Control Technique for Wind Turbine of Water Pumping System

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Abstract – This paper proposes a control technique of water pumping system based on wind turbine generator in an isolated area. The turbine is used to drive the PMSG in order to feed an isolated load composed of a DC motor and a hydraulic centrifuge pump. The considered load receives the required active power from the DC generator. The models of the wind turbine, the PMSG Generator and the DC motor are developed and used in the control scheme. The performances of the turbine, the PMSG and the DC motor are analyzed. Simulation results have proven good performances and verified the validity of the proposed pumping system.

Keywords – Control strategies, energy conversion, wind energy, water pumping system, Permanent Magnet Synchronous Generator (PMSG).

I. NOMENCLATURE

V_1: wind speed [m/s]
t: time [s]
P_m: The power captured by the wind turbine
A: blade swept area [m^2]
ρ: specific density of air [kg/m^3]
V_1 : wind speed [m/s]
R_t : radius of the turbine blade[m]
Ω_t: rotating speed [rpm]
C_p : coefficient of power conversion
Ω_{ref} : reference rotating speed
λ: tip-speed ratio (specified speed)
P_{Max}: maximum power captured by the wind turbine
P_{opt}: optimal power captured by the wind turbine
λ_{opt}: optimal pre-specified speed
b_0, b_1 and τ : controller parameters
S :Laplace magnitude.
T_{em} : motor torque
T_M : reference motor torque
C_{ass}: speed controller.
v_{ds} ,v_{qs} :*d-q* axis stator voltage
i_{ds} ,i_{qs} : *d-q* axis stator current
L_d L_q: *d-q* axis inductance
R_s : stator resistance
ω : electric pulsation
φ_f: magnetic flux leakage
p: number of poles pairs.
K: torque constant
P,*Q:* respectively are active and reactive power
v_g,i_g: respectively are grid voltage and grid current.
d,q: respectively are direct and quadrature components,
V_{dc}:DC-link voltage
β: pitch angle

II. INTRODUCTION

The research for wind power industry started to be improved in the last century, mainly due to the oil crisis and environment pollution. The electrical power produced by the wind turbine is proportional with its size [2].The growing interest in wind turbine applications and the fast development of power electronics allow the manufacturers to find the most suitable and low cost technologies to realize them. In this case, the used generator can be double fed induction generator or a PMSG. The advantages of PMSG over induction generators are the high efficiency and reliability, more than that, there is no need of external excitation which decreases Joule losses, smaller in size and easy to control [1], [2]. Actually, the PMSG has become a more attractive solution to use it in variable speed wind turbine applications.

In Algeria, before the project of Kaberten(in Adrar) wind power connected to grid, the wind energy was only used for pumping water; the first experience of pumping water with wind turbine in Africa was conducted in 1957 in Adrar "*Ksar Ouled Aroussa*" 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 region of Adrar, in South Algeria, presents an excellent potential of wind energy as it is shown in the figure below. The annual mean of the wind speed reaches over than 6m/s [4]. Which allows supplying electrical energy to remote areas (Forages, Kessour), where the connection to the grid is not possible or very expensive [3].

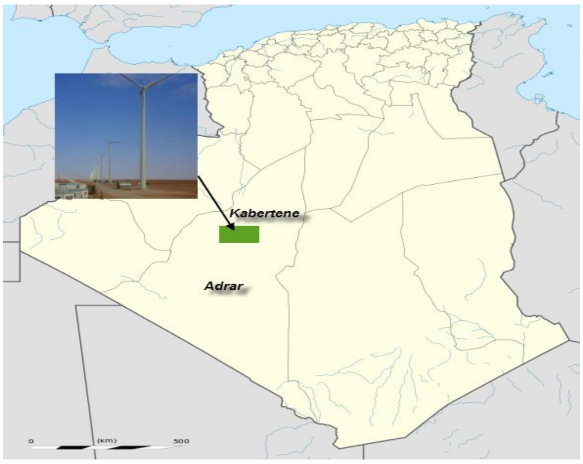

Fig.1. The new power generation central, first of its kind at national level, has a capacity of 10 megawatts, is located on a surface of 30 hectares in the zone of Kabertene, 72km north of the Willaya of Adrar. It is constituted by 12 wind turbines with an output of 0.85MW each.

The turbines of small and medium powers in three range [5]:

- Micro-wind turbines: a range of nominal power of 20 W to 500 W.
- Mini wind turbines: a range of nominal power of 500 W to 1 kW.
- Small Wind: from 1 kW to 100 kW.

In our study, water pumping system used a wind turbine based on PMSG which supplies DC motor to generate the torque required to the centrifuge hydraulic [6], 'fig.2'.

