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Backstepping Approach applied to the DFIG-WECS

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Abstract. The growing need for energy in the world and the depletion of classical energy resources (fuels) have led researchers to develop new means of producing abundant and inexhaustible energies called "renewable energies". In this context, we propose the study of a Wind Energy Conversion System (WECS) driven by a Doubly Fed Induction Generator (DFIG). This non-linear system is controlling by a recent approach called "Backstepping" based on Lyapunov's theory. So, we will explain the structure of this control to reach the convergence of errors towards zero and to ensure the stability of the system. Finally, we will present the results obtained from the simulation.

Keywords. Backstepping Control ; DFIG ; WECS.

Modeling of The WECS :

The figure below represents the synopsis of the wind energy conversion system proposed :

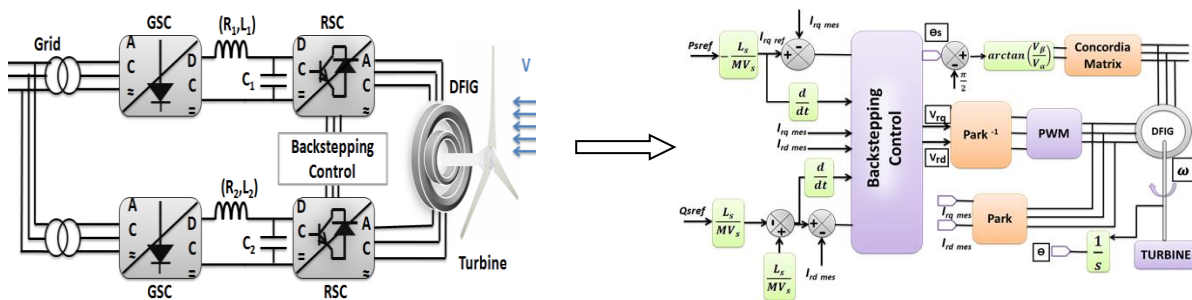


Figure 1. Synopsis of the Backstepping control of the DFIG-WECS

By applying the theory of momentum and Bernoulli's theorem, we can determine the theoretical wind power [1]:

$$P_{theor} = \frac{1}{2} \cdot \rho \cdot S \cdot v^3 \quad (1)$$

The aerodynamic power appearing at the rotor of the turbine is written [2]:

$$P_{aeor} = \frac{1}{2} \cdot \rho \cdot S \cdot C_p(\lambda, \beta) \cdot v^3 \quad (2)$$

The Backstepping Control will be applied in the reference (d, q) considering the orientation of the stator flux: $\Phi_{sq} = 0$ and $\Phi_{sd} = \Phi_s$. The equations of the DFIG are given by:

$$\begin{cases} V_{sd} = 0 \\ V_{sq} = \Phi_s \omega_s \\ V_{rd} = R_r i_{rd} + \frac{d\Phi_{rd}}{dt} - \omega_r \Phi_{rq} \\ V_{rq} = R_r i_{rq} + \frac{d\Phi_{rq}}{dt} + \omega_r \Phi_{rd} \end{cases} \quad (3)$$

The relationship between references of stator powers and rotor currents is written [3, 4]:

$$\begin{cases} P_s^{ref} = -\frac{V_s M}{L_s} i_{rq}^{ref} \\ Q_s^{ref} = \frac{V_s^2}{\omega_s L_s} - \frac{V_s M}{L_s} i_{rd}^{ref} \end{cases} \xrightarrow{\text{Derivation}} \begin{cases} i_{rq}^{ref} = -\frac{L_s}{MV_s} P_s^{ref} \\ i_{rd}^{ref} = -\frac{L_s}{MV_s} Q_s^{ref} \end{cases} \quad (4)$$

Synthesis Of The Backstepping Control :

The calculation of reference quantities of the currents and voltages are made on the basis of Lyapunov functions. This command is based on two steps:

Step 1: It consists of identifying the errors " E_1 " and " E_2 ", which respectively represent the error between the stator powers " P_s " and its reference " P_s^{ref} ", as well as " Q_s " and " Q_s^{ref} ":

$$\begin{cases} E_1 = (i_{rq}^{ref} - i_{rq}) \\ E_2 = (i_{rd}^{ref} - i_{rd}) \end{cases} \xrightarrow{\text{Derivation}} \begin{cases} \dot{E}_1 = (i_{rq}^{ref} - i_{rq}) \\ \dot{E}_2 = (i_{rd}^{ref} - i_{rd}) \end{cases} \quad (5)$$

The first function of Lyapunov is defined by: $v = \frac{1}{2}(E_1^2 + E_2^2)$ (6)

