Control and simulation of a Double Star Induction Machine Using Direct Torque Control DTC

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Abstract- *This paper describes the control of double star induction machine, using direct torque control (DTC).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 implimentation of the DTC applied to a double stator induction motor is validated with simulated results.*

Key words- *Direct Torque Control "DTC", double star induction machine, modelling, state equations.*

1. Introduction

For the last 20 years the induction machines with a double star have been used in many applications for their performances in the power fields because of their reduced pulsation when the torque is minimum [1].The double stator induction machine needs a double three phase suply which has many advantages. It minimise the torque pulsations and uses a 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 harmonic which results in supplementary losses [2].The double star induction machine is not a simple system, because a number of complicated phenomenas appears in its function, as saturation and skin effects [3].

The double star induction machine is based on the principle of a double stators displaced by $\alpha=30^0$ 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 widings with their axes spaced by $2\pi/3$ in the space. Therefore, the orthogonality created between the two oriented fluxes, which must be strictly observed, leads to generate decoupled control with an optimal torque [4].

This is a maintenance free machine.

The machine stydied is represented with two stars widings: $A_{s1}B_{s1}C_{s1}$ et $A_{s2}B_{s2}C_{s2}$ which are displaced by $\alpha = 30°$ and thee rotorical phases: A_r B_r C_r.

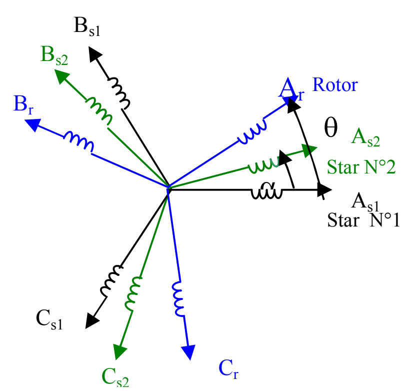


Fig.1. Double star winding representation

2. Double star induction machine modelling

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

$$[V_{abc,s1}] = [R_{s1}]\ [I_{abc,s1}] + \frac{d}{dt}[\Phi_{abc,s1}]$$

$$[V_{abc,s2}] = [R_{s2}]\ [I_{abc,s2}] + \frac{d}{dt}[\Phi_{abc,s2}] \qquad (1)$$

$$[V_{abc,r}] = [R_r]\ [I_{abc,r}] + \frac{d}{dt}[\Phi_{abc,r}]$$

$$J\frac{d\Omega}{dt} = C_{em} - C_r - K_f\Omega. \qquad (2)$$

Where:

J is the moment of inertia of the revolving parts.

K_f is the coefficient of viscous friction, arising from the bearings and the air flowing over the motor.

C_{em} is the electromagnetic 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].

$$\frac{d}{dt}[\Phi] = [A].[\Phi] + [B].[v] \qquad (3)$$

$$[\Phi] = \begin{bmatrix} \Phi_{ds1} \\ \Phi_{ds2} \\ \Phi_{qs1} \\ \Phi_{qs2} \\ \Phi_{dr} \\ \Phi_{qr} \end{bmatrix} \quad [V] = \begin{bmatrix} v_{ds1} \\ v_{ds2} \\ v_{qs1} \\ v_{qs2} \end{bmatrix} \qquad (4)$$

The equation of the electromagnetic torque is given by

$$Cem = p\,\frac{Lm}{Lm + Lr}\,(\Phi_{dr}\,(i_{qs1}+i_{qs2}) - \Phi_{qr}\,(i_{ds1}+i_{ds2})) \qquad (5)$$

The flux equation is:

$$\Phi_{md} = L_a\left(\frac{\Phi_{ds1}}{L_{s1}} + \frac{\Phi_{ds2}}{L_{s2}} + \frac{\Phi_{dr}}{L_r}\right) \qquad (6)$$

$$\Phi_{mq} = L_a\left(\frac{\Phi_{qs1}}{L_{s1}} + \frac{\Phi_{qs2}}{L_{s2}} + \frac{\Phi_{qr}}{L_r}\right) \qquad (7)$$

