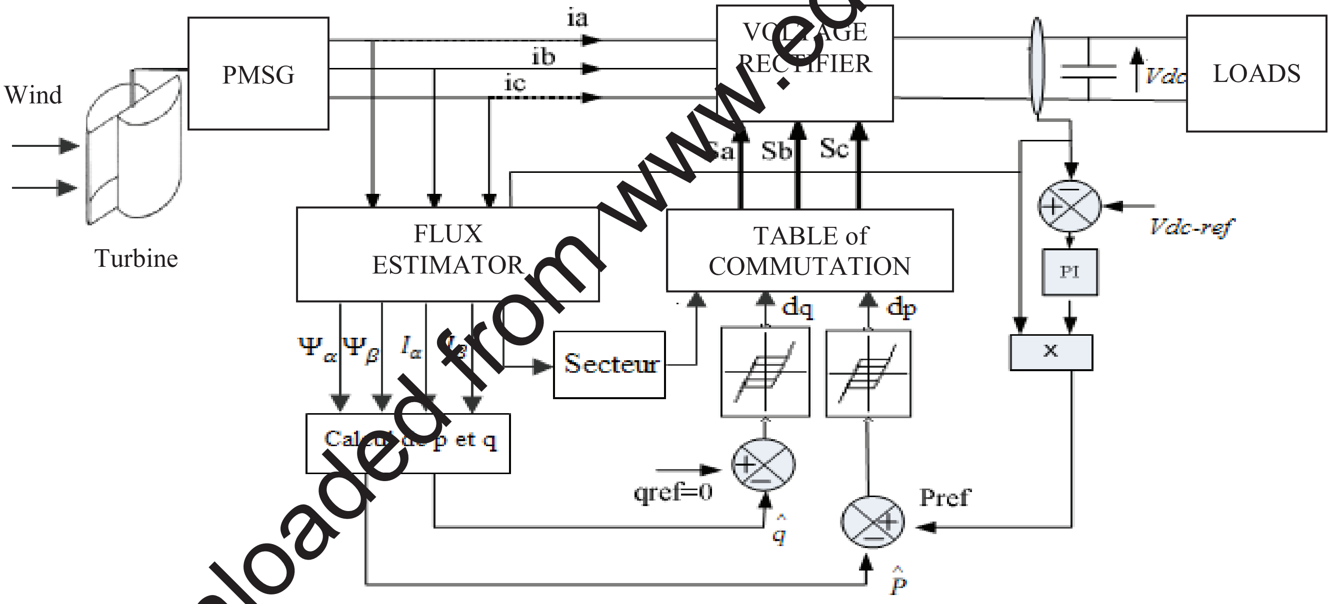

Figure 2. Control of DPC wind power system

E. Control of system

Control (DPC) is based on the concept of Direct Torque Control (DTC) applied to electric machines [2]. The controllers used are hysteresis comparators for the mistakes of instantaneous active and reactive power Δq and Δp. The output regulators with the sector where the position of the voltage vector of PMSG, constitute the inputs of a switch panel which in turn determines the switching state of the switches, the active power reference is obtained from controller DC bus voltage. Figure 2 shows the principle of direct control of power (classical" DPC"). The power calculation, instantaneous active and reactive, is given by the following equations:

$$\begin{aligned} p &= U_{dc}(S_a i_a + S_b i_b + S_c i_c) + L\left(\frac{di_a}{dt}.i_a + \frac{di_b}{dt}.i_b + \frac{di_c}{dt}.i_c\right) \\ q &= \frac{1}{\sqrt{3}}\left\{-U_{dc}\left[S_a(i_b - i_c) + S_b(i_c - i_a) + S_c(i_a - i_b)\right] + 3L\left(\frac{di_a}{dt}.i_c - \frac{di_c}{dt}.i_a\right)\right\} \end{aligned} \tag{7}$$

But this power estimation method has many inconveniences such as the evaluation of power depends on the switching state. Therefore, the calculation of the power must be avoided at the time of switching, due to the high error of the estimate.

The estimation method of virtual stream has advantages; it allows working with a smaller sampling rate. If considering the voltage rectifier (αβ) coordinates, the expression of the virtual stream is given as following equitation's:

$$\Psi_\alpha = \int\left\{\sqrt{\frac{2}{3}}.U_{dc}(S_a - \frac{1}{2}(S_b + S_c)\right\}dt - Li_\alpha \qquad (8)$$

$$\Psi_\beta = \int\left\{\sqrt{\frac{2}{3}}.U_{dc}(S_b - S_c)\right\}dt - Li_\beta$$

The instantaneous powers in αβ coordinates are calculated by:

$$p = w.(\Psi_\alpha i_\beta - \Psi_\beta i_\alpha) \qquad (9)$$

$$p = w.(\Psi_\alpha i_\alpha - \Psi_\beta i_\beta)$$

Figure 3, shows the six vectors batch which determine the field of voltage vector coordinates from stationary (αβ). These sectors can be expressed as the following:

$$(n-2)\frac{\pi}{3}\langle \sec tor \langle (n-1)\frac{\pi}{3} \qquad (10)$$

Where, n=1, 2… 6. The choice of switching mode rectifier is imposed by two bands of hysteresis H_p, H_q so that the errors between the reference values of power (p_{ref} and q_{ref}) and the measured values must remain in these bands. To achieve this goal has, errors of instantaneous active and reactive power are handled by two hysteresis comparators of two levels, whose outputs (dp and dq) are set to 1 to increase the control variable (p or q) and 0 for any unchanged or must decrease [8].

