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Control of a Double Feed Induction Machine Using Direct Torque Control

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Abstract: This stduy describes the control of doubly fed 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 feed induction motor is validated with simulated results.

Key words: Direct Torque Control (DTC), double-feed induction machine, modelling, equations of state

INTRODUCTION

In the training domain of high power as the rolling mill, ther is a new and original solution using a Double Feed Induction Motor (DFIM). The stator is feed by a fixed network while the rotor by a variable supply which can be either a voltage or current source.

In the mid-1980s, an advanced scalar control technique, known as Direct Torque and Flux Control (DTFC or DTC) (Takahashi and Noguchi, 1986) was introduced for voltage-fed inverter drives. This technique was claimed to have nearly comparable performance with vector controlled drives. Recently, the scheme was introduced in commercial products by major company and therfore created wide interst.

The scheme, as the name indicates, is the direct control of torque and stator flux of a drive by inverter voltage space vector selection through a lookup Table (Buga *et al*., 1997).

The three phase induction motor with wound rotor is doubly fed when, as well as the stator windings being supplied with three phas power at an angular frequencyω_s, the rotor windings are also fed with three phase power at a frequency ω_{rr}. Under synchronous operating conditions, as shown in (Prescott *et al*., 1958; Petersson, 2003) the shaft turns at an angular velocityω_r, such that:

$$\omega_r = \omega_s + \omega_{rr}$$

The sign on the right hand side is (+) when the phase sequences of the three phase supplies to the stator and rotor are in opposition and (-) when these supplies have the same phase sequence. The rotational velocity of the shaft,ω_r, is expressed in electric radians per second, to normalize the number of poles.

DOUBLE FEED INDUCTION MACHINE MODELLING

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

$$\frac{dX}{dt} = \dot{X} = AX + BU \tag{1}$$

Where:

$$X = \begin{bmatrix} I_{r\alpha} \\ I_{r\beta} \\ \Phi_{s\alpha} \\ \Phi_{s\beta} \end{bmatrix} \text{ and } U = \begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \\ V_{r\alpha} \\ V_{r\beta} \end{bmatrix} \tag{2}$$

The matrices A and B are given by:

$$A = \begin{bmatrix} \frac{-1}{T_s'\delta} & \omega_r & \frac{1-\delta}{\delta M T_s} & \frac{1-\delta}{\delta M}\omega_r \\ -\omega_r & \frac{-1}{T_s'\delta} & -\frac{1-\delta}{\delta M}\omega_r & \frac{1-\delta}{\delta M T_s} \\ \frac{M}{T_s} & 0 & -\frac{1}{T_s} & 0 \\ 0 & \frac{M}{T_s} & 0 & -\frac{1}{T_s} \end{bmatrix} \tag{3}$$

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$$B=\begin{bmatrix} -\frac{1-\delta}{\delta M} & 0 & \frac{1}{L_r\delta} & 0 \\ 0 & -\frac{1-\delta}{\delta M} & 0 & \frac{1}{L_r\delta} \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \quad (4)$$

$$J\frac{d\Omega}{dt}Cem\text{-}Cr\text{-}Kf\,\Omega. \quad (5)$$

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 equation of the electromagnetic torque is:

$$C_e = \frac{3pM}{2L_s}(\Phi_{s\alpha}I_{r\beta} - \Phi_{s\beta}I_{r\alpha}) \quad (6)$$

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 Courtine, 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 (Carlos *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. 1. The stator flux Ψ_{ref} and the torque C_{emref} magnitudes are compared with respective estimated values and errors are processed through hysteresis-band controllers.

Stator 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 hestheresis tolerance band (Kouang *et al.*, 2000; Xu and Cheng, 1995). Finally, in every sampling time the voltage vector selection block chooses the inverter switching state, which reduces the instantaneous flux and torque errors (Presada *et al.*, 1998).