Given that the "dq"axes are fixed in the synchronous rotating coordinate system, we have:

$$[A] = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \\ a_{31} & a_{32} & a_{33} & a_{34} & a_{35} & a_{36} \\ a_{41} & a_{42} & a_{43} & a_{44} & a_{45} & a_{46} \\ a_{51} & a_{52} & a_{53} & a_{54} & a_{55} & a_{56} \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & a_{66} \end{bmatrix} \qquad (8)$$

$$[B] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \qquad (9)$$

where:

$\frac{R_{s1}L_a}{L_{s1}^2} - \frac{R_{s1}}{L_{s1}}$ $a_{11} = a_{33} =$

$\frac{R_{s1}L_a}{L_{s1}L_{s2}}$ $a_{12} = a_{34} =$

ω_s $a_{13} = a_{24} = -a_{31} = -a_{42} =$

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

$a_{15} = a_{36} = \frac{R_{s1}L_a}{L_rL_{s1}}$, $a_{21} = a_{43} = \frac{R_{s2}L_a}{L_{s1}L_{s2}}$

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

$a_{51} = a_{63} = \frac{R_rL_a}{L_rL_{s1}}$, $a_{52} = a_{64} = \frac{R_rL_a}{L_rL_{s2}}$

$a_{55} = a_{66} = \frac{R_rL_a}{L_{r2}^2} - \frac{R_r}{L_r}$, $a_{56} = -a_{65} = \omega_{gl}$

3. Direct torque control for the double star induction machine

Direct torque control is based on the flux orientation, using the instantaneous values of voltage vector.

An inverter provide eight voltage vector, among which two are zeros [5],[6] .This vector are chosen from a switching table according to the flux and torque errors as well as the strator flux vector position. In this technique, we dont need the rotor position in order to chose the voltage vector. This particularity defines the DTC as an adapted control technique of ac machines and is inherently a motion sensorless control method [7],[8].

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 Ψ_{ref} and the torque C_{emref} magnitudes are compared with estimated values respectively and errors are processed through hysteresis-band controllers.

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 motor torque inthe defined-by hysteresis tolerance band[9]. Finally, in every sampling time the voltage vector selection block chooses the inverter switching state, which reduces the instantaneous flux and torque errors.

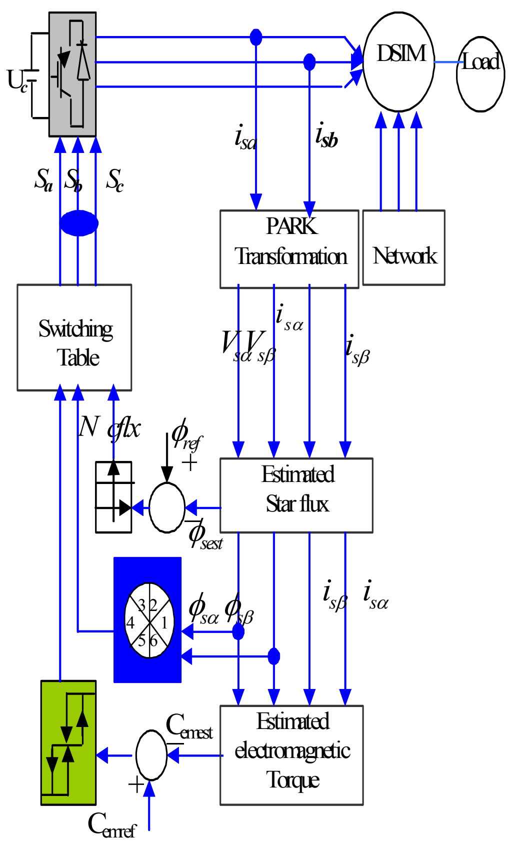


Fig.2: DTC applied to the double star induction machine

4. Simulation results

Figure 3 refer in order, to the variation in magintude of the following quantities, speed, electromagnetic torque, current and flux obtained while starting up the induction motor initialy under no load then connecting the nominal load.During the starting up with no load the speed recheas rapidely its reference value without overtaking, however when the nominal load is applied a little ovetaking is noticed and the command reject the disturbance.The excelent dynamic performance of torque and flux control is evident.