III. CASE STUDY

Direct Power Control of classical (DPC) calculating the instantaneous powers as a function of the virtual flux estimation, was studied by simulation in MATLAB / SIMULINK according to the diagram in Fig. 2.

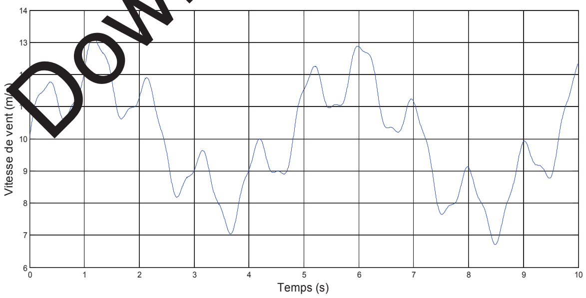

Figure 3. Wind speed as a function of time

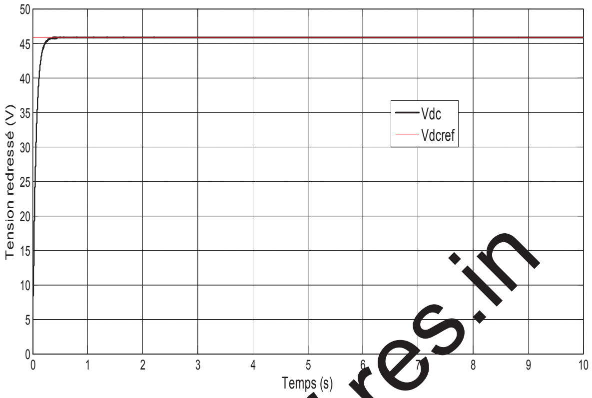

Figure 4. DC bus voltage and its reference

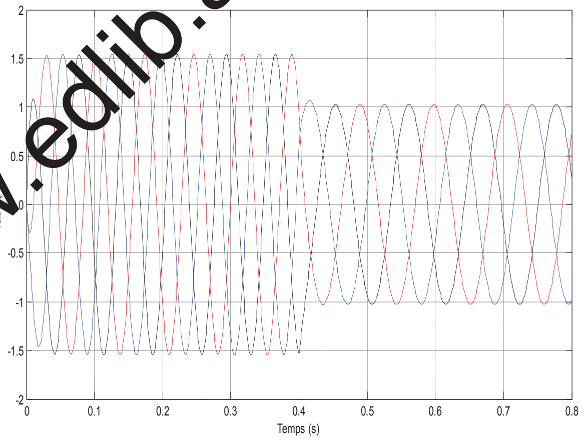

Figure 5. Stator currents of PMSG

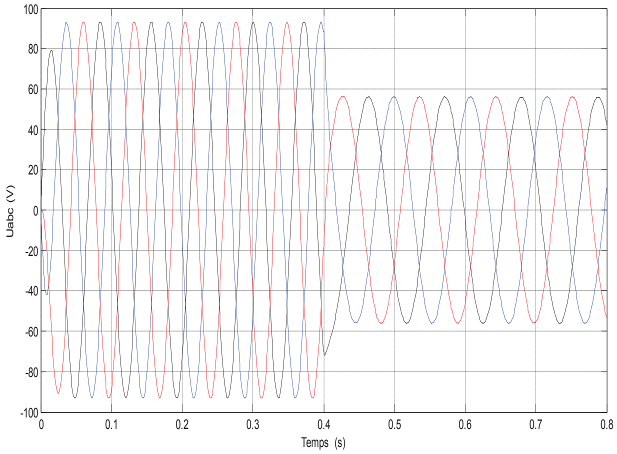

Figure 6. Stator tensions

- *Analysis of Simulation Results*

It is observed that the stator tensions and currents are sinusoidal that improve the performances of PMSG (Figures 5 and figures 6). Figure 3 and 4 shows that by maintaining the voltage at this desired level of 45.8V DC bus to a wind speed deterministic form of a sum of several harmonics (Eq" 1"). of his, the rectified voltage after its reference and it is independent of external variations.

CONCLUSION

Almost all wind energy systems require a controller to prevent damage to the turbine and the load. With advances in power electronics and microcontrollers, inexpensive yet sophisticated power controllers can be produced which are also capable of enhancing the power extraction of the overall system. The goal of this work is to characterize small wind turbines, modelling and control the system of electricity generation from renewable resources based on permanent magnet synchronous machine PMSG.

With structure of controls DPC classic and converter we can developed which includes many functions such as load over charging protection, load prioritization, and turbine breaking. Such a peak-power tracking controller can greatly enhance the overall power production of a wind turbine system, and may cost a small fraction of the price of the turbine.

This method is built around two hysteresis controllers that allow the setting of active and reactive power. This technique of control DPC presents a variable switching frequency for the uncontrolled rectifier and not very precise estimate of the flow.

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