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A NEW SIMULATION OF SYMMETRICAL THREE PHASE INDUCTION MOTOR UNDER TRANSFORMATIONS OF PARK

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ABSTRACT
The induction motor itself is a very superior electric motor, being simple and robust in structure, easy to maintain and very reliable. This paper shows that it is possible to use currently available commercial software to easily simulate a symmetrical three-phase induction machine. The components of a typical induction machine are introduced and a method to incorporate these in the MATLAB/SIMULINK software package is given. The computer simulation for various modes of operation is conveniently obtained from the equation that describes the symmetrical induction motor in an arbitrary reference frame. This simulation would be useful to study the performance of the induction machine when used in conjunction with electronic switching devices. The motor is studied under free acceleration, variable loads and open phases. This model is valid for most of the common machines.

KEYWORDS
Simulation, induction motor, MatLab, Simulink, reference frame.

INTRODUCTION
The induction motor is used extensively in homes and in industry. It is the most popular electrical motor and its production increases more than for any other type of motors. The dq induction motor model has been used for a long time, especially for transient studies. It has been introduced to facilitate the motor analysis and reduce computation time. A symmetrical machine (Krause et al. (1986), Krause et al. (1965), Novotny and Lipo (1996)) is generally defined as a polyphase machine with

1) uniform air gap.
2) linear magnetic circuit.
3) identical stator windings, spatially distributed to produce a sinusoidal m.m.f. wave in space and arranged so that only one rotating m.m.f. wave is established by balanced stator currents.
4) rotor coils or bars arranged so that, for any fixed time, the rotor m.m.f. wave can be considered to be a space sinusoid having the number of poles equals to the stator m.m.f. wave.

In this work, we make the simulation of the induction motor using SIMULINK program. The model of motor was discussed in Krause et al. (1986) and Krause et al. (1965). It is explained using the following references:

(1) A synchronously rotating reference frame $\omega=\omega_e$.
(2) A reference frame fixed in the rotor $\omega=\omega_r$.
(3) A reference frame fixed in the stator $\omega=0$.

The motor model is tested under different motor conditions.

REPRESENTATION OF AN INDUCTION MACHINE IN AN ARBITRARY REFERENCE FRAME
Generally, the motor parameters are measured with respect to the stator windings. Therefore, it is convenient to refer all rotor quantities to the stator winding. With the rotor variables referred to the stator windings and with self inductance separated into a leakage inductance component and a magnetizing inductance component the voltage equations of a three phase machine become

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$$v_{qs} = p\lambda_{qs} + \lambda_{ds}\omega + r_s i_{qs} \quad (1)$$

$$v_{ds} = p\lambda_{ds} - \lambda_{qs}\omega + r_s i_{ds} \quad (2)$$

$$v'_{qr} = p\lambda'_{qr} + \lambda'_{dr}(\omega - \omega_r) + r'_r i'_{qr} \quad (3)$$

$$v'_{dr} = p\lambda'_{dr} - \lambda'_{qr}(\omega - \omega_r) + r'_r i'_{dr} \quad (4)$$

$$i_{qs} = \frac{1}{X_{ls}}(\Psi_{qs} - \Psi_{mq}) \quad (5)$$

$$i_{ds} = \frac{1}{X_{ls}}(\Psi_{ds} - \Psi_{md}) \quad (6)$$

$$i'_{qr} = \frac{1}{X'_{lr}}(\Psi'_{qr} - \Psi_{mq}) \quad (7)$$

$$i'_{dr} = \frac{1}{X'_{lr}}(\Psi'_{dr} - \Psi_{md}) \quad (8)$$

Where ω is the angular speed of arbitrary reference frame and ω_r is angular speed of the rotor. The currents equations are shown in eq. (5)-(8). In these equations, we have $\Psi_{qs} = \omega_e.\lambda_{qs}$, where ω_e is the base electrical angular velocity corresponding to the applied frequency, X_{ls} and X'_{lr} are the leakage reactance of the stator and the rotor with the stator as reference, i_{qs} and i_{ds} are the stator q- and d-axis stator currents, i'_{qr} and i'_{dr} are the rotor q- and d-axis current with the stator as reference, λ is the flux linkage and Ψ_{qs}, Ψ_{ds}, Ψ'_{qr} and Ψ'_{dr} are the resulting voltages.

