

Speed Control of Doubly Star Induction Motor Using Direct Torque DTC Based to on Model Reference Adaptive Control (MRAC)

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Abstract

This paper presents the analysis and simulation of the control of double star induction motor, using direct torque control (DTC) based on model reference adaptive control algorithm (MRAC). The DTC is an excellent solution for general- purpose induction drives in very wide range the short sampling time required by the TC schemes makes them suited to a very fast torque and flux controlled drives as well the simplicity of the control algorithm. DTC is inherently a motion sensorless control method. The model reference regulator (MRAC) can improve the double star induction motor performance in terms of overshoot, rapidity, cancellation of disturbance, and capacity to maintain a high level of performance. Simulation results indicate that the proposed regulator has better performance responses. The implementation of the DTC applied to a double star induction motor based on model reference regulator is validated with simulated results.

Keywords: *Direct Torque Control (DTC), Double Star Induction Motor (DSIM), Model Reference Regulator (MRAC)*

1. Introduction

AC machines with variable speed drives are widely employed in high power applications. In addition to the multilevel inverter fed electric machine drive systems, one approach in achieving high power with rating limited power electronic devices is the multiphase inverter system [1, 2]. In a multiphase inverter feeding machine, the winding of more than three phases are connected in the same stator of the machine, consequently the current per phase in machine is reduced [3, 4].

The double stator induction machine needs a double three phase supply which has the many advantages [5, 7]. It minimise the torque pulsations and uses power electronics components which allow a higher commutation frequency compared to the simple machines. However the double stator Induction machines supplied by a source inverter generate harmonics which result in supplementary losses [5]. The double star induction machine is not a simple system, because a number of complicated phenomena which appear in its function, as saturation and skin effects [6].

The double star induction machine is based on the principle of a double stators displaced by $\alpha=30^\circ$ and rotor at the same time. The stators are similar to the stator of a simple induction machine and fed with a 3 phase alternating current and provide a rotating flux. Each star is composed by three identical windings with their axes spaced by $2\pi/3$ [8, 13].

Therefore, the orthogonality created between the two oriented fluxes, which must be strictly observed, leads to generated coupled control within optimal torque [8, 14].

This is a most rugged and maintenance free machine [15].

The machine studied is represented by two star winding: $A_{S1} B_{S1} C_{S1}$ et $A_{S2} B_{S2} C_{S2}$ which is displaced by $\alpha=30^\circ$ and three rotorical phases: A_r, B_r, C_r .

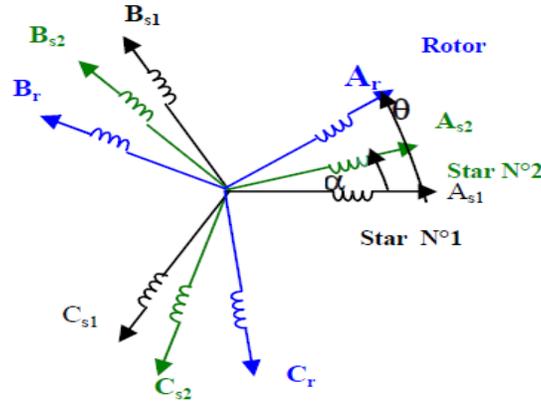


Figure 1. Double star winding representation

2. Double Star Induction Machine Modeling

The equations of the double star induction machine in the reference of Park are given by equation (1):

$$\begin{aligned}
 V_{ds1} &= R_s I_{ds1} + \frac{d\phi_{ds1}}{dt} - \omega_s \phi_{qs1} \\
 V_{qs1} &= R_s I_{qs1} + \frac{d\phi_{qs1}}{dt} + \omega_s \phi_{ds1} \\
 V_{ds2} &= R_s I_{ds2} + \frac{d\phi_{ds2}}{dt} - \omega_s \phi_{qs2} \\
 V_{qs2} &= R_s I_{qs2} + \frac{d\phi_{qs2}}{dt} + \omega_s \phi_{ds2} \\
 0 &= R_r I_{dr} + \frac{d\phi_{dr}}{dt} - (\omega_s - \omega_r) \phi_{qr} \\
 0 &= R_r I_{qr} + \frac{d\phi_{qr}}{dt} + (\omega_s - \omega_r) \phi_{dr}
 \end{aligned} \tag{1}$$

The mechanical dynamic equation is given by:

$$J \frac{d\Omega_m}{dt} + f \Omega_m = C_e - C_r \tag{2}$$

Where J is the moment of inertia of the revolving parts, f is the air flowing over the motor and C_{em} is the load Torque.

