COMPUTER AIDED ANALISYS OF INDUCTION MOTOR

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Abstract - **Sometimes the digital control system of an electrical machine has some parameters that are unknown or they are known, but can vary in time. The control circuits with self-tuning controllers are using parameter identification of a system that needs to be controlled. This paper presents a modelling example in MATLAB of an asynchronous machine. We will present the asynchronous machine in permanent behavior and transient behavior. It will be shown the response for starting point and short circuit. Steady state equations will be used. We can deduce a method of electrical parameter identification (R_1, L_s, L_m, L_r, R_2) of the induction machine based on the mathematical model using (d,q,0) equations. This paper will focus on the electrical and mechanical quantities that are obtained from the motor model at the starting point and at short circuit. The induction motor will be simulated in Matlab by creating a function named ec_difma_lin_D.m, which contains a vector of six components. This function will help obtaining the values for the rotor and stator fluxes, the angular velocity, the electrical angle θ, the rotor and stator currents and the three phases currents. The results of present paper are important for designing and exploitation of the induction motor.**

Keywords: *asynchronous machine, transient behavior and permanent behavior, steady-state equations.*

1. INTRODUCTION

An induction machine can have its parameters identified through its digital controller, used in control circuits.

This paper presents a simulation of an induction motor with focus on the electrical and mechanical quantities that are obtained from the motor model at the starting point and at short circuit. We can deduce a method of electrical parameter identification (R_1, L_s, L_m, L_r, R_2) of an induction machine based on the mathematical model using (d,q,0) equations,e.g. [2].

The representative phasors, such as u_{sK}, i_{sK}, φ_{sK}, φ_{rK}, from the mobile coordinate system (d,q,0), which is none other than the fixed system "K", that can be written as follows:

$$u_{sK} = u_{sd} + ju_{sq} \quad (1)$$

$$i_{sK} = i_{sd} + ji_{sq} \quad (2)$$

$$i_{rK} = i_{rd} + ji_{rq} \quad (3)$$

$$\varphi_{sK} = \varphi_{sd} + j\varphi_{sq} \quad (4)$$

$$\varphi_{rK} = \varphi_{rd} + j\varphi_{rq} \quad (5)$$

$$u_{sd} = R_1 i_{sd} + \frac{d\varphi_{sd}}{dt} - \omega_K \varphi_{sq} \quad (6)$$

$$u_{sq} = R_1 i_{sq} + \frac{d\varphi_{sq}}{dt} + \omega_K \varphi_{sd} \quad (7)$$

$$0 = R_2 i_{rd} + \frac{d\varphi_{rd}}{dt} - (\omega_K - \omega)\varphi_{rq} \quad (8)$$

$$0 = R_1 i_{sq} + \frac{d\varphi_{rq}}{dt} + (\omega_K - \omega)\varphi_{rd} \quad (9)$$

$$\varphi_{sd} = L_s i_{sd} + L_m i_{rd} \quad (10)$$

$$\varphi_{rd} = L_r i_{rd} + L_m i_{sd} \quad (11)$$

$$\varphi_{rq} = L_r i_{rq} + L_m i_{sq} \quad (12)$$

$$J\frac{d\Omega}{dt} = \frac{3}{2} p(\varphi_{sd} i_{sq} - \varphi_{sq} i_{sd}) - m_r \quad (13)$$

Where ω is the angular velocity of the mobile d-q coordinate system, which is related to the fixed "K" coordinate system; ω_2 is the electrical angular velocity of the rotor.

The study of static and dynamic behavior of an induction motor is based on the next considerations:

- The saturation of the magnetic circuit is negligible, which can lead to considering the flux expression as a linear function which depends on the currents;
- Both the stator and rotor windings have their conductors assigned in a sinusoidal manner, which can lead to ignoring the spatial harmonics;
- Negligible conductor section, which leads to considering the skin effect as null (uniform current density);
- The resistances and reactances do not vary with temperature;
- The air gap is considered constant;
- We consider only the fundamental harmonic of the magnetic voltage created by each of the phases

of both the stator and rotor windings, where, because of the constant air gap, the inductances are constant, and the mutual inductances between the windings depend on the angle between their magnetic axes ($M_{sr}=M_m\cos\theta$), where θ is the electrical angle between the magnetic axes of the two windings and M_m is the maximum mutual inductance, e.g. [3].

