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# Study and Simulation of RST Regulator Applied to a Double Fed Induction Machine (DFIM)

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**Abstract** – This article proposes the study and simulation of an RST regulator based on a double fed induction machine. The RST polynomial controller can improve the double fed induction machine performance in terms of overshoot, rapidity, cancellation of disturbance, and capacity to maintain a high level of performance. A control law is synthesized using an RST controller.
Simulation results indicate that the proposed regulator has better performance response to speed variation, sensitivity to perturbation, and robustness. The designed control algorithm is tested on a simulation matlab code.

**Keywords:** Double fed induction machine (DFIM), RST regulator, Vector control

## 1. Introduction

The diversity of control structures available today related to the objectives given by the specifications and the quality of the proposed model in the process must respect the following objectives:

- Stability of the loop;
- Rejection of the disturbances;
- Follow-up of an instruction.

The RST polynomial controller has proved to be efficient, flexible, and successful for industrial applications [1].

It has the advantage of simplicity in implementation since it is based on a formal principle of handling a polynomial, leading to transfer functions that are easy to treat. Thus, the objectives of continuation and regulation are explained through constraints on the polynomials R, S, and T for the rejection of the disturbances and the follow-up of the instruction. The calculation of the polynomials occurs by the resolution of Besout's equation.

The proposed approach presented the analysis of robust control of a linear system monovariable invariant. It is based on the design of the control law through three polynomial RSTs. It is the most general type of invariant linear regulator.

This later is designed by a poles placement method of the buckled system in a certain manner, and thus any method of synthesis can be regarded as a particular case [1].

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## 2. Regulator RST

The RST is a polynomial regulator and is presented in the form of an interesting alternative to the classical PI regulator. The RST polynomial controller can improve the double fed induction machine performance in terms of overshoot, rapidity, cancellation of disturbance, and capacity to maintain high level performances of machine speed.

The elements R, S, and T are polynomials in which the degree is fixed according to the degree of the transfer functions of continuation and regulation in open loop. They are calculated using a strategy of robust pole placement [1].

The block diagram of the RST controller is presented in Figure 1.

The system with the transfer function B/A has $Y_{ref}$ as a reference and is disturbed by the variable $\gamma$ . R, S, and T are polynomials which constitute the controller.

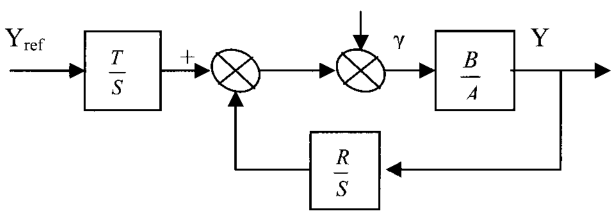


**Fig. 1.** Block diagram of the RST controller

The transfer function of the system is written as:

$$Y = \frac{BT}{AS + BR} Y_{ref} + \frac{AS}{AS + BR} \gamma \tag{1}$$

By applying Besout's equation,

$$A.S + B.R = D \tag{2}$$

We have chosen a strictly proper regulator. So if A is a polynomial of n degree we must have:

$$\begin{aligned} d^0(S) &= d^0(A) + 1 \\ d^0(D) &= 2d^0(A) + 1 \\ d^0(R) &= d^0(A) \end{aligned} \tag{3}$$

The transfer function of the system is written as follows:

$$FT\Omega = \frac{1}{Js + f} \tag{4}$$

Where:

$$\begin{aligned} A &= Js + f \\ B &= 1 \\ \deg A &= n = 1 \\ \deg B &= n = 1 \end{aligned}$$

According to Equation (3), we can write:

$$\begin{aligned} \deg R &= \deg A = 1 \\ \deg S &= \deg A + 1 = 2 \\ \deg D &= 2.\deg A + 1 = 3 \end{aligned} \tag{5}$$

## 3. Application with the Regulation of the Speed of DFIM

In a regulation polynomial, with an RST controller applied to the speed and regarding the load couple as disturbance, the simplified block diagram of the system control is represented in Figure 2.