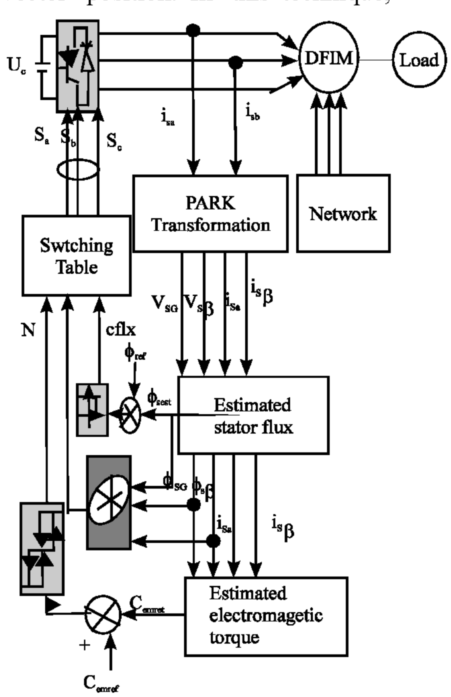

Fig. 1: DTC apllied to double feed inducation machine

SIMULATION RESULTS

Figure 2 refer in order, to the variation in magintude of the following quantities, speed, flux and

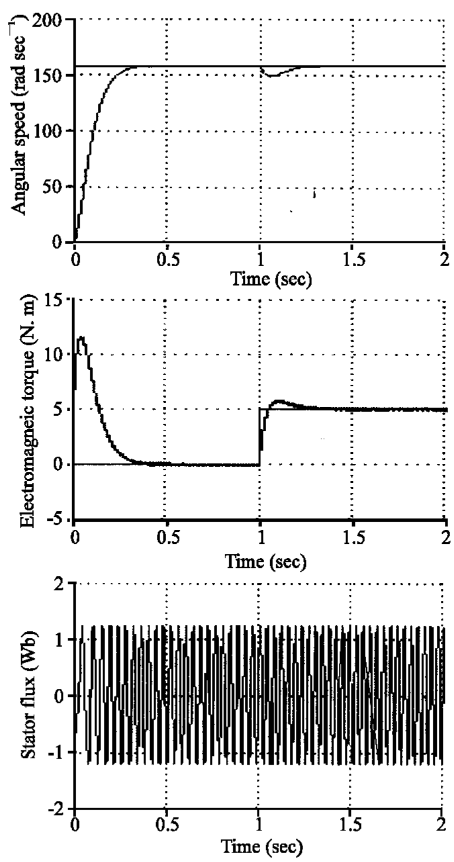

Fig. 2: Simulation results obtained with an IP regulator

electromagnetic torque 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.

ROBUST CONTROL OF THE IP REGULATOR

Speed variation: Figure 3 shows the simulation results obtained for a speed variation for the values: (Ω_{ref} = 157, 100 and 157 rad sec^{-1}), with the load of 3 N.m applied at t = 0.8 s.

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.

Speed reversal of rated value: The excellent dynamic performance of torque control is evident in Fig. 4, which shows torque reversal for speed reversal of (157, -157 rad sec^{-1}), with a load of 5N.m applied at t = 1 sec. The speed and torque response follow perfectly their reference values with the same response time. The reversal speed lead to a delay in the speed response, to a peak oscillation the current as well as a fall in the flux magnitude which stabilise at its reference value.

