

RST controlled DFIG based wind energy conversion systems

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Abstract

This work presents a field oriented control (FOC) of active and reactive power applied on Doubly Fed Induction Machine (DFIM) 1.5MW integrated in wind energy conversion system (WECS). The main objective of this work is to compare the performances of energy produced by the use of two types of controllers (PI regulator and the RST regulator) in order to control the wind power conversion system to compare their precision & robustness against the wind fluctuation and the impact on the quality of produced energy. A field oriented control of DFIG stator is also presented to control the active and reactive power. To show the efficiency of the performances and the robustness of the two control methods those were analyzed and compared by simulation using Matlab/Simulink software. The results described the favoured method.

Keywords: field oriented control (FOC), wind energy conversion system (WECS), Doubly Fed Induction Machine (DFIM), PI regulator and the RST regulator.

1. Introduction

The wind power is one of renewable energies which news fast growth in the world due to clean and nonpolluting nature [1]. Several machines were used in WECS, but the range of wind speed was limited in classical machines, the advanced technology created DFIM witch solves this problem and makes it more powerful [2].

Several control methods of the DFIM appeared, among them, the vector control [3]. The principle of this control is to make DFIM similar to separate excitation DC machine.

This paper presents a comparison of performance in vector control using PI and controllers RST in WECS. The first regulator is PI, which is simple and easy in implementation and gives acceptable performances [4], but it has not robustness in case of parameter variations .Then, a control device by Polynomial RST regulator is used. This type of controller proved to be an interesting method for the design of controllers and was applied in many fields. It can present fast dynamic responses if the switching devices support a high frequency. The studied system is presented in (Fig. 1).

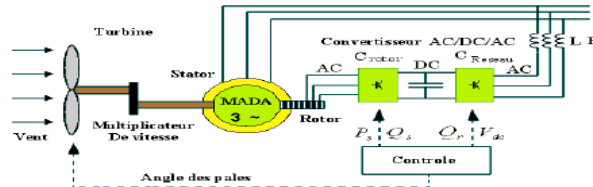


Fig. 1. Scheme of the studied system.

2. Modeling and control of DFIM

2.1. Modeling of DFIM

The of Park transformation on electrical equations of DFIM in field reference frame gives the following equations:

$$\begin{cases} V_{sd} = R_s i_{sd} + \frac{d\Phi_{sd}}{dt} - \omega_s \Phi_{sq} \\ V_{sq} = R_s i_{sq} + \frac{d\Phi_{sq}}{dt} + \omega_s \Phi_{sd} \\ V_{rd} = R_r i_{rd} + \frac{d\Phi_{rd}}{dt} - \omega_r \Phi_{rq} \\ V_{rq} = R_r i_{rq} + \frac{d\Phi_{rq}}{dt} + \omega_r \Phi_{rd} \end{cases} \quad (1)$$

The fields are given by:

$$\begin{cases} \Phi_{sd} = L_s i_{sd} + M_{sr} i_{rd} \\ \Phi_{sq} = L_s i_{sq} + M_{sr} i_{rq} \\ \Phi_{rd} = L_r i_{rd} + M_{sr} i_{sd} \\ \Phi_{rq} = L_r i_{rq} + M_{sr} i_{sq} \end{cases} \quad (2)$$

The electromagnetic torque is given by:

$$C_{em} = P \frac{M s_r}{L_s} (\Phi_{sq} i_{rd} - \Phi_{sd} i_{rq}) \quad (3)$$

$$J \frac{d\Omega_{mec}}{dt} = C_{em} - C_r - f \cdot \Omega_{mec} \quad (4)$$

2.2 Power Control

In order to control easily the electrical power produced by the WECS, we applied an independent control of the active and reactive powers by FOC of stator the principle consists in aligning stator field along the d axis of Park reference frame. This choice is to eliminate the coupling between powers.

We have $\Phi_{sq} = 0$ then $\Phi_{sd} = \Phi_s$.

In this method, we power is controlled using two cascade controllers. The first is for power control, the second is for current control [5], the coupling terms appeared after this last, fig.2.

