Advances in Mechanical Engineering and its Applications
Vol. 1, No. 1, March 2012

www.worldsciencepublisher.org

A Power Drive Scheme for an Isolated Pitched Wind Turbine Water Pumping System based on DC machine

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Abstract – In this paper, the authors present a power control of an isolated wind turbine water pumping system. The turbine is used to drive the DC Generator 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 DC Generator and the DC motor are developed and used in the control scheme. The dynamic performances of the turbine, the generator and the motor are analyzed. The simulation results have shown that the proposed methodology is an efficient solution of a fully control system.

Keywords – Power drive, wind turbine, water pumping system, DC machine

1. Introduction

In the isolated area as the mountain and the rural zones, the use of the renewable energy such as photovoltaic [3,4] and the wind energy is a better solution for such applications as the electrification and the water pumping system [1,2,5].

Many types of electric generator have been associated with wind turbines and proposed to convert wind power into electric power such as permanent magnet synchronous generator (PMSG) [6,7,8,9], Doubly-fed Induction generator [10,11,12], Squired-cage Induction generator [2] and Synchronous Generator with external field excitation. DC generators with different coupling mode are also used for wind power generating system [13,14].

Different types of motors are used in the wind turbine water pumping system. Asynchronous motor is used with different control strategies [16,17], Permanent Magnet Synchronous Motors are also used in the pumping system applications [4,5,15].

The DC motor is used in the wind turbine water pumping systems according to different coupling modes and with several control strategies.

In this paper we synthesized a pitched power control for wind turbine water pumping system based on DC machine in order to generate the torque required by the centrifuge pump load. This control scheme has also shown a good power control.

2. The Wind Water Pumping System Model

The proposed wind turbine water pumping system considered in this paper is presented in figure 1. In order to convert the mechanical power to electric power, the rotor of the pitch controlled wind turbine is coupled to direct current generator through a gear-box. The produced generator armature winding supply is used to feed the armature winding motor that is coupled to a hydraulic centrifuge pump.

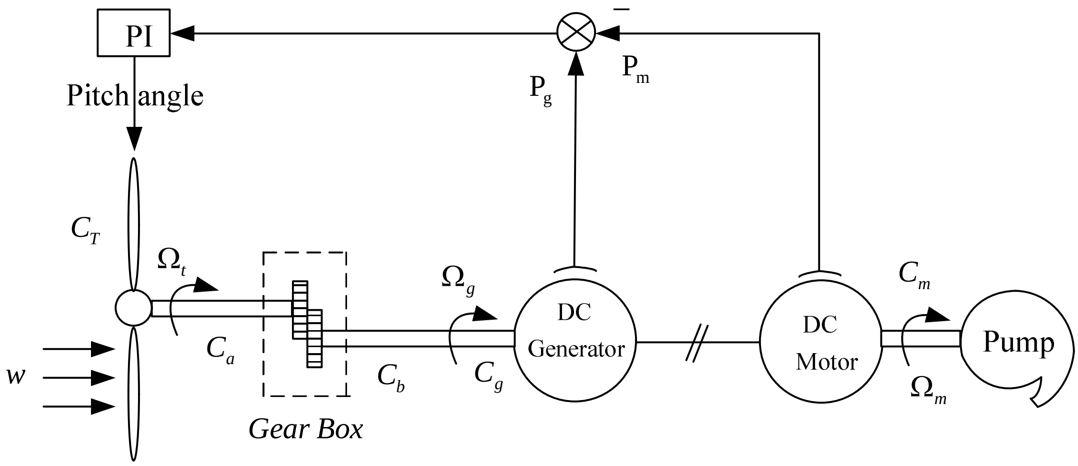

Figure 1. Proposed wind turbine pumping system

2.1. Turbine Model

A wind turbine can only convert some percentage of the captured wind power [2,4,10]. This percentage is represented by the power coefficient $C_p(\beta,\lambda)$ which is a nonlinear function of the tip speed ration λ and the pitch angle β given by (1) where c_1 to c_6 represents the turbine characteristic coefficients.

$$\begin{cases} C_p(\beta,\lambda) = c_1\left(\dfrac{c_2}{\lambda_i} - c_3\beta - c_4\right)e^{-\frac{c_5}{\lambda_i}} + c_6\lambda \\ \dfrac{1}{\lambda_i} = \dfrac{1}{\lambda + 0.008\beta} - \dfrac{0.035}{\beta^3 + 1} \end{cases} \quad (1)$$

The tip-speed ratio is defined as the ratio between blade tip speed and wind speed; it's expressed as [2,4,10]:

$$\lambda = \frac{R\Omega_T}{v_w} \quad (2)$$

The mechanical power extracted by a wind turbine from the wind is expressed by the well-known formula:

$$P_T = \frac{1}{2}\rho A C_p(\beta,\lambda) v_w^3 \quad (3)$$

The developed turbine torque C_T is:

$$C_T = \frac{P_T}{\Omega_T} \quad (4)$$

The mechanical system of the wind turbine system can be described by the simplified motion equation:

$$C_T = \frac{1}{2}\rho\pi R^3 \frac{C_p(\beta,\lambda)}{\lambda} v_w^2 \quad (5)$$

2.2. DC Generator and DC motor Models

In this work, DC machine is operated with generator and motor convention indicated respectively by index (g) and index (m) in different relations used in their models.