The electrical state variables are the flux transformed into vector $[\phi]$ by the “dq” transform, while the input are the “dq” transforms of the voltages, in vector $[V]$.

$$\frac{d}{dt}[\phi] = A[\phi] + B[V] \quad (3)$$

$$[\phi] = \begin{bmatrix} \phi_{ds1} \\ \phi_{qs1} \\ \phi_{ds2} \\ \phi_{qs2} \\ \phi_{dr} \\ \phi_{qr} \end{bmatrix}, [V] = \begin{bmatrix} V_{ds1} \\ V_{qs1} \\ V_{ds2} \\ V_{qs2} \end{bmatrix}$$

The generated torque of doubly star induction can be expressed in terms of stator currents and stator flux linkage as :

$$C_{em} = p \frac{L_m}{L_m + L_r} [\phi_{dr}(i_{qs1} + i_{qs2}) - \phi_{qr}(i_{ds1} + i_{ds2})] \quad (4)$$

The equations of flux are:

$$\begin{cases} \phi_{md} = L_a \left(\frac{\phi_{ds1}}{L_{s1}} + \frac{\phi_{ds2}}{L_{s2}} + \frac{\phi_{dr}}{L_r} \right) \\ \phi_{mq} = L_a \left(\frac{\phi_{qs1}}{L_{s1}} + \frac{\phi_{qs2}}{L_{s2}} + \frac{\phi_{qr}}{L_r} \right) \end{cases} \quad (5)$$

$$L_a = \frac{1}{\frac{1}{L_{s1}} + \frac{1}{L_{s2}} + \frac{1}{L_r} + \frac{1}{L_m}} \quad (6)$$

Given that the “dq” axes are fixed in the synchronous rotating coordinate system we have:

$$\begin{cases} \phi_{sd1} = L_{s1}i_{ds1} + L_m(i_{ds1} + i_{ds2} + i_{dr}) \\ \phi_{sq1} = L_{s1}i_{qs1} + L_m(i_{qs1} + i_{qs2} + i_{qr}) \\ \phi_{sd2} = L_{s2}i_{ds2} + L_m(i_{ds1} + i_{ds2} + i_{dr}) \\ \phi_{sq2} = L_{s2}i_{qs2} + L_m(i_{qs1} + i_{qs2} + i_{qr}) \\ \phi_{dr} = L_r i_{dr} + L_m(i_{ds1} + i_{ds2} + i_{dr}) \\ \phi_{qr} = L_r i_{qr} + L_m(i_{qs1} + i_{qs2} + i_{qr}) \end{cases} \quad (7)$$

$$[A] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix}, [B] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Where:

$$a_{11} = a_{33} = \frac{R_{s1}L_a}{L_{s1}^2} - \frac{R_{s1}}{L_{s1}}, a_{12} = a_{34} = \frac{R_{s1}L_a}{L_{s1}L_{s2}}, a_{31} = a_{24} = -a_{31} = \omega_s, a_{21} = a_{43}$$

$$= \frac{R_{s2}L_a}{L_{s1}L_{s2}}$$

$$a_{14} = a_{16} = a_{23} = a_{26} = a_{32} = a_{35} = a_{41} = a_{45} = a_{53} = a_{54} = a_{61} = a_{62} = 0$$

$$a_{15} = a_{36} = \frac{R_{s1}L_a}{L_rL_{s1}}, a_{22} = a_{44} = \frac{R_{s2}L_a}{L_{s2}^2} - \frac{R_{s1}}{L_{s1}}, a_{25} = a_{46} = \frac{R_{s2}L_a}{L_rL_{s2}}, a_{51} = a_{63} = \frac{R_rL_a}{L_rL_{s1}}$$

$$a_{52} = a_{64} = \frac{R_rL_a}{L_rL_{s2}}, a_{55} = a_{66} = \frac{R_rL_a}{L_r^2} - \frac{R_r}{L_r}, a_{56} = -a_{65} = \omega g_1$$

