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Direct Power Control of a PMSG Dedicated to the Conversion of Wind Power Off-Grid

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Abstract

This paper presents a full model of generation system power from wind energy. The modelled system consists of a rectifying control connected by the DPC to the PMSM which is driven by a turbine vertical axis wind type "remembered". The study concerns the method of control by the converter (DPC). The proposed method is around two hysteresis controllers that enable the adjustment of active and reactive power. The simulation results show a high performance proposed as control strategies.

Keywords: Wind turbine; PMSG; Rectifier; Control Direct Power.

1. Introduction

Pushed by new environmental and economic imperatives, the wind power sector has experienced strong growth in recent years. Development and research are mainly on the side of large wind turbines. These turbines are grouped into wind farms, at sea or on land, and are connected to mains electricity. They have blades measuring several tens of meters and a power in the megawatt range.

We also find small scale wind turbines, with power ratings from 100 watts to tens of kilowatts, which are intended for the isolated network [5]. They are used primarily to power plants too far from the electricity distribution network: shelters, cabins, communication sites, sailboats and remote areas (drilling, the Kessours, water pumping). The permanent magnet synchronous machine is characterized by a high torque density, very low inertia and low inductance. All these features offer the generator of high performance, high efficiency and better control. What makes this machine as a competitor of the asynchronous generator [6].

The amount of energy obtained from a wind energy conversion system depends not only on the characteristics of the wind regime at the site, but it also depends on the control strategy used. Different control techniques based on the 'PMSG', such as ordering by the field guides 'FOC', forward power control 'DPC' and direct torque control 'DTC'.

This paper presents the operating principle of the direct drive power 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 (PWM) control variables instead of the three-phase line currents usually used. Moreover, line voltage sensors are replaced by a virtual flux (VF) estimator.

The advantage of the direct control of power is that it is no need the internal regulation loops or blocks current PWM modulation. Indeed, the converter switching states are selected from a switching table. The latter is based on the error between the active and reactive power estimates and references [4].

2. Wind Modeling

The wind is highly variable, both geographically and in time. It varies from one place to another, from one day to another, from one second to another. These fluctuations are influenced by the movement of air masses at high altitude, but also by the terrain, type of ground covered and the thermal stability of the atmosphere. The wind varies in direction and intensity, but for the purposes of the model, we limit ourselves to the change in wind intensity in one direction to determine a sequence of valid and representative of actual winds [5].

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 [7]:

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

Where: V_0 is a value of wind velocity, A_K is amplitude of harmonic and W_k is frequency of harmonic.

3. The Turbine Modeling

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. 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:

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

Or ρ is the density of air, which are approximately 1.2 kg / m³. The turbine used in the context of our work, is a wind turbine "Savonius" vertical axis.

The model of the turbine is based on the characteristics of steady state power of the turbine. The rigidity of the drive shaft is assumed to be infinite, the coefficient of friction and inertia of the turbine must be combined with those of the generator coupled to the turbine. The output power is given by the following equation that we will standardize in up:

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

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

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

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

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

The maximum power coefficient ($Cp_{max} = 0.15$) is attained for ($\lambda_{max} = 0.78$).

4. Model Dynamic

The dynamic behavior of the generator can be represented by the following equation:

$$J\frac{dw}{dt} = T_w - T_{em} - B.w \tag{6}$$

Where 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 [N.m] and B is the coefficient of viscous friction.

5. Modeling of PMSG

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

$$\begin{cases} V_d = -R_s . I_d - L_d \dfrac{d\,I_d}{dt} + L_q\,\omega . I_q \\ V_q = -R_s . I_q - L_q \dfrac{d\,I_q}{dt} - L_d\,\omega . I_d + \phi_f\,\omega \\ J\dfrac{dw}{dt} = T_w - T_{em} - B.w \\ T_{em} = \dfrac{3}{2}P\left[(Lq - Ld)\,I_d . I_q + \phi_f . I_q\right] \end{cases} \tag{7}$$

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.