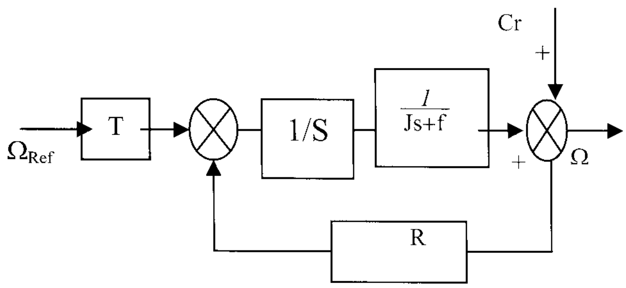


**Fig. 2.** Block diagram of regulation speed of the DFIM

The polynomial T in our case is fixed at a constant, then we have:

$$\begin{aligned} R(s) &= r_0 s + r_1 \\ S(s) &= s_0 s^2 + s_1 s \\ D(s) &= d_0 s^3 + d_1 s^2 + d_2 s + d_3 \end{aligned}$$

Besout's equation has four unknowns where the coefficient of polynomial D is dregs with the coefficient of the polynomials R and S by the matrix of the system:

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ a_1 & 1 & 0 & 0 \\ 0 & a_1 & b_1 & 0 \\ 0 & 0 & 0 & b_1 \end{bmatrix} \begin{bmatrix} s_0 \\ s_1 \\ r_0 \\ r_1 \end{bmatrix} = \begin{bmatrix} d_0 \\ d_1 \\ d_2 \\ d_3 \end{bmatrix}$$

What web ring to the following regulation

$$\begin{aligned} R(s) &= 112.4287s + 0.0032 \\ S(s) &= s^2 + 0.8964s \\ T(s) &= 98.525 + 0.0032 \end{aligned}$$

Where:

$a_1$ et $b_1$: Coefficient of the speed transfer function.

## 4. Double Fed Induction Machine Modeling

In our case we are interested in voltage supply. The state variables are the stator flux ($\phi_{sd}$, $\phi_{sq}$) and the rotor current ($i_{rd}$, $i_{rq}$). The control variables are the speed and the voltages ($v_{sd}$, $v_{sq}$, $v_{rd}$, $v_{rq}$) [3], [4], [5].

The equations of the asynchronous machine in the reference of Park are given by Equation (6):

$$\begin{cases} V_{sd} = R_s I_{sd} + \dfrac{d\phi_{sd}}{dt} - \omega_s \phi_{sq} \\ V_{sq} = R_s I_{sq} + \dfrac{d\phi_{sq}}{dt} + \omega_s \phi_{sd} \\ V_{rd} = R_r I_{rd} + \dfrac{d\phi_{rd}}{dt} - \omega_r \phi_{rq} \\ V_{rq} = R_r I_{rq} + \dfrac{d\phi_{rq}}{dt} + \omega_r \phi_{rd} \end{cases} \tag{6}$$

The equations of the flux are given by:

$$\begin{cases} \phi_{sd} = L_s I_{sd} + M I_{rd} \\ \phi_{sq} = L_s I_{sq} + M I_{rq} \\ \phi_{rd} = L_r I_{rd} + M I_{sd} \\ \phi_{rq} = L_r I_{rq} + M I_{sq} \end{cases} \tag{7}$$

The mathematical model is written as a set of equations of state, both for the electrical and mechanical state:

$$\frac{dX}{dt} = AX + BU \quad (8)$$

$$X = \begin{bmatrix} \phi_{sd} \\ \phi_{sq} \\ I_{rd} \\ I_{rq} \end{bmatrix}, \quad U = \begin{bmatrix} V_{sd} \\ V_{sq} \\ V_{rd} \\ V_{rq} \end{bmatrix}$$

$$A = \begin{bmatrix} \frac{-1}{T_s} & \omega_s & \frac{M}{T_s} & 0 \\ -\omega_s & \frac{-1}{T_s} & 0 & \frac{M}{T_s} \\ \frac{\gamma}{T_r} & -\gamma\omega & -\left(\frac{1}{\sigma T_r}+k\right) & (\omega_s-\omega) \\ \gamma\omega & \frac{\gamma}{T_r} & -(\omega_s-\omega) & -\left(\frac{1}{\sigma T_r}+k\right) \end{bmatrix}$$

$$B = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -\gamma & 0 & \frac{1}{\sigma L_r} & 0 \\ 0 & -\gamma & 0 & \frac{1}{\sigma L_r} \end{bmatrix}$$