Applied to the machine phasor, the Ohm's law describing the armature winding and the field winding are respectively given by relations (6) and (7):

$$\begin{cases} V_{ga} = K_{ge} i_{gf} \Omega_g - R_{ga}\, i_{ga} - L_{ga}\dfrac{di_{ga}}{dt} \\ V_{ma} = K_{me} i_{mf} \Omega_m + R_{ma}\, i_{ma} + L_{ma}\dfrac{di_{ma}}{dt} \end{cases} \quad (6)$$

$$\begin{cases} V_{gf} = R_{gf}\, i_{gf} + L_{gf}\dfrac{di_{gf}}{dt} \\ V_{mf} = R_{mf}\, i_{mf} + L_{mf}\dfrac{di_{mf}}{dt} \end{cases} \quad (7)$$

The electromagnetic torque is given by (8).

$$\begin{cases} C_{gem} = -K_{ge} L_{gf}\, i_{gf}\, i_{ga} \\ C_{mem} = K_{me} L_{mf}\, i_{mf}\, i_{ma} \end{cases} \quad (8)$$

After the gearbox, the mechanical dynamics of the considered system can be described be the following famous relations, where C_T and C_a represents respectively the input wind torque and the torque before the gearbox:

$$C_T - C_a = J_T \frac{d\Omega_T}{dt} + f_T \Omega_T \quad (9)$$

Before the gearbox, the mechanical dynamics system can be described by relation (10) where C_b and C_g represents respectively the torque after the gearbox and the produced generator torque.

$$C_b - C_g = J_g \frac{d\Omega_g}{dt} + f_g \Omega_g \quad (10)$$

Before and after the gearbox, the power equality is given by (11).

$$C_b \Omega_g = C_a \Omega_T \quad (11)$$

The transmission gear-box ratio is defined as:

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

Relations (9), (10), (11) and (12) leads (13)

$$\begin{cases} J_{tg}\dfrac{d\Omega_T}{dt} + f_{tg}\Omega_T = C_T - G C_{gem} \\ J_{tg}\dfrac{d\Omega_T}{dt} + f_{tg}\Omega_T = \dfrac{P_T}{\Omega_T} - G\dfrac{P_{gem}}{\Omega_g} \end{cases} \quad (13)$$

Where:

$$\begin{cases} J_{tg} = J_T + G^2 J_g \\ f_{tg} = f_T + G^2 f_g \end{cases} \quad (14)$$

2.3. Centrifugal pump model

The centrifugal pump model can be described by the well known mechanical characteristic illustrated in relation (15).

$$h = a_0 \Omega_m^2 - a_1 \Omega_m Q - a_2 Q^2 \quad (15)$$

The hydraulic power P_H and the load torque of the centrifugal pump can be described respectively by (16) and (17).

$$P_H = \rho g H \tag{16}$$

$$C_r = k_r \Omega_m^2 + C_s \tag{17}$$

The mechanical model of the electric motor and the centrifugal pump can be described by (18).

$$C_{mem} = J_{mp} \frac{d\Omega_m}{dt} + f_{mp}\Omega_m + C_r \tag{18}$$

3. Simulation results and discussion

3.1. Wind turbine analysis

The proposed wind profile is presented is figure 2, it covers a speed range between 2 m/s And 12 m/s. The nominal wind turbine speed is equal to 9 m/s.

Le pitch angle response is shown by figure 3, it varies with the wind in order to adapt the extracted turbine torque to the direct generator torque.

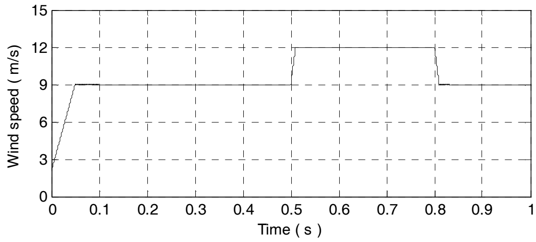

Figure 2. Proposed wind profile

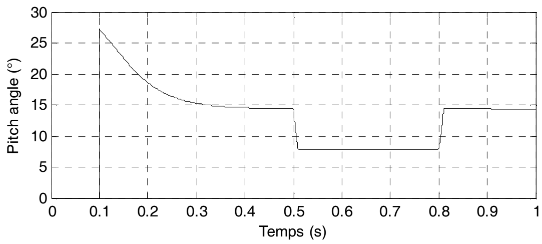

Figure 3. Pitch angle response

3.2. Validation and discussion of the DC Generator Control.

Relatively to pitch angle response (figure (3)), Figure 4 and Figure 5 prove that the mechanical turbine torque and the electromagnetic generator torque are continuously adapted to the wind speed and the considered load, in such a way that the turbine extracts the required torque.