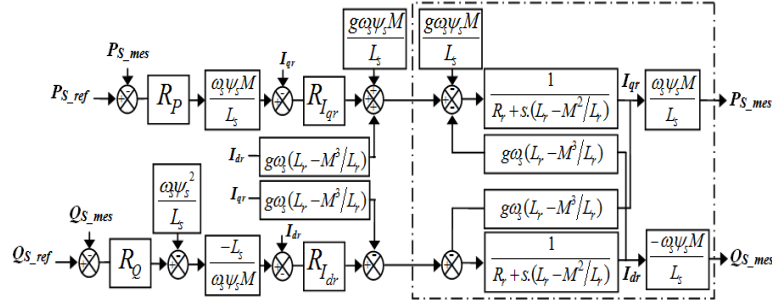


Fig. 2. Control scheme of DFIM

The aim of these regulators is to obtain high dynamic performances in terms of reference tracking, sensitivity to perturbations and robustness. To realize these objectives, two types of regulators are studied and compared: Proportional Integral and RST controller based on pole placement theory [6]. The synthesis of Proportional-integral controller is achieved by the classical method of pole compensation and will not be detailed afterwards. The RST controller synthesis is detailed below.

3. RST control

We use the field-oriented control with RST regulator. This control technique is conducted to improve the performance of the command (Performing active and reactive power reference tracking; Efficient disturbance rejection ; Parametric robustness) [7],[8].

The principle is based on solving the Bezout equation, which leads to the identification of the polynomials R, S and T.

4.1 RST controller synthesis

The block-diagram of a system with its RST controller is presented on Fig. 4 [9].

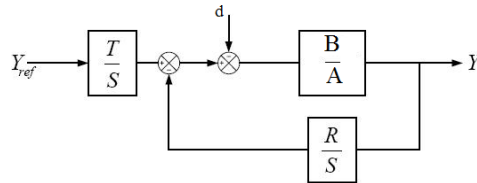


Fig. 4. Block diagram of the RST controller.

With A, B, R, S and T are polynomials of the "s" variable for continuous systems or "z" in the case of discrete systems [10].

The transfer-function of the regulated system is [8] :

$$y = \frac{B.T}{A.S+B.R} y_{ref} + \frac{R.B}{A.S+B.R} \cdot b \quad (5)$$

By applying the Besout equation, we put:

$$D = A.S + B.R \quad (6)$$

In our case, the control systems are systems of first order (for rotor currents or stator powers). we choose a strictly proper regulator [11] [12] [13]. So if A is a polynomial of n degree ($\deg(A)=n$) we must have :

$$\deg re(S) = \deg rs(R) + 1$$

$$\deg re(R) = \deg rs(A)$$

(7)

$$\deg re(D) = 2 \cdot \deg rs(R) + 1$$

In our case:

$$\begin{cases} A = a_1s + a_0 \\ B = b_0 \\ D = d_3s^3 + d_2s^2 + d_1s^1 + d_0 \\ S = s_2s^2 + s_1s^1 + s_0 \end{cases} \quad (8)$$

According to the robust pole placement strategy, the polynomial is written as:

$$D = C.F = (s - P_c).(s - P_c)^2 = (s - \frac{1}{T_c}).(s - \frac{1}{T_f})^2 \quad (9)$$

Where C is the command polynomial and F is the filtering polynomial.

$P_c = -\frac{1}{T_c}$ is the pole of C with T_c as control horizon;

$P_f = -\frac{1}{T_f}$ is double pole of the polynomial filter horizon and T_f as filtering horizon [14].

Perturbations are generally considered as piecewise constant. d can then be modeled by a step input. To obtain good disturbance rejections, the final value theorem indicate that the term $\frac{A.S}{A.S+B.R}$ must tend towards zero

$$\lim_{s \rightarrow 0} s \cdot \frac{A.S}{A.S+B.R} \cdot \frac{d}{R} = 0 \quad (10)$$

To obtain a good stability in steady-state, we must

have $D(0) \neq 0$ and respect relation (21). The Bezout equation leads to four equations with four unknown terms where the coefficients of D are related to the coefficients of polynomials R and S by the Sylvester Matrix :

$$\begin{bmatrix} d_3 \\ d_2 \\ d_1 \\ d_0 \end{bmatrix} = \begin{bmatrix} a_1 & 0 & 0 & 0 \\ 0 & a_1 & 0 & 0 \\ 0 & a_0 & b_0 & 0 \\ 0 & 0 & 0 & b_0 \end{bmatrix} \begin{bmatrix} s_2 \\ s_1 \\ r_1 \\ r_0 \end{bmatrix} \quad (11)$$

In order to determine the coefficients of T, we consider that in steady state y must be equal to y_{ref} so:

$$\lim_{s \rightarrow 0} \frac{B.T}{A.S+B.R} = 1 \quad (12)$$

As we know that $S(0)=0$, we conclude that $T=R(0)$. In order to separate regulation and reference tracking, we to try make the term $\frac{B.T}{A.S+B.R}$ only dependent on C.