Where the values of γ and k are given by:

$$\gamma = \frac{M}{\sigma L_s L_r}, k = \frac{-M^2}{\sigma L_s L_r T_s}$$

Moreover, the equation of the electromagnetic torque can be expressed according to the current stator and rotor flux as follows:

$$C_e = p\frac{M}{L_s L_r}\left[\phi_{sq} I_{rd} - \phi_{sd} I_{rq}\right] \quad (9)$$

$$J\frac{d\Omega}{dt} = C_e - C_r - f\Omega \quad (10)$$

## 5. Vector Control

In the referential axis linked to the rotating field, the stator flux vector $\phi_s$ is aligned with the d axis [6], [7], [8].

By considering the steady state operation, we can write:

$$I_{rd} = \frac{\phi_s^*}{M} \quad (11)$$

$$I_{rq} = -\frac{L_s}{PM}\frac{C_e^*}{\phi_s^*} \quad (12)$$

The angular speed

$$\frac{d\theta_s}{dt} = \omega_s = \left(\frac{R_s M}{L_s} I_{rq} + V_{sq}\right) / \phi_s^* \quad (13)$$

Since $\phi_{sd} = \phi_s$, $\phi_{sq} = 0$, we can write the following equations:

$$\frac{d\phi_s}{dt} = -\frac{1}{T_s}\phi_s + \frac{M}{T_s} I_{rd} + V_{sd} \quad (14)$$

$$\frac{d\phi_{sq}}{dt} = 0 = -\omega_s\phi_s + \frac{M}{T_s} I_{rq} + V_{sq} \quad (15)$$

According to Equations (6), (14) and (15), we can deduce the equations from voltage orders such as:

$$\frac{1}{\sigma L_r}V_{rd} = \frac{1}{\sigma}\left(\frac{1}{T_r} + \frac{M^2}{L_s T_s L_r}\right) I_{rd} - \frac{M}{\sigma L_s T_s L_r}\phi_s - (\omega_s - \omega) I_{rq} + \frac{dI_{rd}}{dt} + \frac{M}{\sigma L_s L_r} V_{sd} \quad (16)$$

$$\frac{1}{\sigma L_r}V_{rq} = \frac{1}{\sigma}\left(\frac{1}{T_r} + \frac{M^2}{L_s T_s L_r}\right) I_{rq} - \frac{M}{\sigma l_s L_r}\omega\phi_s \\ (\omega_s - \omega) I_{rd} + \frac{dI_{rq}}{dt} + \frac{M}{\sigma L_s L_r} V_{sq} \quad (17)$$

Where:

$V_{sd}$, $V_{sq}$, $V_{rd}$, and Vrq: Two- phase stator and rotor.
$\Phi_{sd}$, $\Phi_{sq}$, $\Phi_{rd}$, $\Phi_{rq}$ : Two- phase stator and rotor fluxes.
$I_{sd}$, $I_{sq}$, $I_{rd}$, and Irq: Two- phase stator and rotor currents.
$L_s$, $L_r$: Total cyclic stator and rotor inductance.
$R_s$, $R_r$: Per phase stator and rotor resistances.
M : Magnetizing inductance.
σ : Coefficient of total escape.
$T_s$, Tr: Stator and rotor time constants.
P: Number of pole pairs.

## 6. Simulation Resultants of DFIM

The simplified model under MATLAB- SIMULINK is given by Figure 3. The stator of the DFIM is supplied by the network.

Figure 4 represents the obtained simulation results of a double fed induction machine, DFIM. The first figure shows that before the application of a load, the speed has a linear characteristic and stabilizes to the reference speed value. After the application of a load of Cr=10N.m at time t=1.5s, the speed falls to its value and then stabilizes to a speed reference value of 157 rad/sec.