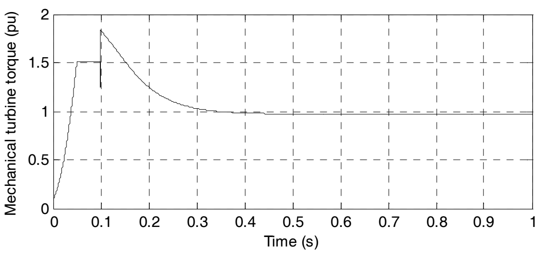

Figure 4. Mechanical turbine torque (pu)

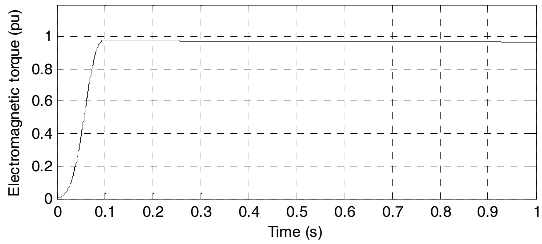

Figure 5. Electromagnetic generator torque response

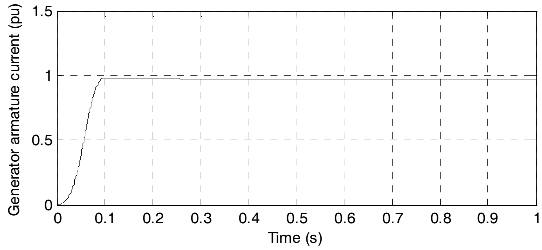

Figure 6. Armature generator current (pu)

Figure 7 gives the generator armature power (pu).
Figure 8 shows the rotor electric speed response result of a good pitch control according to the required power.

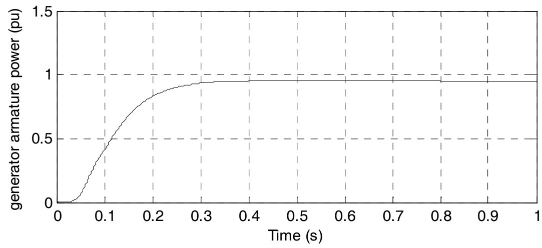

Figure 7. Generator armature power (pu)

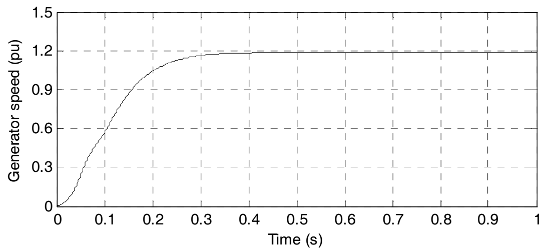

Figure 8. Electric generator rotor speed (pu)

3.3. Validation and discussion of the DC Motor Control.

Initially, the motor is at stopped, when the wind speed is sufficient, the electromagnetic torque response (figure 9) as well as the electric rotor speed (figure 10) converge towards their target ones (rated values). Then, the armature motor current response (figure 11) goes towards the nominal value of the motor current as an image of the torque.

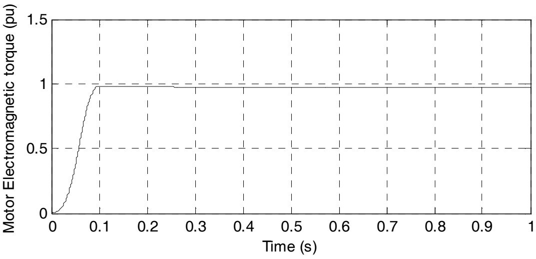

Figure 9. Motor Electromagnetic torque (pu)

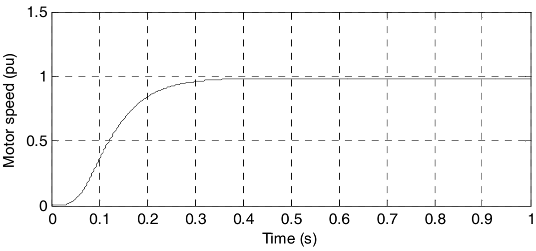

Figure 10. Response of the electric motor rotor speed (pu)

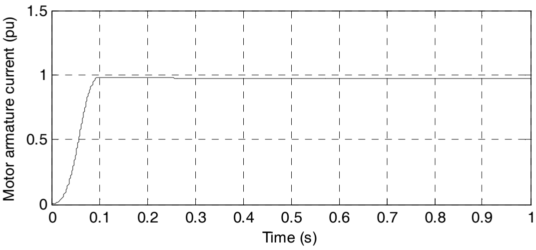

Figure 11. Armature motor current response (pu)

4. 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.

Appendix

Table 1. Wind turbine Parameters

Rated power	**10 Kw**
Rotor diameter	**4 m**
Rated wind speed	**9 m /s**

Table 2. DC machine Parameters

DC supply voltage V_{DC}	**400 V**
Rated Armature current I_{aN}	**25 A**
Rated torque C_{emN}	**57.5 N.m**
Rated speed Ω_N	**157 rad / s**
Armature resistance R_a	**1.5 Ω**
Armature inductance L_a	**47 mH**
Torque constant	**2.3 Nm/A**

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