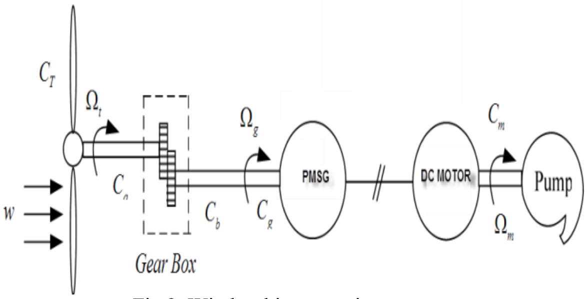

Fig.2. Wind turbine pumping system

III. MODELLING OF WIND TURBINE PUMPING SYSTEM

A. Turbine model

The wind turbine collects the kinetic energy of the wind and converts it into a torque which turns the blades of the rotor [6]. The evolution of the used power coefficient is given by the following relation [7]:

$$\begin{cases} C_p(\lambda,\beta) = C_1\left(\frac{C_2}{\lambda_i} - C_3\beta - C_4\right)e^{\frac{-C_5}{\lambda_i}} + C_6\lambda \\ \frac{1}{\lambda_i} = \frac{1}{\lambda + 0.008\beta} - \frac{0.035}{\beta^3+1} \end{cases} \quad (1)$$

$$P_m = \frac{1}{2}C_p(\lambda)\rho A V_1^3 \quad (2)$$

The tip-speed ratio is defined as:

$$\lambda = \frac{\Omega_t R_t}{V_1} \quad (3)$$

Where,
A: blade swept area [m^2]
ρ: specific density of air [kg/m^3]
V_1 : wind speed [m/s]
R_t: radius of the turbine blade[m]
Ω_t: rotating speed [rpm]
C_p : coefficient of power conversion

The mechanical torque of the wind turbine system can be described by the following equation:

$$T_t = \frac{P_m}{\Omega_t} = \frac{1}{2}\rho\pi R^3 \frac{C_p(\beta,\lambda)}{\lambda} V^2 \quad (4)$$

B. PMSG model

The voltage equation of the PMSG is expressed at synchronous reference frame by [7]:

$$\begin{bmatrix} v_{ds} \\ v_{qs} \end{bmatrix} = \begin{bmatrix} R_s + SL_d & -\omega L_q \\ \omega L_d & R_s + SL_q \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} + \begin{bmatrix} 0 \\ \omega.\Phi_f \end{bmatrix} \quad (5)$$

Where:
S: differential operator
v_{ds} ,v_{qs} :*d-q* axis stator voltage
i_{ds} ,i_{qs} : *d-q* axis stator current
L_d L_q : *d-q* axis inductance
R_s : stator resistance
ω : electric pulsation
Φ_f: magnetic flux of permanent magnet

The electromagnetic torque is expressed as

$$T_{em} = \frac{3}{2}p\left[\left(L_q - L_d\right)i_{ds}i_{qs} + i_{qs}\varphi_f\right] \quad (6)$$

Where

p: number of poles pairs.

By using the vector control, q-axis is aligned with the magnetic flux, then

$$T_{em} = \frac{3}{2}p.i_{qs}\varphi_f = K.i_{qs} \quad (7)$$

The q-axis current component can be used for the speed control of the generator, and d-axis current is set to zero [8].

C. DC Motor model

In this work, DC machine is operated in motor mode different relations used in their models.
Applied to the machine phase, the Ohm's law describing the armature winding and the field winding are respectively given by relations below:

$$\begin{cases} V_{ma} = K.w + R.i_a + \frac{Ld\, i_a}{dt} \\ V_{mf} = R\ .i_f + \frac{Ld\, i_f}{dt} \end{cases} \quad (8)$$

The electromagnetic torque is given by:

$$T_M = Ki_a \quad (9)$$

After the gearbox, the mechanical system can be described as following relations, where T_t and T_a represent respectively the input wind torque and the torque before the gearbox:

$$T_t - T_a = J_t \frac{Ld\Omega_t}{dt} + f_f\Omega_t \quad (10)$$

Before the gearbox, the mechanical dynamics system can be described by relation (11) where T_b and T_g represents respectively the torque after the gearbox and the produced generator torque.

$$T_b - T_g = J_g \frac{Ld\Omega_g}{dt} + f_g\Omega_g \quad (11)$$

The transmission gear-box ratio is defined as:

$$G = \frac{\Omega_g}{\Omega_t} \quad (12)$$

D. Model Of PWM Rectifier

Contrary to the traditional rectifiers, PWM rectifiers are controlled by opening and closing semiconductors in a way allows obtaining the imposed references according to needs. Thus, we have a total control of the converter [9], [10].

This rectifier is controlled to keep the voltage of the continuous bus at a wished value of reference, by using a closed loop control, as it is shown in “Fig.3”.