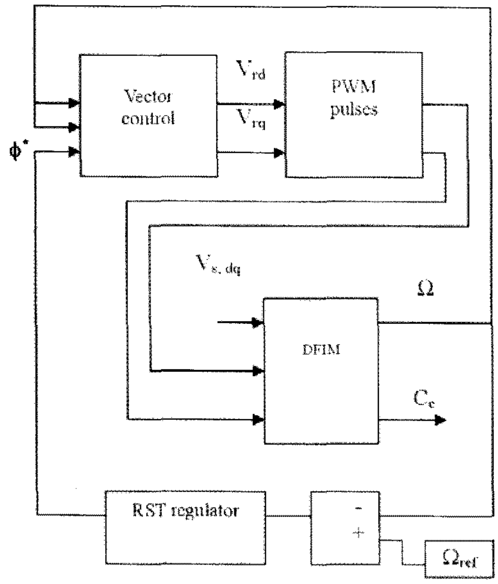


**Fig. 3.** Diagram of RST regulator applied to double fed induction machine, DFIM

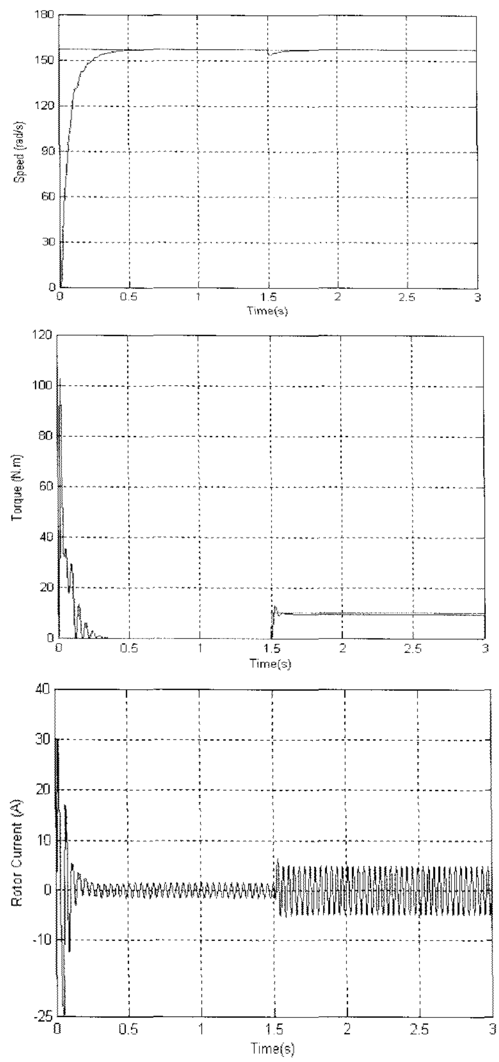


**Fig. 4.** Results of simulation of the double fed induction machine, DFIM

The torque undergoes a peak at the first time of starting, and then reaches the value of resistive torque before and after the application of a load.

## 7. Robust Control of the RST Regulator

### 7.1 Speed Variation

Figure 5 reveals the simulation results obtained for a speed variation for the values: ($\Omega_{REF}$ = 157, 130 and 157 rad/s), with a load of 10 N.m applied at t=1s.

This result shows that the variation leads to a variation in flux and torque. The response of the system is positive. The speed follows its reference value while the torque returns to its reference value with a slight error.

