International Journal of Electrical and Power Engineering 2 (1): 1-5, 2008
ISSN: 1990-7958

Control of a Double Stator Induction Machine Using Direct Torque Control

L. Benalia, A. Chaghi and R. Abdessemed
Laboratory of LEB Research, Department of Electrical Engineering, Batna University,
Chahid Med El Hadi Boukhlouf, Batna 05000, Algeria

Abstract: This study describes the control of doubly stator induction machine, using Direct Torque Control (DTC). The DTC is an excellent solution for general-purpose induction drives in avery wide range. Instead, the short sampling time required by the DTC schemes makes them suited to a very fast torque and flux controlled drives in spite of 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), doubly stator induction machine, modelling, equations of state

INTRODUCTION

For the last 20 years, the induction machines with a double stator have been used in many applications for their performances in the over power fields for their reduced pulsation when the torque is minimum (Kalantari *et al.*, 2002). The double stator induction machine needs a double three phase suply which has the 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 (Hadiouche *et al.*, 2000). The double stator induction machine is not a simple system, because a number of complicated phenomenas appears in its funcion, as saturation and skin effects (Hadiouche *et al.*, 2000).

The double stator 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 provides a rotating flux.

Each stator is composed by three identical widings and 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 withan optimal torqu (Hadiouche *et al.*, 2000).

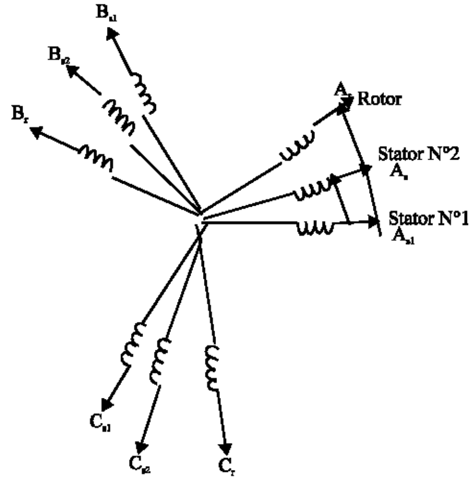

Fig. 1: Double stator winding representation

The machine stydied is represented by with two stators 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).
This is a most rugged and maintenance free machine.

DOUBLE STATOR INDUCTION MACHINE MODELLING

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

Corresponding Author: L. Benalia, Laboratory of LEB Research, Department of Electrical Engineering, Batna University, Chahid Med El Hadi Boukhlouf, Batna 05000, Algeria

$$\begin{aligned}
\left[V_{abc,s1}\right] &= \left[R_{s1}\right]\left[I_{abc,s1}\right] + \frac{d}{dt}\left[\Phi_{abc,s1}\right].\\
\left[V_{abc,s2}\right] &= \left[R_{s2}\right]\left[I_{abc,s2}\right] + \frac{d}{dt}\left[\Phi_{abc,s2}\right].\\
\left[V_{abc,r}\right] &= \left[R_{r}\right]\left[I_{abc,r}\right] + \frac{d}{dt}\left[\Phi_{abc,r}\right].
\end{aligned} \tag{1}$$

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

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 and C_{em} is the load couple.

The electrical state variables are the flux, transformed into vector [Φ] by the "dq" transform, wihle the the input are the "dq" transforms of the voltages, in vector [V].

$$\frac{d}{dt}[\Phi] = [A]\,.[\Phi]\ + [B]\,.[v] \tag{3}$$

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

The equation of the electromagnetic couple or torque as:

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

The equation of flux are:

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

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

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

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

$$B = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \tag{9}$$

Where:

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

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

$a_{13} = a_{24} = -a_{31} = -a_{42} = \omega_s$

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

$a_{15} = a_{36} = \frac{R_{s1}L_a}{L_r L_{s1}}$

$a_{21} = a_{43} = \frac{R_{s2}L_a}{L_{s1}L_{s2}}$

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

$a_{25} = a_{46} = \frac{R_{s2}L_a}{L_r L_{s2}}$

$a_{51} = a_{63} = \frac{R_r L_a}{L_r L_{s1}}$

$a_{52} = a_{64} = \frac{R_r L_a}{L_r L_{s2}}$

$a_{55} = a_{66} = \frac{R_r L_a}{L_{r2}^2} - \frac{R_r}{L_r}$

$a_{56} = -a_{65} = \omega_{gl}$

Direct torque control for the double feed 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 (Radwan, 2005; Roys, 1995). 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 (Ortega *et al.*, 2005; Casdei *et al.*, 2001).

The block diagram for the direct torque and flux control applied to the double feed induction motoris shown in Fig. 2. The stator flux y_{ref} and the torque c_{emref} magnitudes are compared with respective estimated values and errors are processed through hysteresis-band controllers.