$$\Psi_{mq} = X_m(i_{qs} + i'_{qr}) = X_{mq}\left(\frac{\Psi_{qs}}{X_{ls}} + \frac{\Psi'_{qr}}{X'_{lr}}\right) \quad (9)$$

$$\Psi_{md} = X_m(i_{ds} + i'_{dr}) = X_{md}\left(\frac{\Psi_{ds}}{X_{ls}} + \frac{\Psi'_{dr}}{X'_{lr}}\right) \quad (10)$$

Where $X_{mq} = X_{md} = \dfrac{1}{\left(\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X'_{lr}}\right)}$

Equations (5) to (8) are used to eliminate the currents in (1) to (4), as well as in (9) and (10), and if the resulting voltage equations are solved for ψ_{qs}, ψ_{ds}, ψ'_{qr} and ψ'_{dr} the following equations are obtained:

$$\Psi_{qs} = \frac{\omega_e}{p}\left[v_{qs} - \frac{\omega}{\omega_e}\Psi_{ds} + \frac{r_s}{X_{ls}}(\Psi_{mq} - \Psi_{qs})\right] \quad (11)$$

$$\Psi_{ds} = \frac{\omega_e}{p}\left[v_{ds} + \frac{\omega}{\omega_e}\Psi_{qs} + \frac{r_s}{X_{ls}}(\Psi_{md} - \Psi_{ds})\right] \quad (12)$$

$$\Psi'_{qr} = \frac{\omega_e}{p}\left[v'_{qr} - \left(\frac{\omega - \omega_r}{\omega_e}\right)\Psi'_{dr} + \frac{r'_r}{X'_{lr}}(\Psi_{mq} - \Psi'_{qr})\right] \quad (13)$$

$$\Psi'_{dr} = \frac{\omega_e}{p}\left[v'_{dr} + \left(\frac{\omega - \omega_r}{\omega_e}\right)\Psi'_{qr} + \frac{r'_r}{X'_{lr}}(\Psi_{md} - \Psi'_{dr})\right] \quad (14)$$

The equation of the torque is

$$Te = \left(\frac{n}{2}\right)\left(\frac{P}{2}\right)\left(\frac{1}{\omega_e}\right)(\Psi'_{qr}i'_{dr} - \Psi'_{dr}i'_{qr}) \quad (15)$$

The equation of the speed is

$$\omega_r = \frac{1}{p}\frac{(T_e - T_l)}{\left(\frac{2}{P}\right).J\omega_e} \quad (16)$$

The equation of position is

$$\theta_r = \frac{1}{p}\omega_r \quad (17)$$

THE MODEL OF INDUCTION MOTOR

Simulink is a kind of block and graphic language so it was necessary to develop some blocks and functions that work inside others in order to solve the motor equations. The block diagram of the whole induction motor is drawn in fig.1. Many blocks compose the model and the most important will be explain above.

Motor block solves equations (5)-(8) and (15)-(17). Its inputs are v_{qs}, v_{ds}, reference frame angle and load torque (Tload). The outputs are i_{qs}, i_{ds}, motor torque (Te), angular speed (ω_r) and rotor position. Its block diagram is depicted in fig. 2. There are other blocks inside will not be presented. One of them solves equations (9)-(10) and the other solves equations (11)-(14).

abc's-->>qd's block performs the frame transformation from abc reference to qd reference. The inputs are v_{sa}, v_{sb}, v_{sc} and reference angle(theta). The outputs are v_{qs} and v_{ds}. The block diagram is shown in fig. 3.

qs's-->>abc block performs the inverse reference frame transformation, from dq reference to abc reference. Inputs are i_{qs}, i_{ds} and reference angle. Outputs are i_{sa}, i_{sb} and i_{sc}. The block diagram is shown in fig. 4.

w of frame block allows to change the reference frame that is used for computation. The input is ω_r and the output is w of frame. It has 3 switches for user reference frame definition. Block diagram is shown in fig. 5.

THE SIMULATION RESULTS

Figure 6 shows the torque, speed and the speed-torque characteristic under free-acceleration for a 3 Hp motor, fig. 7a shows i_{sa}, i_{qs}, i_{ds}, v_{qs} and v_{ds} on a synchronously rotating reference frame, fig. 7b Illustrate them on the stator reference frame and fig. 7c show them on the rotor reference frame. Fig. 8 shows the response of the motor under load variation.