3. Direct Torque Control for the Double Star Induction Motor

Direct torque control is based on the flux orientation, using the instantaneous values of voltage vector. An inverter provides eight voltages vector, among which two are zeros [11], [13]. This vector is chosen from a switching table according to the flux and torque errors as well as the stator flux vector position. In this technique, we don't need the rotor position in order to choose the voltage vector. This particularity defines the DTC as an adapted control technique of AC machines and is inherently a motion sensorless control method [8, 12].

Figure 2 shows the block diagram for the direct torque and flux control applied to the double star induction motor shown in. The star flux ϕ_{ref} and the torque C_{emref} magnitudes are compared with estimated values respectively and errors are processed through hysteresis-band controllers [16].

Star flux controller imposes the time duration of the active voltage vectors, which move the stator flux along the reference trajectory, and torque controller determinates the time duration of the zero voltage vectors, which keep the defined motor torque by hysteresis tolerance band [9].

Finally, in every sampling time the voltage vector selection block choses the inverter switching state, which reduces the instantaneous flux and torque errors [17, 18].

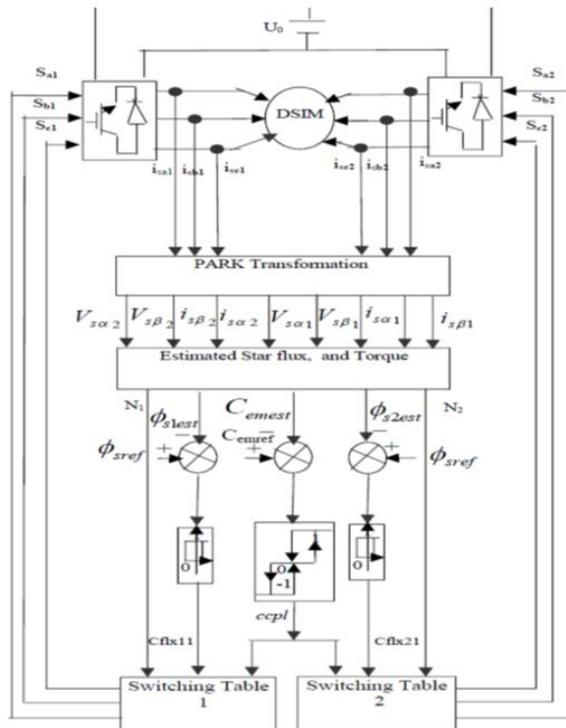


Figure 2. DTC applied to the double star induction motor

4. Model Reference Adaptive Control MRAC

This procedure is presented by the introduction of adaptive algorithms with simplified model reference. The structure of adaptive control with model reference is shown in Figure 3 using a first-order model reference for the speed and a simple formulation of the electromagnetic torque reference based on measured quantities [19, 20].

The adaptation of the parameters is carried out using the error resulting from the comparison of the rotor speed and the model reference speed as shown in Figure 3.

This control method is generally used to reduce the computational complexity for algorithm implementation. A first order a model reference is select [21, 22].

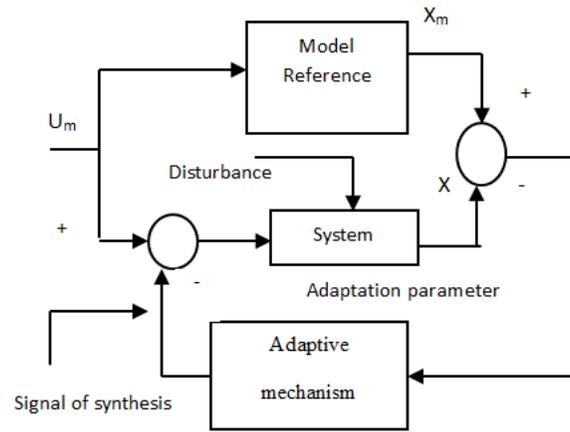


Figure 3. Structure of model reference adaptive control

5. Model Reference equation

The first order model reference can be written as :