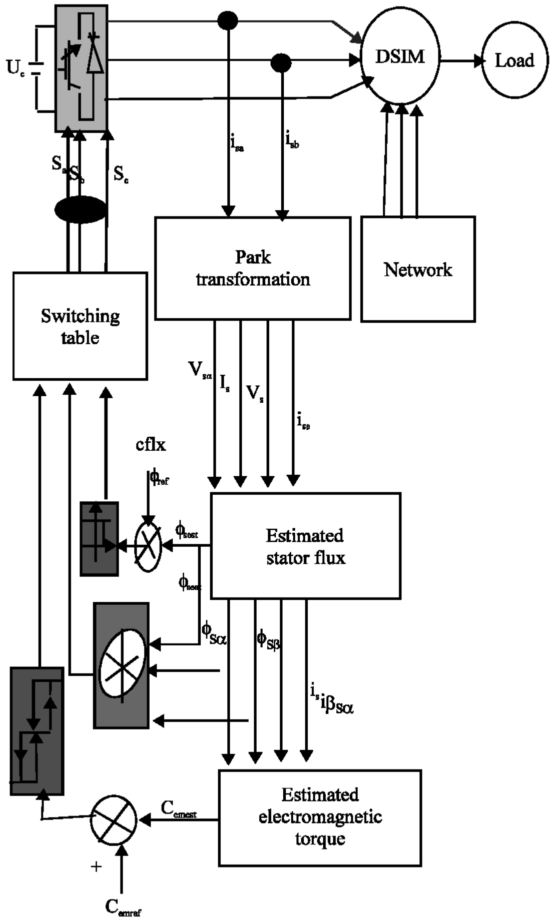

Fig. 2: DTC applied to bouble stator induction machine

Stator flux controller imposes thet ime 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 hestheresis tolerance band (Kouang *et al*., 2000). Finally, in every sampling time the voltage vector selection block chooses the inverter switching state, which reduces the instantaneous flux and torque errors.

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 refrence 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.

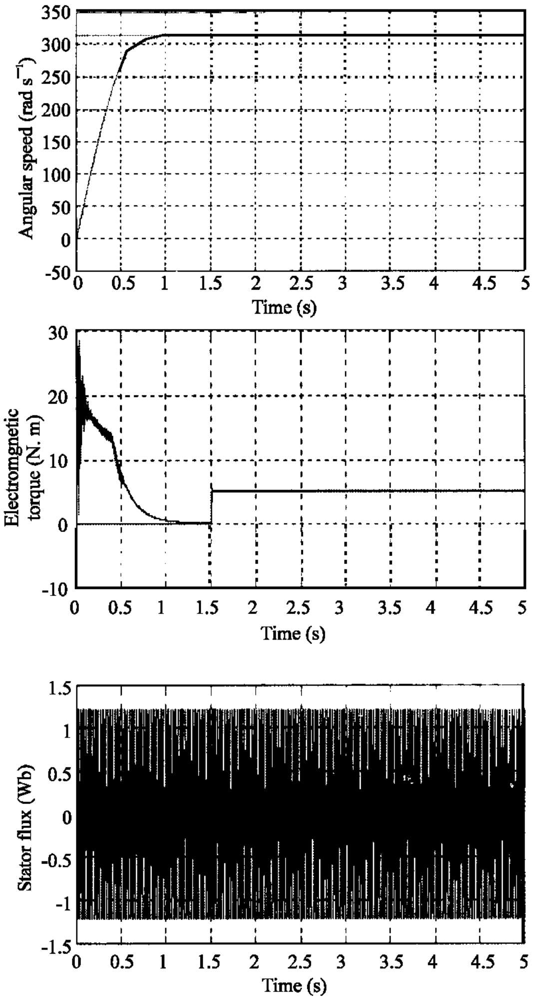

Fig. 3: Simulation results obtained with an plregulator

ROBUST CONTROL OF THE REGULATOR

Speed variation: Figure 4 shows the simulation results obtained for a speed variation for the values: (Ω_{ref} = 314 and 260 rad s^{-1}), with the load of 5 N.m applied at t = 1.5s.

This results shows that the varaition lead to the varaition 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.