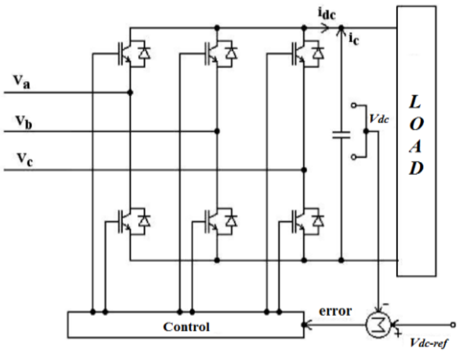

Fig.3. Basic topologies of a rectifier of voltage

We can simplify modelling and reduce the time of simulation by modelling the rectifier with ideal switches, these switches being complementary; their state is defined by the following function [11]:

$$S_j = \begin{cases} +1, S_j = -1 \\ -1, \overline{S_j} = +1 \end{cases} \quad (13)$$

The simple input voltages and the output current can be written in function of S_j, V_{dc} and the input currents i_{sa}, i_{sb}, i_{sc}.

$$i_{sa} + i_{sb} + i_{sc} = 0 \quad (14)$$

The compound input voltages of the rectifier can be described by

$$\begin{aligned} U_{Sab} &= (S_a - S_b) * V_{dc} \\ U_{Sbc} &= (S_b - S_c) * V_{dc} \\ U_{Sca} &= (S_c - S_a) * V_{dc} \end{aligned} \quad (15)$$

Voltage equations of the three-phase system balanced without connection to neutral point can be written as follows:

$$\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} = R_s \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} + L_s \frac{d}{dt} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} + \begin{bmatrix} U_{sa} \\ U_{sb} \\ U_{sc} \end{bmatrix} \quad (16)$$

With:

$$\begin{aligned} U_{sa} &= \frac{2S_a - S_b - S_c}{3} V_{dc} \\ U_{sb} &= \frac{2S_b - S_a - S_c}{3} V_{dc} \\ U_{sc} &= \frac{2S_c - S_a - S_b}{3} V_{dc} \end{aligned} \quad (17)$$

Finally, we deduce the equation from coupling the AC and DC sides:

$$C.\frac{dV_{dc}}{dt} = (S_a.i_a + S_b.i_b + S_c.i_c) - I_L \quad (18)$$

E. Modelling of Hydraulic pump

The centrifugal pump model can be described by Knowing the mechanical characteristics illustrated in relation (19):

$$h = a_0\Omega^2 - a_1\Omega \ Q - a_2 Q^2 \quad (19)$$

The hydraulic power P_H and the torque of the centrifugal pump can be given respectively by (20) and (21):

$$P_H = \rho g H \quad (20)$$

$$T_r = \alpha.\Omega_m^{\ 2} + T_s \quad (21)$$

The mechanical model of the electric motor and the centrifugal pump can be described by (22).

$$T_{Mem} = J_{mp}.\frac{d\Omega_m}{dt} + f_{mp}.\Omega_m + T_r \quad (22)$$

IV. Simulation Results and Discussion

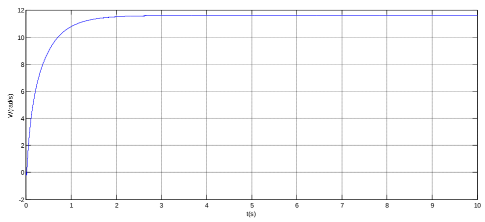

Fig.4 Rotor speed of generator PMSG

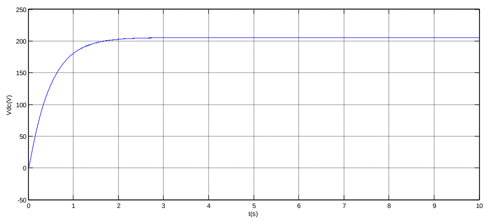

Fig.5 DC bus voltage

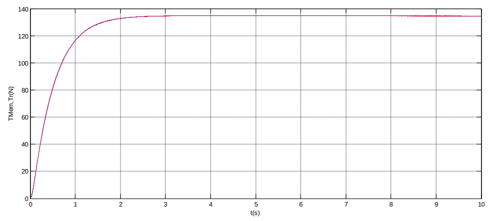

Fig.6 Electromagnetic & load torque

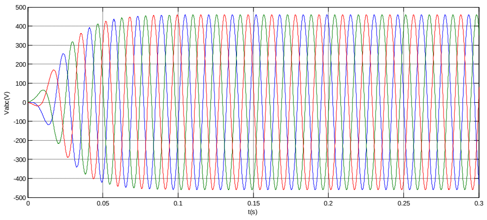

Fig.7 Stator voltage

- *Analysis of Simulation Results*

Firstly, the motor is at stopped, when the wind speed is sufficient, the electromagnetic torque response (figure 6) as well as the electric rotor speed (figure 4) converge towards their target ones (rated values). Then, the stator tensions are sinusoidal that improve the performances of PMSG (figures 7). Figure 4 and 5 shows that Following the simulation results obtained, we conclude that the response of the output voltage of the rectifier (rectified) to a change in speed is relatively fast.

Spite of increasing 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.

V. Conclusion

In this work a pitched power control for wind turbine water pumping system based on DC machine is developed and simulated. When the power control scheme is applied to proposed wind turbine pumping system, both generator and turbine torques are adapted to the load power when the wind varies. Simulation results have shown the good performances of the proposed control system. These promising results open the possibility for the reconstitution of the proposed scheme to be set up for an on-line implementation.

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