$$J \frac{d\Omega_m}{dt} + f\Omega_m = C_e - C_r \quad (8)$$

The mode reference for the system:

$$\frac{J}{K} \frac{d\Omega_m}{dt} + \Omega_m = U_m \quad (9)$$

The decoupling control of model reference is given by:

$$e = \Omega_m - \Omega \quad (10)$$

$$U = K_u \cdot U_m + K_p \cdot x + K_e \cdot e \quad (11)$$

Where the values of K_u , K_p are:

$$K_u(e, t) = \int_0^t \alpha \cdot y \cdot u_m^T \cdot dt + \beta \cdot y \cdot u_m^T \quad (12)$$

$$K_p(e, t) = \int \alpha \cdot y \cdot x^T dt + \beta \cdot y \cdot x^T \quad (13)$$

6. Simulation Results

Figure 4 represents the simulation results of double star induction motor (DSIM). This figure shows before the application of load the speed is a linear characteristic stabilized by the value of speed reference. After the application of $C_r=15N.m$ load to $t=1s$, it represents a fall in its value then stabilizes to the value of speed reference (3000 tr/mn). The torque undergoes a peak at the first time of starting, and then reaches the value of resistive torque before and after the load application.

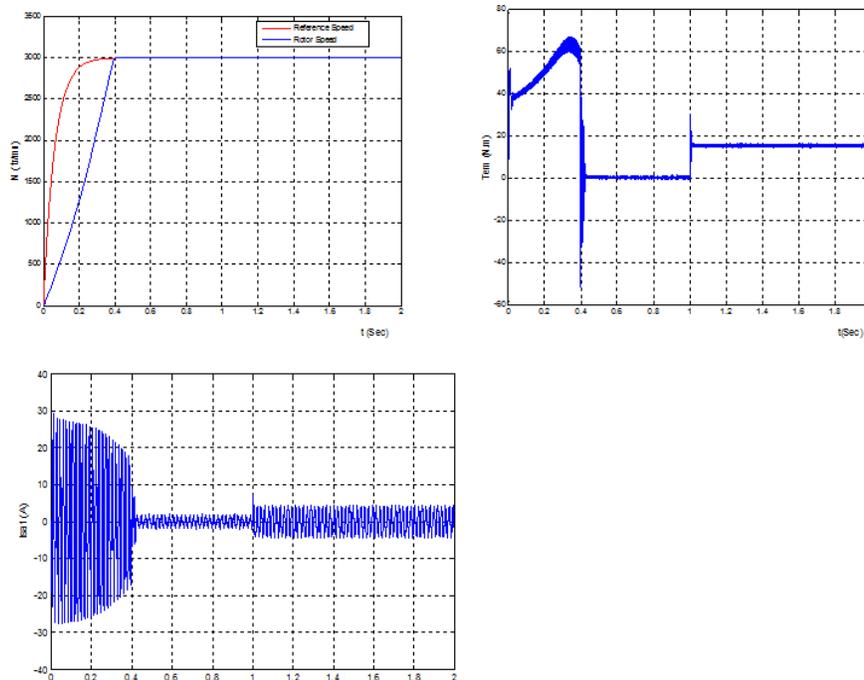


Figure 4. Simulation Results of the double star induction machine (DSIM) ¶

7. Robust Control of Adaptive Control MRAC

7.1 Speed Variation

Figure (5) shows the simulation results obtained for a speed variation for the values: ($\Omega_{REF}=1000, 2000$ and $3000tr/mn$), with the load of $15 N.m$ applied at $t=1s$.

These results show that the speed and torque response follow perfectly their reference values with the same time response.