CONCLUSIONS

The versatility of SIMULINK to simulate complex systems was shown in this work. The simulations of induction motor subjected to different operating conditions, which are cumbersome, have been analyzed with this program. It is possible to use this program to analyze situations of practical importance difficult to realize. The use of the SIMULINK as an instructional aid to demonstrate free acceleration, load torque and other characteristics has proved advantageous.

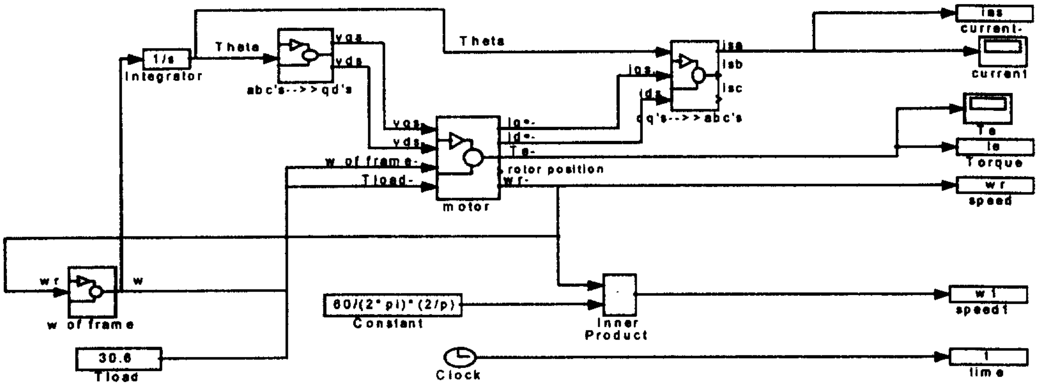

Fig. 1. Block diagram of induction motor

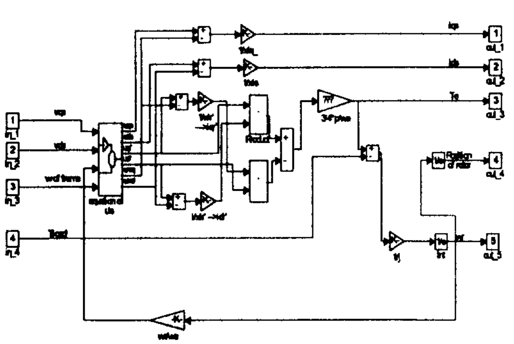

Fig 2. Motor block

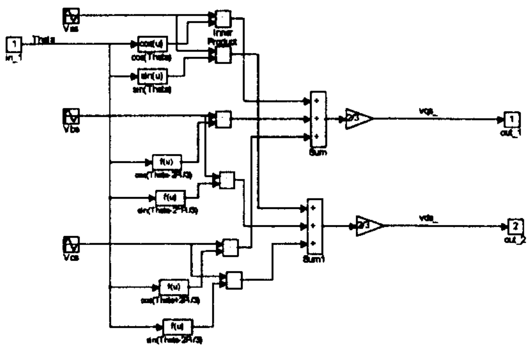

Fig. 3. abc's-->qd's block

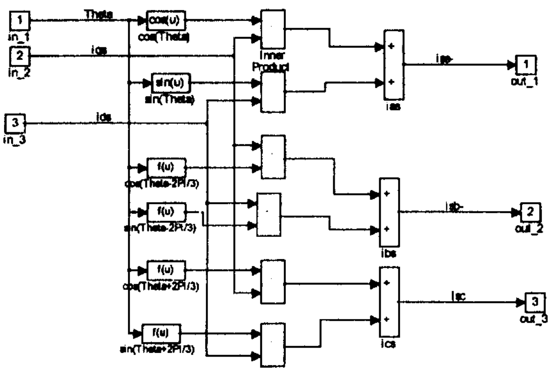

Fig. 4. dq's --> abc's block.