We then consider $T=hF$ (where h is real) and we can write :

$$\frac{B.T}{A.S+B.R} = \frac{B.T}{D} = \frac{B.hF}{C.F} = \frac{B.F}{C} \quad (13)$$

$$\text{As } T=R(0) \text{ we conclude that : } h = \frac{R(0)}{F(0)} \quad (14)$$

4.2 Application of the RST command to the DFIG

The terms A and B are expressed by

$$\begin{cases} A=L_sR_r+s.L_rL_s\sigma \\ B=L_m.V_s \end{cases} \quad (15)$$

The choice of these poles is based on the poles of the open loop. The role of the control pole is to accelerate the system, and is generally chosen three to five times greater than the pole of A. In our case:

$$\begin{cases} P_c = 5.P_c = -5 \frac{L_sR_r}{(L_rL_s - L_m^2)} \\ T_c = \frac{1}{P_c} = \frac{(L_rL_s - L_m^2)}{5L_sR_r} \end{cases} \quad (16)$$

We choose T_c three times higher than T_f , so :

$$T_c = -\frac{1}{3} \frac{(L_rL_s - L_m^2)}{5L_sR_r} \quad (17)$$

The polynomial D is written as:

$$D_{PQ} = (s + \frac{1}{T_c}).(s + \frac{1}{T_f})^2 = (s + \frac{1}{T_c}).(s^2 + \frac{2s}{T_f} + \frac{1}{T_f^2}) = s^3 + (\frac{2}{T_f} + \frac{1}{T_c})s^2 + (\frac{1}{T_f^2} + \frac{2}{T_cT_f})s + \frac{1}{T_cT_f^2} \quad (18)$$

The coefficients of polynomial D which are linked to the coefficients of R and S by the Sylvester matrix . Thus, we can determine the parameters of the RST controller as follows:

$$\left\{ \begin{array}{l} d_3 = a_1 s_2 \rightarrow s_2 = \frac{a_3}{a_1} \\ d_2 = a_1 s_1 \rightarrow s_1 = \frac{d_2}{a_1} \\ d_1 = a_0 s_1 + b_0 r_1 \rightarrow r_1 = \frac{d_1 - a_0 s}{b_0} \\ d_1 = b_0 r_0 \rightarrow r_0 = \frac{d_0}{b_0} \\ T = r_0 \end{array} \right. \quad (19)$$

4. Simulation Results

To analyze the system and compare efficiently the two proposed controllers, a set of simulation tests have been performed for 0.8 s, using Matlab/Simulink environment. The PWM inverter on the rotor side of the DFIG is controlled. Both controllers PI and RST are tested and compared by two different criteria, namely, reference tracking, and robustness by varying the parameters of the system. DFIG and the turbine parameters used in the simulation are listed in table I and II, respectively.

The block diagram of indirect command by RST regulator of the active and reactive power and rotor currents represented in the figure (5). The idea is to replace the four PI regulators of FOC by RST regulators.

DFIM Parameters are: Stator resistance R_s is 0.012 Ω ; Rotor resistance R_r is 0.021 Ω ; Stator inductance L_s is 0.0137 H; Rotor inductance L_r is 0.0136 H; Mutual inductance L_m is 0.0135 H.

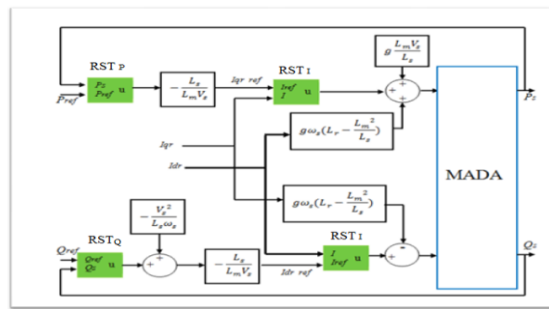


Fig. 5. Global scheme of FOC control with RST regulators

5.1 The reference pursuit

In this test, the simulation was done while keeping the same parameters of the GADA. It provides echelons of active and reactive power to observe the behavior of this command. The results obtained are illustrated in Figure (6).