6. Direct Power Control

Direct Power Control "DPC" is based on the concept of Direct Torque Control "DTC" applied to electric machines [1]. The goal is to directly control the active and reactive power in a PWM rectifier, the same principle was applied to control the torque and flux in electrical machinery alternatives. 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.

The power instantaneous active and reactive, is given by the following equations:

$$p = U_{dc}(S_a i_a + S_b i_b + S_c i_c) + L\left(\frac{di_a}{dt}.i_a + \frac{di_b}{dt}.i_b + \frac{di_c}{dt}.i_c\right) \tag{8}$$

$$q = \frac{1}{\sqrt{3}}\left\{-U_{dc}\left[S_a(i_b - i_c) + S_b(i_c - i_a) + S_c(i_a - i_b)\right] + 3L\left(\frac{di_a}{dt}.i_c - \frac{di_c}{dt}.i_a\right)\right\}$$

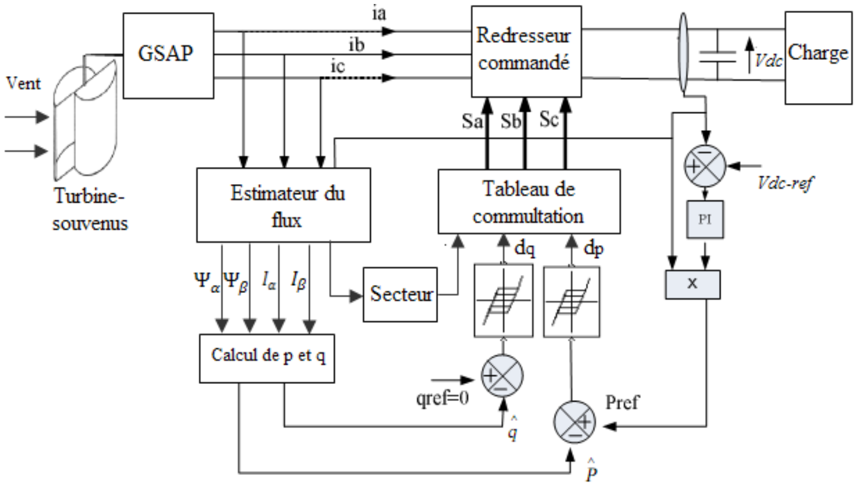

Fig. 1. Schema of the principle of control of DPC wind power system

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 (α-β) coordinates, the expression of the virtual stream is given as following:

$$\Psi_\alpha = \int\left\{\sqrt{\frac{2}{3}}.U_{dc}\left(S_a - \frac{1}{2}(S_b + S_c)\right)\right\}dt - Li_\alpha \tag{9}$$

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

The instantaneous powers in (α-β) coordinates are calculated by:

$$p = w.(\Psi_\alpha i_\beta - \Psi_\beta i_\alpha) \tag{10}$$

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

Figure 2, shows the six vectors batch which determine the field of voltage vector coordinates from stationary (α-β). These sectors can be expressed as the following:

$$(n-2)\frac{\pi}{3}\langle sector\langle (n-1)\frac{\pi}{3} \tag{11}$$

Where, n=1, 2… 6

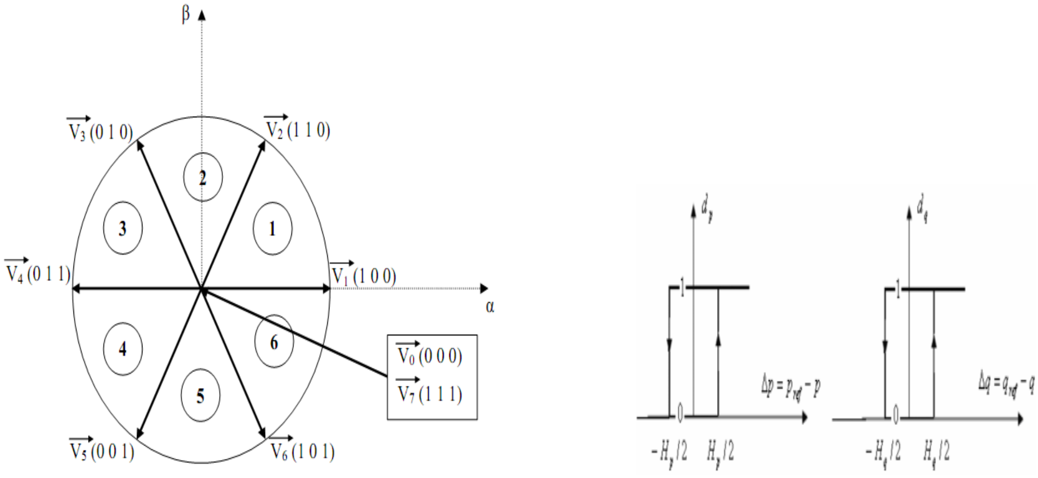

Fig. 2. (a) The voltage vector plane Vs (Sa Sb Sc); (b) the hysteresis regulatory on two levels

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 [6].

The errors of active and reactive power and the work sector "sector (n)" were inputs table 1.

Table 1. The control commutation DPC.

dp	dq	1	2	3	4	5	6
1	0	V6	V7	V1	V0	V2	V7
	1	V7	V7	V0	V0	V7	V7
0	0	V6	V1	V1	V2	V2	V3
	1	V1	V2	V2	V3	V3	V4

7. Result of Simulation

Direct Power Control of classical (DPC) by 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. 1.

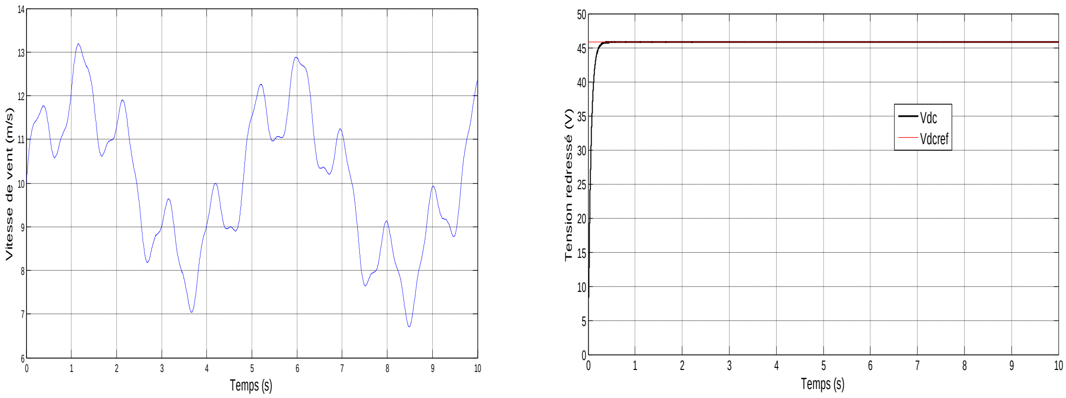

Fig. 3. (a) Wind speed as a function of time; (b) Tension of the DC bus voltage and reference.

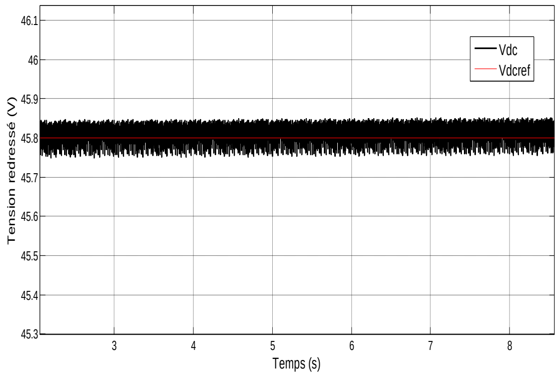

Fig. 4. Zoom of the DC bus voltage.

Fig.3. (b) shows that by maintaining the voltage at its 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.

8. Conclusion

The objective of this paper is to introduce a global model of a wind turbine permanent magnet synchronous. This model is to optimize power output and adjust the DC bus voltage.

We have studied the structure of controls DPC classic, the study is focused on the method of control by the converter (DPC). The method is built around two hysteresis controllers that allow the setting of active and reactive power.

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