For the construction of the phasor model of an electrical machine used the concept of representative space phasor of an electrical machine (u, i, ψ) is being used.

The representative space phasor is equal with the amplitude of the alternative value.

The rotation speed is actually the synchronism velocity (the space phasor is rotating with ω_2).

The projection of the space phasor on the three magnetic axes of the balanced system is equal with instantaneous values of the sinusoidal values.

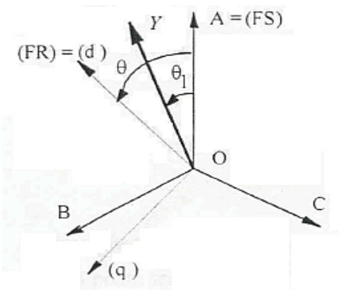

Figure 1: The representative phasor.

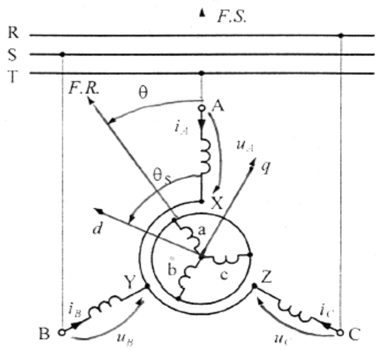

Figure 2: The electrical scheme of an induction motor.

The state vector has the following structure:

$x=[\varphi_{sd},\varphi_{sq},\varphi_{rd},\varphi_{rq},\Omega_2,\Theta]^t$, where

φ_{sd} is the stator magnetic flux on the d axis;

φ_{sq} is the stator magnetic flux on the q axis;

φ_{rd} is the rotor magnetic flux on the d axis;

φ_{rq} is the rotor magnetic flux on the q axis;

Ω_2 is the rotor velocity;

Θ is the electrical angle which provides the rotor position relative to the stator at one point in time(the angle between the A0 axis of the first stator phase and 0d axis is in fig. 2), e.g. [1] .

The state equations of an induction motor are:

$$\frac{d\varphi_{sd}}{dt}=-R_s\left(\frac{1}{\sigma L_s}\left(\varphi_{sd}-\frac{L_m}{L_r}\varphi_{rd}\right)\right)+\omega_1\varphi_{sq}+u_{sd} \quad (14)$$

$$\frac{d\varphi_{sq}}{dt}=-R_s\left(\frac{1}{\sigma L_s}\left(\varphi_{sq}-\frac{L_m}{L_r}\varphi_{rq}\right)\right)-\omega_1\varphi_{sd}+u_{sq} \quad (15)$$

$$\frac{d\varphi_{rd}}{dt}=-R_r\left(\frac{1}{\sigma L_r}\left(\varphi_{rd}-\frac{L_m}{L_s}\varphi_{sd}\right)\right)+(\omega_1-\omega_2)\varphi_{rq} \quad (16)$$

$$\frac{d\varphi_{rq}}{dt}=-R_r\left(\frac{1}{\sigma L_r}\left(\varphi_{rq}-\frac{L_m}{L_s}\varphi_{sq}\right)\right)-(\omega_1-\omega_2)\varphi_{rd} \quad (17)$$

$$\begin{aligned}\frac{d\omega_2}{dt}=\frac{3p^2}{2J}\Big(\varphi_{sd}\frac{1}{\sigma L_s}\left(\varphi_{sq}-\frac{L_m}{L_r}\varphi_{rq}\right)-\\ -\varphi_{sq}\frac{1}{\sigma L_s}\left(\varphi_{sd}-\frac{L_m}{L_r}\varphi_{rd}\right)\Big)-\frac{pM_r}{J}\end{aligned} \quad (18)$$

$$\frac{d\Theta}{dt}=\omega_2 \quad (19)$$

Where,

R_s is the ohmic resistance for a stator phase

R_r is the ohmic resistance for a rotor phase

L_s is the own stator cyclic inductance, which is equal with cyclic dispersion inductance $L_{\sigma 1}$ of the stator and the useful cyclic inductance