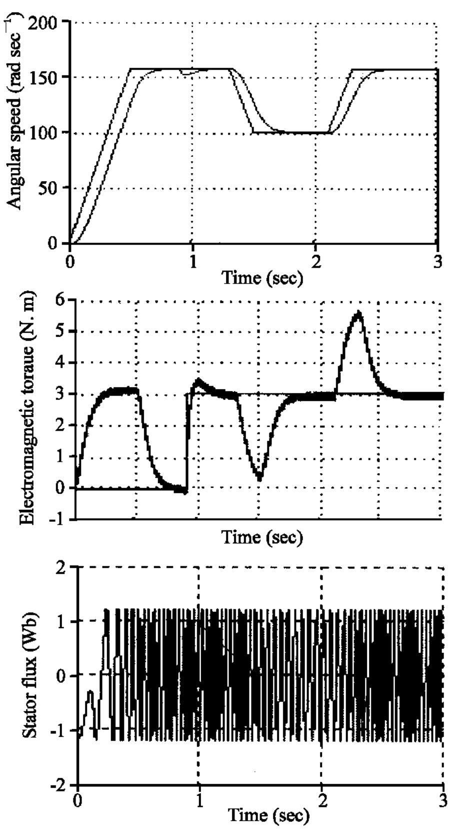

Fig. 3: Robust control for a variation

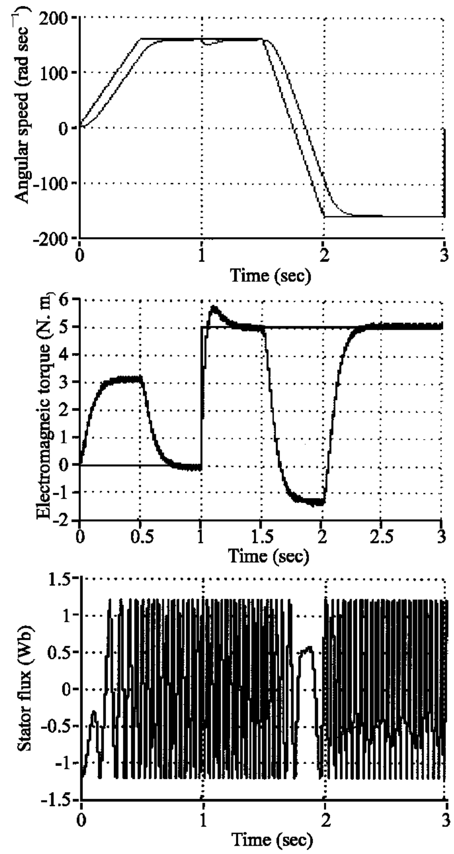

Fig. 4: Robust control under reversal speed

Robust control for load variation: The simulation results obtained for a load variation (C_r = 3 N.m, 6 N.m) in Fig. 5, show that the speed, the torque and the flux 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 tile t = 1.5 sec. the speed is fixed at 157 rad sec^{-1} and a resistant torque of 5 N.m is applied at t = 1 sec. 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.

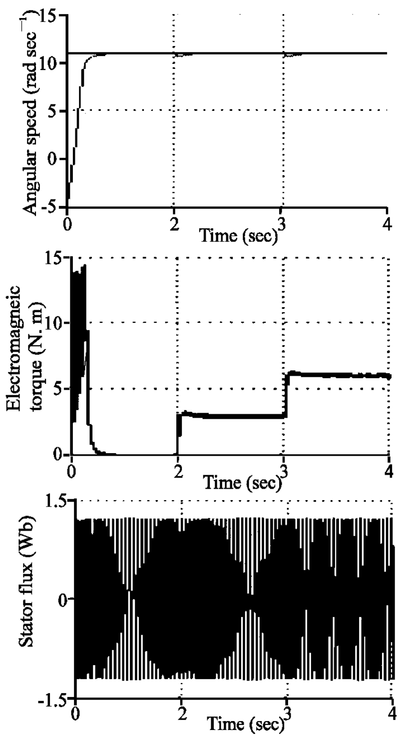

Fig. 5: Robust control under load variation

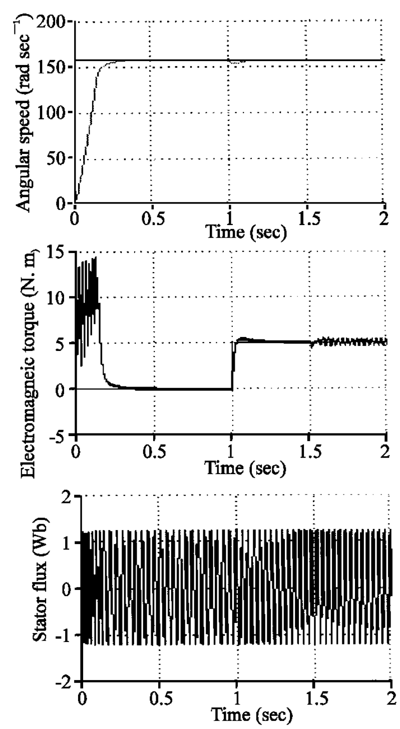

Fig. 6: Robust control under stator resistance variation

CONCLUSION

This study presents a control strategy for a double feed induction machine based on the Direct Control Torque (DTC) using an ip regulator. The simulation results show that the dtc is an excellent solution for general-purpose induction drives in a very wide power range. Theshort sampling time required by the DTC scheme makes it suited to very fast tprque and flux controlled drives in spite ofthe simplicity of the control algorithm. Wi belive that the DTC principle will continue to play a strategic role in the development of high performance motion sensorless AC drives.

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