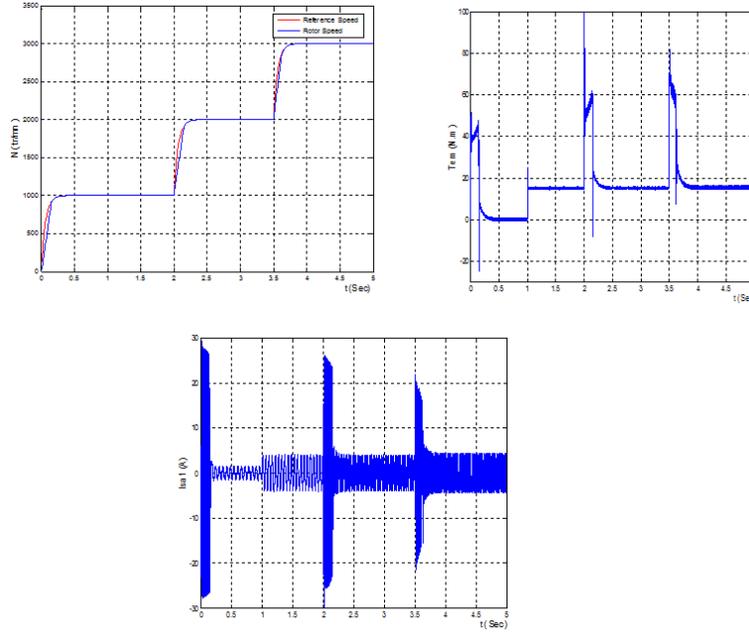


Figure 5. Speed variation robust control

7.2. Robust control for load variation

Figure 6 shows the simulation results obtained for a load variation ($C_r=5\text{N.m}$, 10N.m and 15N.m).

The speed and the torque are not influenced by this variation. We can see that the control is robust from the load variation point of view.

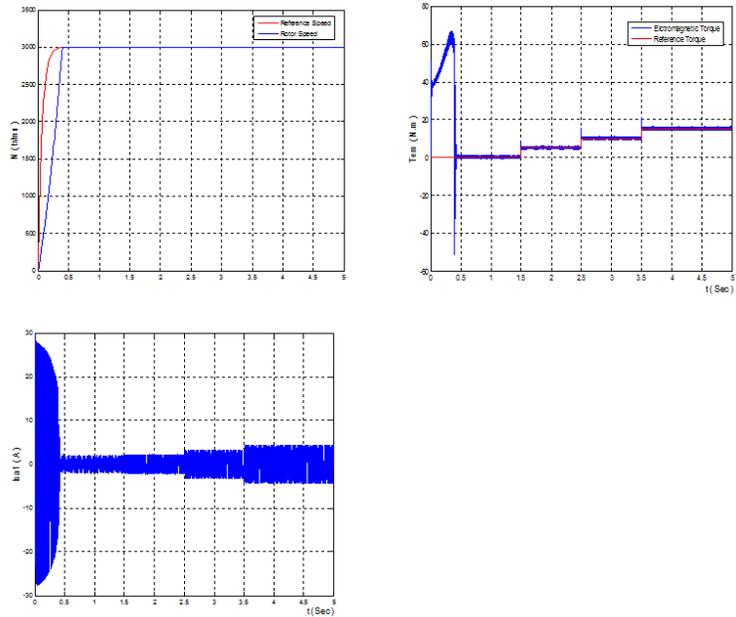


Figure 6. Robust control for load variation

8. Conclusion

In this paper, the analysis and the control of a double star induction motor, using direct torque control (DTC) based on adaptive control which is model by a reference regulator (MRAC) is presented. As can be seen from the simulation results with adaptive regulator (MRAC) control, the robustness in terms of stability and performance is achieved. The DTC control with adaptive control algorithm offers an excellent stability and disturbances rejection with high performance. The robustness is achieved by using a relative error signal in combination with a speed reference and rotor speed in the adaptive law.

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APPENDIX

The machine parameters are as follows:

Rated power; $P_n=4.4\text{Kw}$

Pole pair; $P=1$

Rated frequency; 50Hz

Nominal speed; 3000rpm

Resistance of the stator 1; $R_{s1}=3.72\Omega$

Resistance of the stator 2; $R_{s2}=3.72\Omega$

Resistance of the rotor; $R_r= 2.12 \Omega$

Inductance of the stator1; $L_{s1}=0.022\text{H}$

Inductance of the stator2; $L_{s2}=0.022\text{H}$

Inductance of the rotor; $L_r=0.006\text{H}$

Mutual inductance; $L_m=0.3672\text{H}$

Machine inertia; $J=0.0625\text{Kg.m}^2$

Viscous coefficient; $f=0.001\text{Kg.m}^2/\text{s}$