L_r is the cyclic rotor inductance, equal to the amount of cyclic dispersion inductance $L_{\sigma 2}$ of the rotor and the cyclic inductance of the rotor L_{22}

L_m is the cyclic mutual inductance between the stator and the rotor given by the next equation: $L_m = 3M_m/2$, where M_m is the maximum value of a mutual inductance from a own rotor phase, measured when the two windings coincide

ω_1 is the stator current pulsation

ω_2 is the rotor current pulsation

$$\Omega_1=\frac{\omega_1}{p} \quad (20)$$

is the angular velocity of the rotating magnetic field from the stator

$$\Omega_2=\frac{\omega_2}{p} \quad (21)$$

is the angular velocity of the rotating magnetic field from the rotor

p is the number of pole pairs

J is the moment of inertia of the rotor

M_r is the load torque

The dimensionless factor σ has the following equation:

$$\sigma=1-\frac{L_m^2}{L_r L_s} \quad (22)$$

The stator and rotor currents equations are:

$$i_{sd} = \frac{1}{\sigma L_s}(\varphi_{sd} - \frac{L_m}{L_r}\varphi_{rd}) \quad (23)$$

$$i_{sq} = \frac{1}{\sigma L_s}(\varphi_{sq} - \frac{L_m}{L_r}\varphi_{rq}) \quad (24)$$

$$i_{rd} = \frac{1}{\sigma L_r}(\varphi_{rd} - \frac{L_m}{L_s}\varphi_{sd}) \quad (25)$$

$$i_{rq} = \frac{1}{\sigma L_r}(\varphi_{rq} - \frac{L_m}{L_s}\varphi_{sq}) \quad (26)$$

Electromagnetic torque can be obtained with the following equation, e.g. [2]:

$$M = \frac{3p}{2}(\varphi_{sd} i_{sq} - \varphi_{sq} i_{sd}) =$$

$$= \frac{3p}{2}(\varphi_{sd}\frac{1}{\sigma L_s}(\varphi_{sq} - \frac{L_m}{L_r}\varphi_{rq}) - \varphi_{sq}\frac{1}{\sigma L_s}(\varphi_{sd} - \frac{L_m}{L_r}\varphi_{rd}))$$

Or,

$$M = \frac{3p}{2}(\varphi_{rd} i_{rq} - \varphi_{rq} i_{rd}) =$$

$$\frac{3p}{2}(\varphi_{rd}\frac{1}{\sigma L_r}(\varphi_{rq} - \frac{L_m}{L_s}\varphi_{sq}) - \varphi_{rq}\frac{1}{\sigma L_r}(\varphi_{rd} - \frac{L_m}{L_s}\varphi_{sd}))$$

2. ALGORITHM AND SOFTWARE IMPLEMENTATION

An induction motor will be simulated in Matlab by creating a function named ec_difma_lin_D.m, which contains a vector of six components. This function will help obtaining the values for the rotor and stator fluxes, the angular velocity, the electrical angle θ, the rotor and stator currents and the three phases currents. Also, the electromagnetic torque, the electrical slip, the voltages for the rotor and stator mobile d-q coordinate system and the load torque will be obtained e.g. [4], [5].
The initial conditions are null as follows:

$$x(0) = [0.0 \quad 0.0 \quad 0.0 \quad 0.0 \quad 0.0 \quad 0.0]^t$$

The motor's diagrams are at M_r=0.2*M_n as follows:

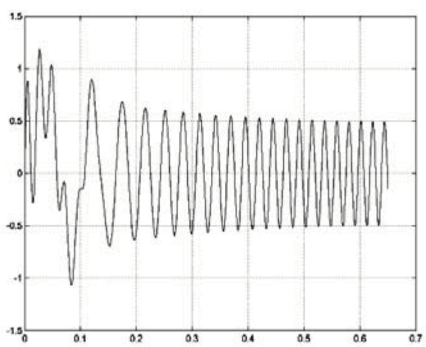

Figure 3: The stator flux in mobile d-q coordinate system

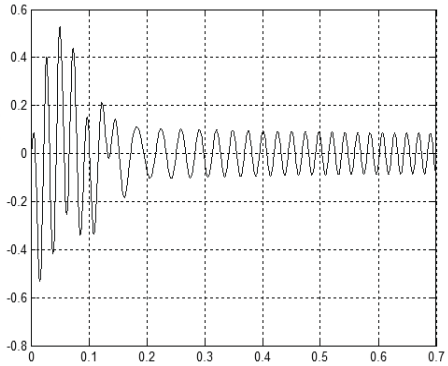

Figure 4: The rotor flux in mobile d-q coordinate system.

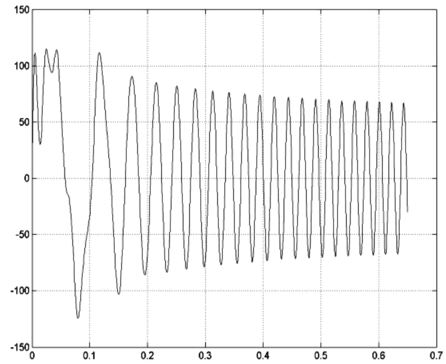

Figure 5: The stator current in mobile d-q coordinate system.

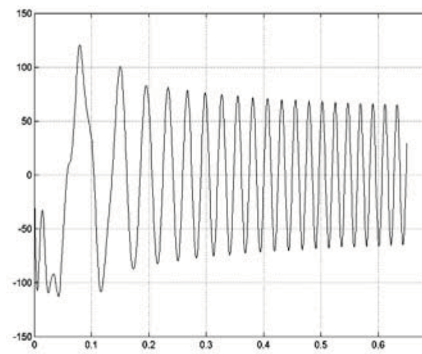

Figure 6: The rotor current in mobile d-q coordinate system.

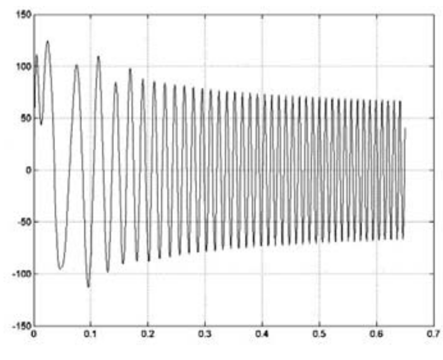

Figure 7: The current i_A of the first phase.

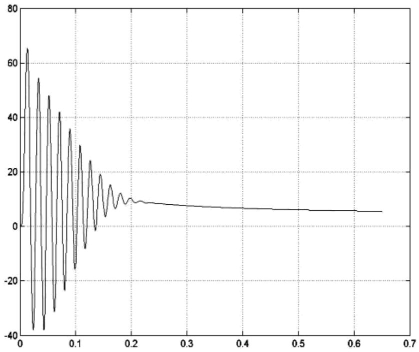

Figure 8: The electromagnetic torque.

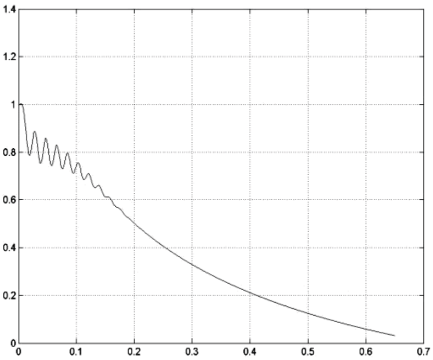

Figure 9: The electrical slip.

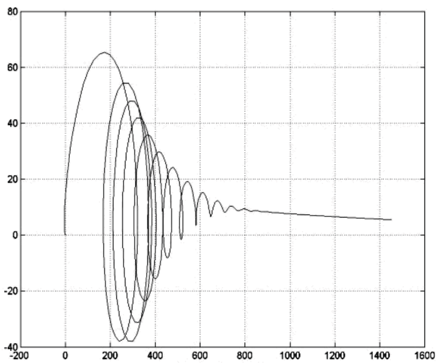

Figure 10: The load torque.