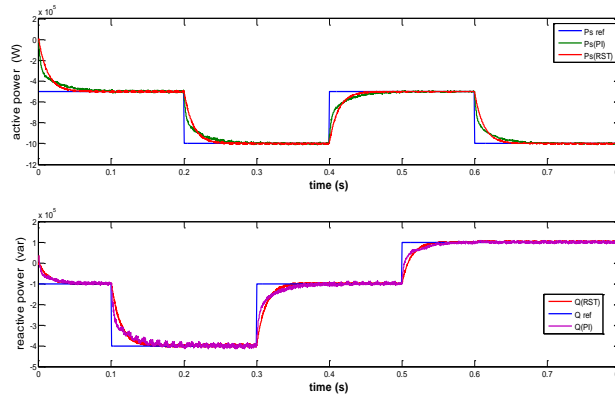


Fig. 6. Simulation results tests of reference tracking using PI and RST regulators.

The simulation results obtained show good performances in following the active and reactive power.

When the reference when changes, it is noticed that the oscillations decrease and the response time is smaller in the case of RST regulator.

5.2 Robustness

In order to test the robustness of PI and RST regulators, the value of the resistor of rotor is 1.5 of its nominal value, the stator and rotor winding values increased by 10% of their nominal values, the value of the mutual is decreased by 10% of its nominal value.

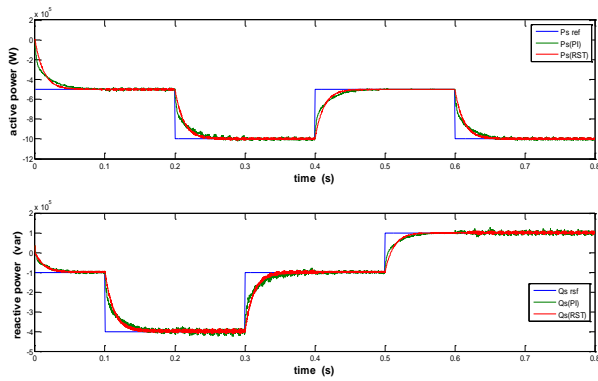


Fig. 7. Influence of rotor resistor variation R_r of +50 %.

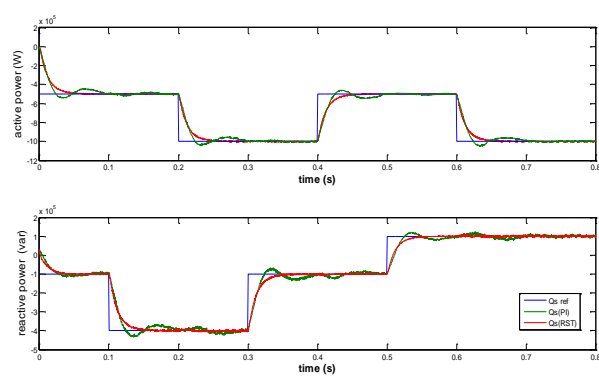


Fig.8. Influence of stator winding variation L_s of +10 %.

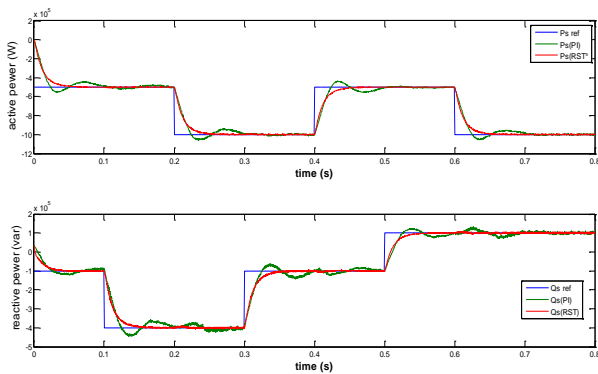


Fig. 9. Influence of rotor winding variation L_r of +10 %.

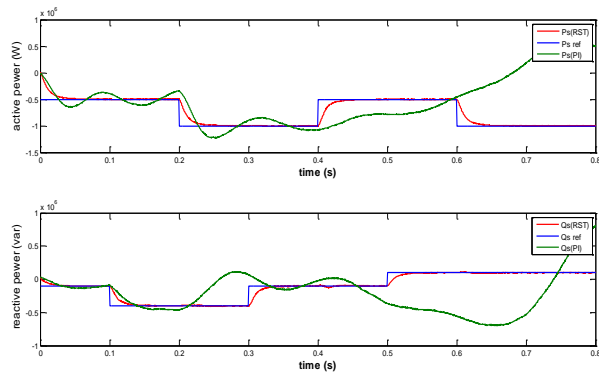


Fig. 10. Influence of mutual winding variation L_m of -10 %.