Robust control for load variation: The simulation results obtained for a load variation (C_r = 5 N.m,2.5 N.m) in Fig. 5, show that the speed, the torque, the

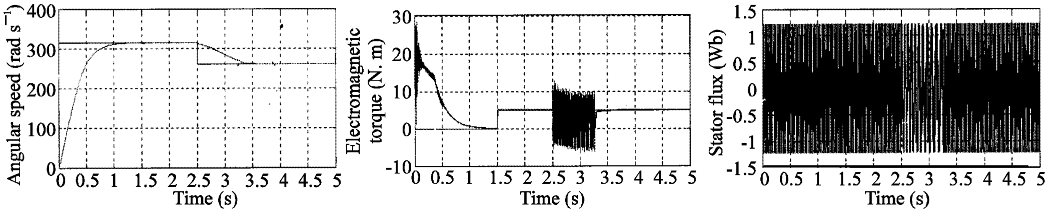

Fig.4: Robust control for a speed variation

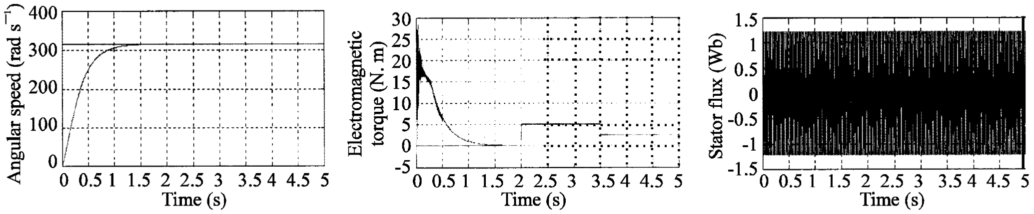

Fig.5: Robust control under load variation

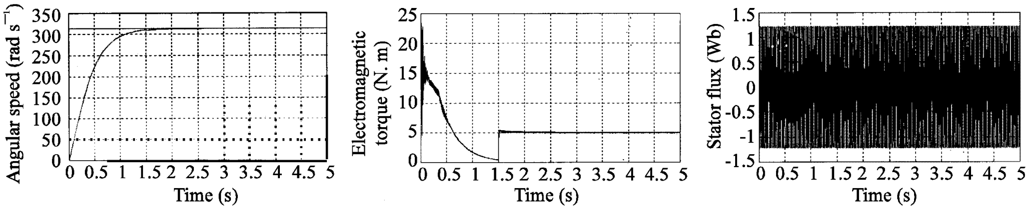

Fig.6: Robust control under stator resistance variation

flux and current are influated with this variation. Indeed the torque and the speed follow their refrence values.

Robust control of the regulator under stator 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 sator resistance at time t= 1.5s. the speed is fixed at 314 rad s^{-1} and a resistant torque of 5n.m is applied at t = 1s. Figure 6 shows the in order the torque response, the current, the staor flux and the speed. The results indicate that the regulator is very sensitive to the resisatance change which results in the influence on the torque and the stator flux.

CONCLUSION

This study presents a control strategy for a double stator induction machine based on the Direct Control Torque (DTC) using an pi regulator. The simulation results show that the dtc is an excellent solution for general-purpose induction drives in a very wide power range.

Simulation results on control robustess with speed varaition, parameters variation and the torque resistant are given.

The simulation results show that the DTC with a PI regulator present a very good performances from the point of view robstess. The DTC control with a PI regulator offers as well a good dynamique and is very pricise. However, when the statorique resistance change the robustenness become weak.

REFERENCES

Carlos Ortega, Antoni Arias and Xavier del Toro, 2005. Novel direct torque control for induction motors using schort voltage vectors of matrix converters. IEEE. Trans. Ind. Applied, pp: 1353-1358.

Casdei, D., G. Serra and A. Tani, 2001. The use of matrix converters in direct torque control of induction machines. IEEE. Trans. Indus. Elec., 48: 6.

Hadiouche, D., H. Razik and A. Rezzoug, 2000. Stady and simulation of space vector PWM control of Double-Star Induction Motors, IEEE-CIEP, Acapulco, Mexico, pp: 42-47.

Hadiouche, D., H. Razik and A. Rezzoug, 2000. Modelling of a double-star induction motor with an arbitrary shift angle between its three phase windings, EPE-PEMC, Kosice.

Kalantari, A., M. Mirsalim, H. Rastegar, 2002. Adjustable speed drive based on fuzzy logic for a dual three-phase induction machine. Electrimacs, pp: 18-21.

Kouang-Kyun La, Myoung-Ho Schin and Dong-Seok Hyun, 2000. Direct torque control of induction motor with reduction of torque ripple. IEEE Trans. Ind. Applied, pp: 1087-1092.

Radwan, T.S., 2005. Perfect speed tracking of directe torque controlled induction motor drive using Fuzzy logic. IEEE. Trans. Ind. Applied, pp: 38-43.

Roys et S. Courtine, 1995. Commande directe du couple d'une machine asynchrone par le contrôle direct de son flux statorique, J. de Physique, France, Mai, pp: 863-880.