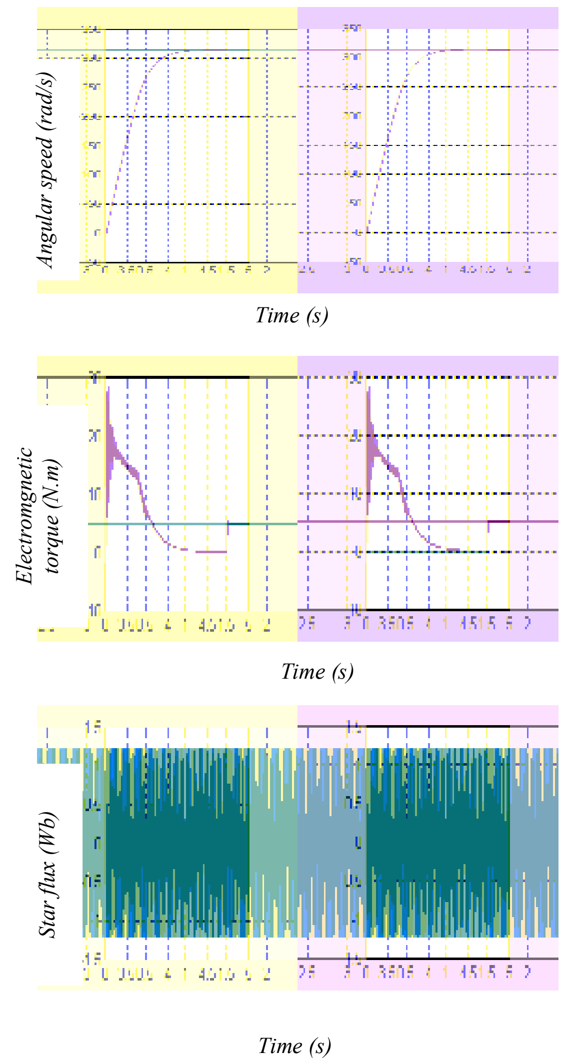
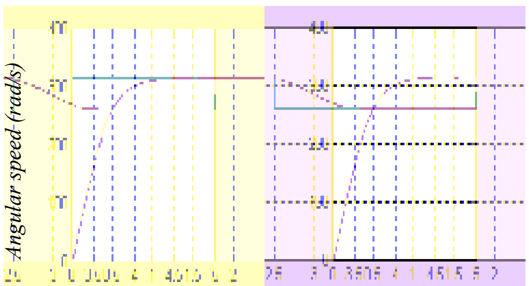


Fig. 3: Simulation results obtained with an PI regulator

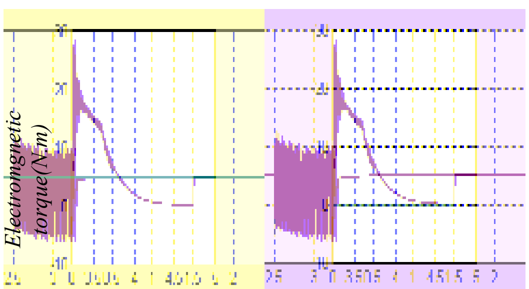
ROBUST CONTROL OF THE REGULATOR

A) Speed variation: Figure.4 shows the simulation results obtained for a speed variation for the values: (Ω_{ref} = 314 and 260 rad/s), with the load of 5 N.m applied at t=1.5s.

These results shows that the variation lead to the variation in flux and the torque. The response of the system is positive, the speed follow its reference value while the torque return to its reference value with a litte error



Time (s)



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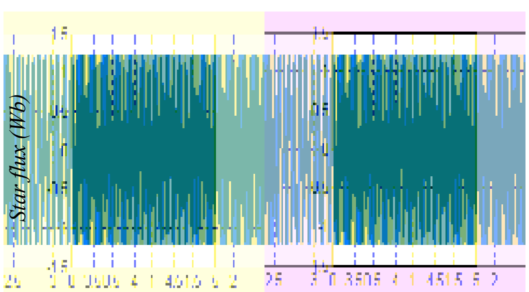
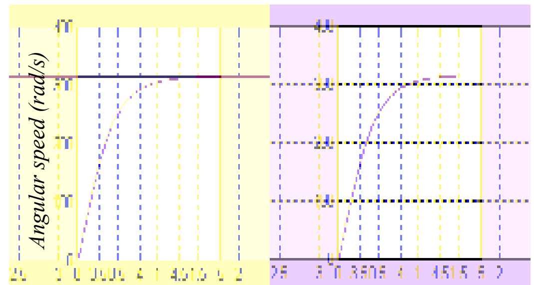


Time (s)

Fig .4: Robust control for a speed variation

B) Robust control for load variation:
Figure.5 shows the simulation results obtained for a load variation (C_r = 5 N.m, 2.5 N.m). As can be seen the speed, the torque, the flux and current are influenced by this variation. The torque and the speed follow their reference values.
We can see that the control is robust from the point of view load variation.