The comparisons between the two controllers' show that the RST presents good performances, but PI controller performances are deteriorate.

5. Conclusion

This work enabled us to study FOC of DFIG which makes it possible to have a decoupling and an independent control of the active and reactive power. Then we studied the WECS. Firstly, the regulation is made with classical proportional-integral (PI). Secondly, is with polynomial RST.

Results show correct performances of the controller in term of reference tracking and disturbance rejection even under some uncertainties of electrical parameters of the generator. These results are very important in renewable energy application because, generally, the electrical parameter such as the rotor resistance varies with the temperature, the inductance may change with the aging of the motor. These situations involve need of more robust controllers. These studies prove that the RST controller can offer satisfactory performances.

References

- [1] T. Ackermann and Soder, L. "An Overview of Wind Energy-Status 2002". Renewable and Sustainable Energy Reviews 6(1-2), 67-127 (2002).
- [2] GE Wind Energy. GE Wind brochure: http://www.gepower.com/prod_serv/products/wind_trubine_es/en/index.html
- [3] Vestas wind turbine brochure : http://www.vestas.com/vestas/global/en/Products/Download_brochures/download_d_brochurer.html.
- [4] T. Burton, D. Sharpe, N. Jenkins and E. Bossanyi, *Wind Energy Handbook*. John Wiley&Sons, Ltd, 2001
- [5] H. Mahvasha, S. A. Taher , M. Rahimi et M. Shahidehpour, «DFIG performance improvement in grid connected mode by using fractional order [PI] controller» *Electrical Power and Energy Systems*, vol. 96, p. 398–411, 2018.
- [6] M. Machmoum, F. Poitiers, C. Darengosse and A. Queric, "Dynamic Performances of a Doubly-fed Induction Machine for a Variable-speed Wind Energy Generation," *IEEE Trans. Power System Technology*, vol. 4, Dec. 2002, pp. 2431-2436.
- [7] N. Akkari, A. Chaghi et R. Abdessemed, «Study and Simulation of RST Regulator Applied to a Double Fed Induction Machine (DFIM),» *Journal of Electrical Engineering & Technology*, vol. 3, n°13, pp. 308-313, 2008.
- [8] D. Robert, O. Sename et D. Simon, «sampling period dependent RST controller used in control,» chez scheduling co-design" *IEEE Conference on Advanced Motion Control AMC'98*, 1998.
- [9] F. Poitiers, T. Bouaouiche et M. Machmoum, «Advanced control of a doubly-fed induction generator for wind energy conversion,» *Electric Power Systems Research*, vol. 79, p. 1085–1096, 2009.
- [10] B.Multon, X.Roboam, B.Dakyo, C.Nichita, O.Gergaud, H.Ben Ahmed, "Aérogénérateurs électriques". *Technique De L'ingénieur*, D 3 960, 2008.
- [11] M. Laakam et L. Sbita, «RST Control of a Doubly-fed Induction Generator for Wind Energy Conversion,» *International Journal of Engineering Research & Technology (IJERT)*, vol. 3, n°13, pp. 2507-2512, 2014.
- [12] A. Elmansouri, J. El mhamdi et A. Boualouch, «Wind energy conversion system using DFIG controlled by back-stepping and RST controller,» *IEEE, International Conference on Electrical and Information Technologies (ICEIT)*, Tangiers, Morocco, pp. 312-318, 2016.
- [13] M. Chakib, A. Essadki et T. Nasser, «A Comparative Study of PI, RST and ADRC Control Strategies of a Doubly Fed Induction generator Based Wind Energy Conversion System,» *International Journal Of Renewable Energy Research*, vol. 8, n°12, pp. 964- 973, 2018.
- [14] B. Hamane, M. L. Doumbia, M. Bouhamida, A. Draou, H. Chaoui et M. Benghanem, «Comparative Study of PI, RST, Sliding Mode and Fuzzy Supervisory Controllers for DFIG based Wind Energy Conversion System,» *International Journal of Renewable Energy Research*, vol. 5, n°14, pp. 1174-1185, 2015.