In order to have the derivative of the Lyapunov's function equal to zero, we choose the errors as follows: $\dot{E}_1 = -K_1 E_1$ and $\dot{E}_2 = -K_2 E_2$. The derivative of the errors " E_1 " and " E_2 " becomes:

$$\begin{cases} \dot{E}_1 = \left(\left(-\frac{L_s}{MV_s} P_s^{ref} \right) - \frac{1}{\sigma L_r} V_{rq} - \frac{1}{\sigma L_r} \left(-R_r i_{rq} - g \omega_s L_r \sigma i_{rd} - g \frac{MV_s}{L_s} \right) \right) \\ \dot{E}_2 = \left(\left(-\frac{L_s}{MV_s} Q_s^{ref} \right) - \frac{1}{\sigma L_r} V_{rd} - \frac{1}{\sigma L_r} \left(-R_r i_{rd} + g \omega_s L_r \sigma i_{rq} \right) \right) \end{cases} \quad (7)$$

Step 2: We use the equations (7) to replace the derivative of the errors with their previously defined values and we deduce the rotor's voltages V_{rq} and V_{rd} :

$$\begin{cases} V_{rq} = \left(\sigma L_r \left(-\frac{L_s}{MV_s} P_s^{ref} + K_1 E_1 \right) + R_r i_{rq} + g \omega_s L_r \sigma i_{rd} + g \frac{MV_s}{L_s} \right) \\ V_{rd} = \left(\sigma L_r \left(-\frac{L_s}{MV_s} Q_s^{ref} + K_2 E_2 \right) + R_r i_{rd} - g \omega_s L_r \sigma i_{rq} \right) \end{cases} \quad (8)$$

Application And Results:

The simulation results of the WECS in Matlab / Simulink are summarized in fig. 2:

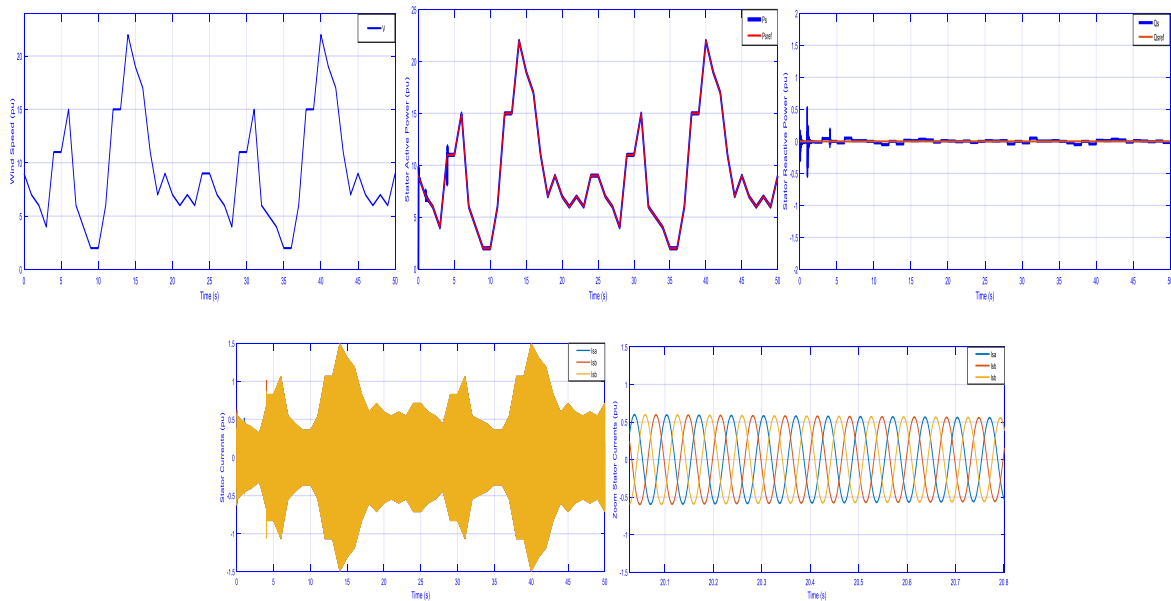


Figure 2. Curves of: the wind speed, the stator's active power, the stator's reactive power, the stator's currents and the zoom of stator's currents

Figure (a) illustrates the profile of the wind speed applied. The figures (b) and (c) show that the stator active and reactive powers follow their references with fewer oscillations. Figures (d) and (e) show the sinusoidal shape of stator currents in the frame (a, b, c).

the simulation results obtained during the application of the control on the variable speed driven system show a good tracking of the powers generated at the corresponding reference values.

References

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