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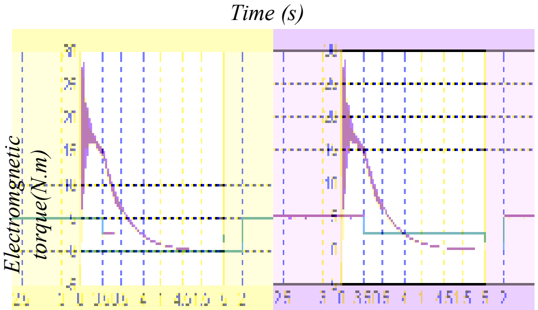

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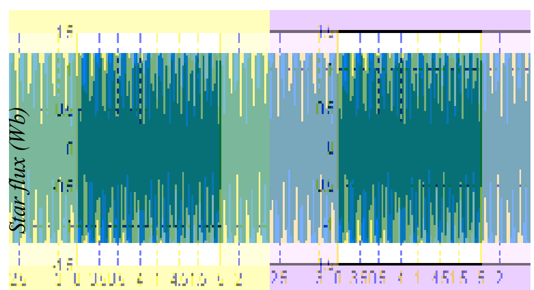

Time (s)

Fig.5: Robust control under load variation

C) Robust control of the regulator under star resistance variation:

In order to verifie the robustess of the regulator under motor parameters variations we carried out a test for a variation of 50% in the value of star resistance at time t= 1.5s. The speed is fixed at 314 rad/s and a resistant torque of 5N.m is applied at t= 1s. Figure 6 shows in order the torque response, the current, the staor flux and the speed. The results indicate that the regulator is very sensitive to the resistance change which results in the influence on the torque and the stator flux

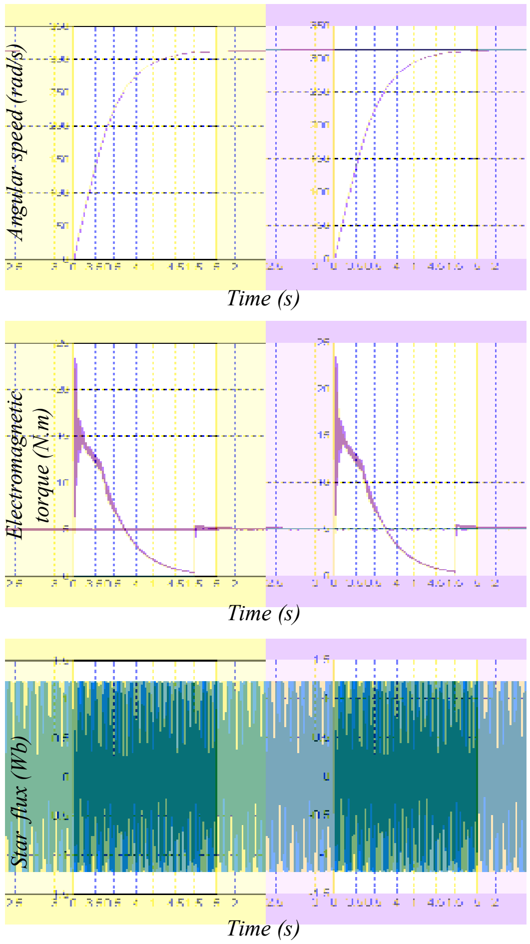

Fig. 6: Robust control under star resistance variation

5. Conclusion

This paper presents a control strategy for a double star induction machine based on the direct control torque (DTC) using a PI regulator. The simulation results show that the DTC is an excellent solution for general-purpose induction drives in a wide range of power.
Simulation results on control robustess with speed variation, parameters variation and the torque resistant are given.

The simulation results show that the DTC with a PI regulator present very good performances from the point of view robustness. The DTC control with a PI regulator offers as well a good dynamique and a very good precision. However when the statorique resistance change the robustness becomes weak.

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