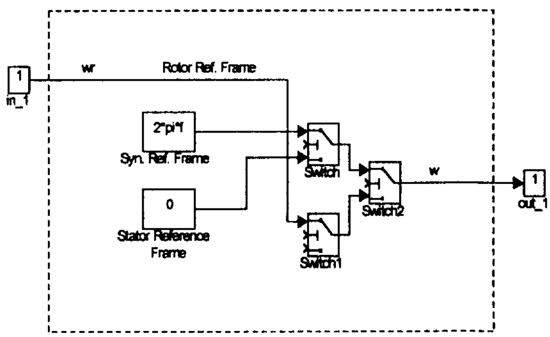

Fig. 5. W of frame

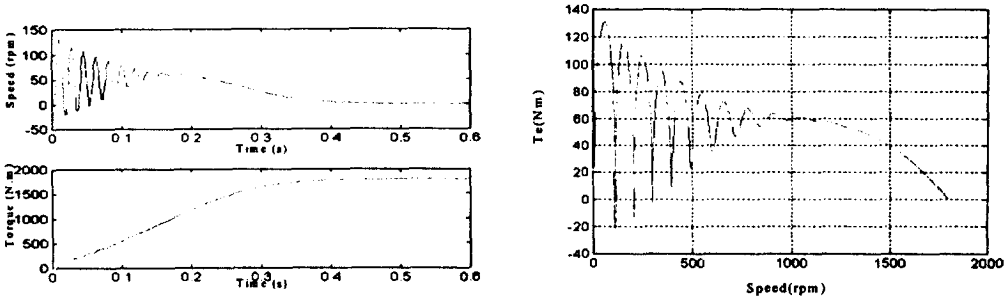

Fig. 6. The Free acceleration characteristics for motor 3 hp.

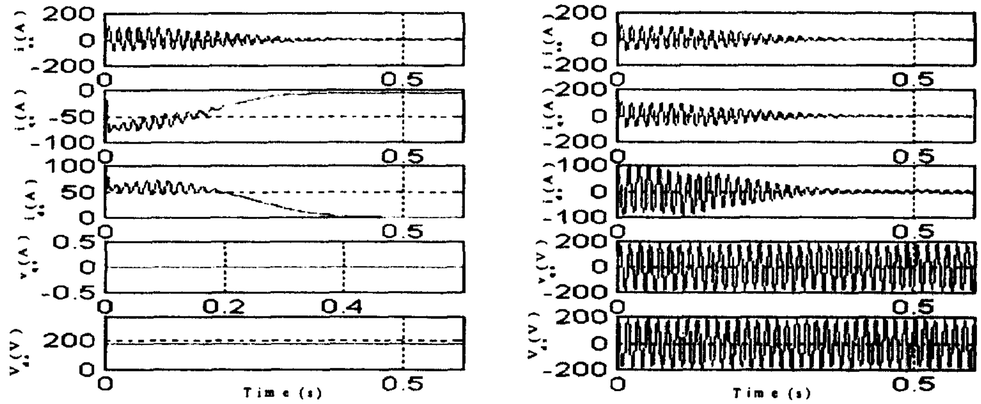

Fig. 7. Free acceleration for (a) Synchronously rotating reference frame (b) Stator reference frame

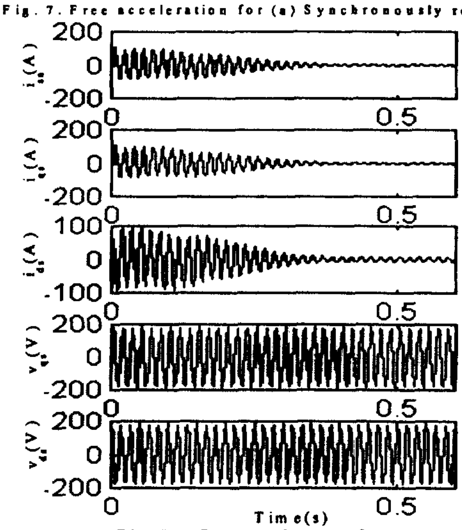

Fig. 7 c. Rotor reference frame.

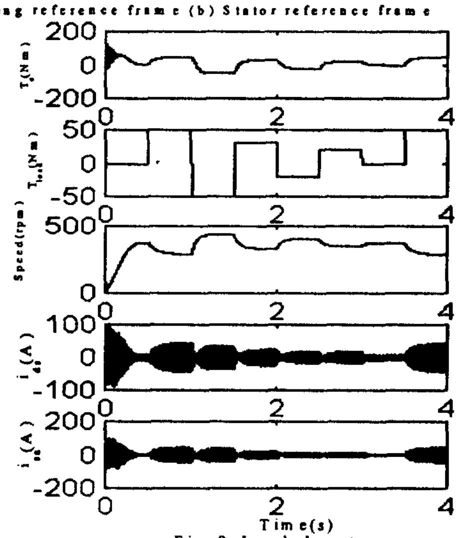

Fig. 8. Loaded motor.

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