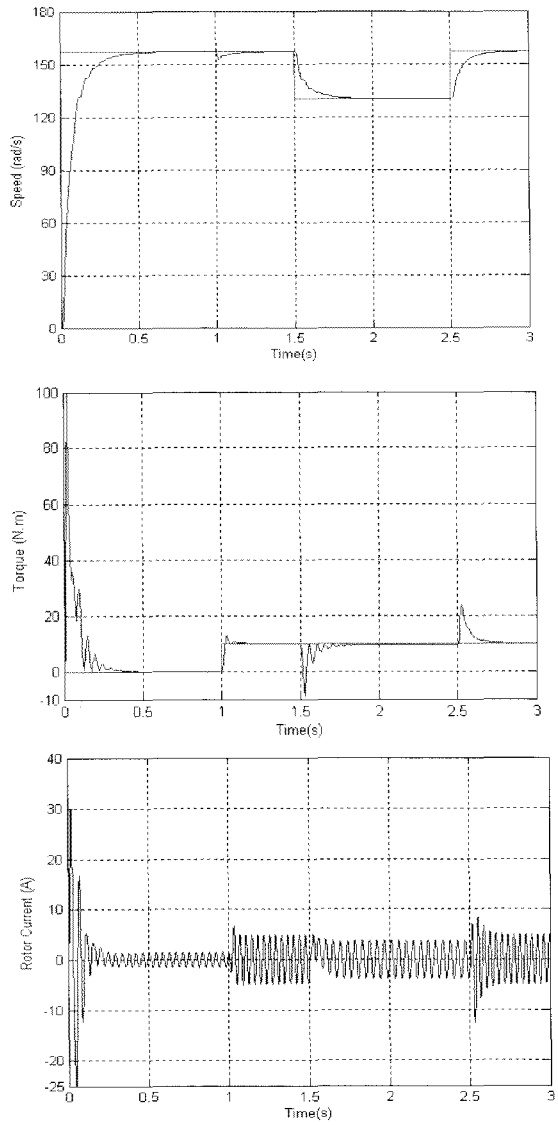


**Fig. 5.** Test of robust control for a speed variation

### 7.2 Robust Control for Load Variation

Figure 6 indicates the simulation results obtained for a load variation (Cr=10N.m, 15N.m).

The speed and the torque are not influenced by this variation.

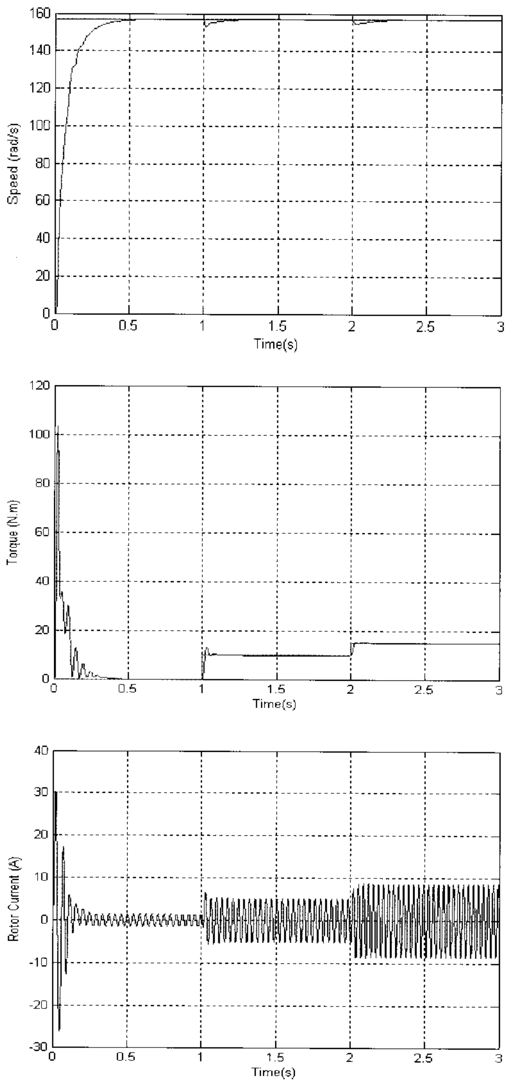


**Fig. 6.** Test of robust control for a load variation

## 8. Conclusion

This paper presents a control strategy for a double fed induction machine based on the regulator RST.

We notice through the obtained simulation results that during the application of the control containing the RST regulator, the double fed induction machine performance in terms of overshoot, rapidity, and cancellation of disturbance is improved

The objectives of regulation which we seek to achieve are related to the robustness in terms of stability and performance.

**Parameters of the DFIM**

$P_n$=1.5kW, $V_{ns}$=220V, $V_{nr}$=12V, $W_n$=1500tr/mn, $R_s$=4.85Ω, $R_r$=3.805Ω, $L_s$=0.274H, $L_r$=0.274H, M=0.258H, p=2, J=0.031kg/m$^2$, f =0.008 N.m.s/rd

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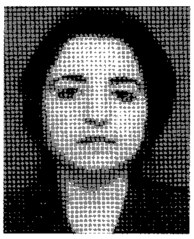

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