For the short circuit test only the four equations (2)-(5) will be taken in consideration, with

$$\omega_2 = 0.0,\ s = 1.0 \text{ and } \theta = 0.0.$$

The initial conditions are as follows e.g. [3], [4]:

$$x(0) = [0.5 \quad 0.5 \quad 0.1 \quad 0.1]^t$$

After the program is compiled the next graphs are obtained for the induction motor studied at starting point:

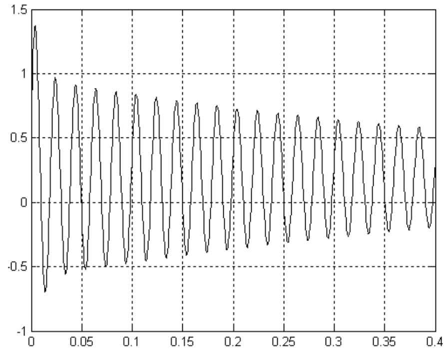

Figure 11: The stator flux in mobile d-q coordinate system.

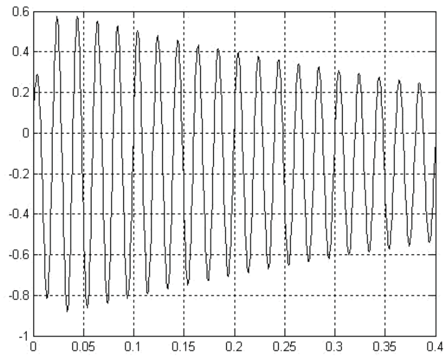

Figure 12: The rotor flux in mobile d-q coordinate system.

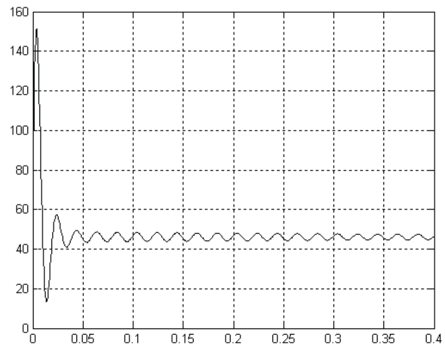

Figure 13: The stator current in mobile d-q coordinate system.

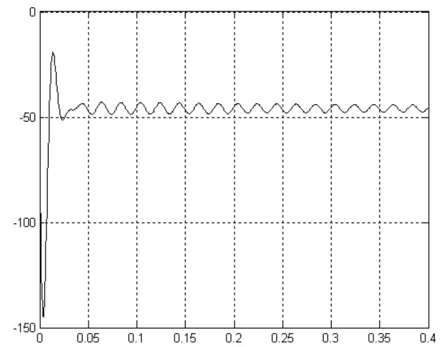

Figure 14: The rotor current in mobile d-q coordinate system.

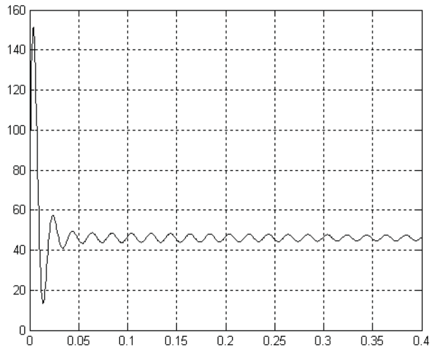

Figure 15: The current i_A of the first phase.

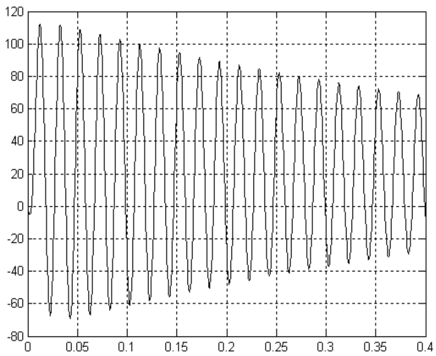

Figure 16: The electromagnetic torque.

3. CONCLUSIONS

These simulations have been made using a load torque of 20% of the rated torque of the motor. The present results are important for designing and exploitation of the induction motor.

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