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TRANSIENT ANALYSIS OF THREE PHASE INDUCTION MACHINES USING THE D,Q TWO-AXIS THEORY AT TWO DIFFERENT REFERENCE FRAME SPEEDS (STATIONARY AND SYNCHRONOUS)

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ABSTRACT: - Induction machines modeling has continuously attracted the attentions of researchers not only because such machines are made and used in larger numbers i.e. (80% of all the electrical loads), but also due to their varied modes of operation both under steady state and dynamic state. The theory of reference frames has been effectively used as an efficient approach to analyze the performance of the induction electrical machines.
In this paper a generalized model of a three phase induction motor is implemented (arbitrary reference frame), two speeds reference frames were used (synchronous and stationary), it uses case studies to demonstrate that the choice of the reference frame speed depends on the problem to be solved.

Keywords: Induction motor, reference frame theory, MATLAB/Simulink, simulation, synchronous reference frame, stationary reference frame.

1- INTRODUCTION

Induction motors are widely being used in industry. Machines of up to 10 MW in size are no longer rarity. During startup, the induction motor draws large current, produces voltage dips oscillator torque and can even generate harmonics in the power system [2, 3].
In order to analyze and study these phenomena different models have been developed. D, Q or two-axis model for the study of transient behavior has been proven to be accurate and reliable [3].

R. H. Park introduced a new approach to electric machine analysis. He formulated a change of variables which, in effect, replaced the variables (voltages, currents, and flux linkages) associated with the stator windings of a synchronous machine with variables associated with fictitious windings rotating with the rotor. In other words, he transformed, or referred, the stator variables to a frame of reference fixed in the rotor. Park’s transformation, which revolutionized electric machine analysis, has a unique property of eliminating all time varying inductances from the voltage equations of the synchronous machine which occur due to electric circuits in relative motion and electric circuits with varying magnetic reluctance [4].
In this paper the relevant equations are stated at the beginning, and then a generalized model of a three phase induction motor is developed and implemented. The obtained results in two reference frame speeds, stationary and synchronous which are most frequently used, it should be noted that the particular reference frame should be chosen in relation to the problem being investigated.

2-INDUCTION MOTOR MODEL:

The work in this section is based mainly on [3, 4, 5]. The induction motor model can be shown as in Figure (1)
the equations subscribe this model is as mentioned below:

$$\frac{d\psi_{qs}}{dt} = \omega_b\left[V_{qs} - \frac{\omega_e}{\omega_b}\psi_{ds} + \frac{R_s}{X_{ls}}\left(\psi_{mq} - \psi_{qs}\right)\right]$$
(1)

$$\frac{d\psi_{ds}}{dt} = \omega_b\left[V_{ds} + \frac{\omega_e}{\omega_b}\psi_{qs} + \frac{R_s}{X_{ls}}(\psi_{md} - \psi_{ds})\right]$$
(2)

$$\frac{d\psi_{qr}}{dt} = \omega_b\left[V_{qr} - \frac{(\omega_e - \omega_r)}{\omega_b}\psi_{dr} + \frac{R_r}{X_{lr}}\left(\psi_{mq} - \psi_{qr}\right)\right]$$
(3)

$$\frac{d\psi_{dr}}{dt} = \omega_b\left[V_{dr} - \frac{(\omega_e - \omega_r)}{\omega_b}\psi_{qr} + \frac{R_r}{X_{lr}}(\psi_{md} - \psi_{dr})\right]$$
(4)

Where

$$\psi_{mq} = X_{ml}\left[\frac{\psi_{qs}}{X_{ls}} + \frac{\psi_{qr}}{X_{lr}}\right]$$
(5)

$$\psi_{md} = X_{ml}\left[\frac{\psi_{ds}}{X_{ls}} + \frac{\psi_{dr}}{X_{lr}}\right]$$
(6)

$$X_{ml} = 1\Big/\left(\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}\right)$$
(7)

Substituting the values of the flux linkages to find the currents:

$$i_{qs} = \frac{1}{X_{ls}}(\psi_{qs} - \psi_{mq})$$
(8)

$$i_{ds} = \frac{1}{X_{ls}}(\psi_{ds} - \psi_{md})$$
(9)

$$i_{qr} = \frac{1}{X_{lr}}(\psi_{qr} - \psi_{mq})$$
(10)

$$i_{dr} = \frac{1}{X_{lr}}(\psi_{dr} - \psi_{md})$$
(11)

From the above equations, the torque and rotor speed can be found as follows:

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\frac{1}{\omega_b}\left(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}\right)$$
(12)

$$\omega_r = \int \frac{P}{2J}(T_e - T_L)$$
(13)

Where P represents the number poles; J: moment of inertia Kg/m^2.
For squirrel cage induction motor, the rotor voltages V_{qr} and V_{dr} in the flux equations are set to zero since the rotor cage bars are shorted. The three phase stator voltages of an induction machine under balanced conditions can be expressed as:

$$V_a = \sqrt{2}V_{rms}\,\sin(\omega t)$$
(14)

$$V_b = \sqrt{2}V_{rms}\,\sin\left(\omega t - \frac{2\pi}{3}\right)$$
(15)

$$V_c = \sqrt{2}V_{rms}\,\sin\left(\omega t + \frac{2\pi}{3}\right)$$
(16)

The three phase supply is transferred to an arbitrarily reference frame through the below transformation matrix:

$$K_s = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$
(17)

θ=ωt, where ω represents the reference frame speed in rad/sec, the transformation relationship between normal axis and DQ axis as following:

$$F_{qd0=}\ K_s f_{abc}$$
(18)

$$K_s = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$
(19)

Where:

$$F_{abc=}\ (K_s)^{-1} f_{abc}$$
(20)

3-MATLAB/SIMULINK IMPLEMENTATION:

The induction machine modeling is being simulated in the Simulink environment, the model is based on the equations in section 2, the complete blocks shown in Figures (2) & (3).

4- RESULTS:

4.1 Part one:

In this part we will verify and test the model and its simulation global results.To test and evaluate the model and simulation of induction motor two induction motors (3 &500) hp were tested respectively, the results of simulation given for the first model with following

specifications: h.p= 3, VL= 220, f=60 Hz, Rs= 0.435, Xls= 0.754, P=4, Rr= 0.816, Xlr= 0.754, J= 0.089, Xm= 26.13 and rpm= 1710. Figures (4) and (5), demonstrate the results of simulation for the 3 hp motor during free acceleration mode, and it's verified.
The same test done on much larger induction motor with 500 hp and following parameters: h.p= 500, VL= 2300, f=60 Hz, Rs= 0.262, Xls= 1.206, P=4, Rr= 0.187, Xlr= 1.206, J= 11.06, Xm= 54.02 and rpm= 1773

4.2 Part two:

Reference frame speed analysis:

In order to analyze the difference between the stationary and synchronous reference frames let's look first at the general performance of the previous 500 hp curves which is shown in Figure (8).

A- Stationary reference frame: in this reference frame the dq axis are fixed, this means that the MMF wave of the stator moves over this frame at the same speed as it does over the stator phase (A) windings[6,7] ; this reference frame stator Q- axis variables behave exactly like physical stator phase a variables of the motor Figure (9) reflects the identical characteristics of stator phase A current and the stator Q- axis current, due to that it's not necessary to go through inverse of Park's transform to compare the phase A current[2].
To calculate Q- axis rotor variables in the stationary reference frame are transformed at the operating frequency (base frequency) and therefore not the same as the actual rotor phase A variables which are at slip frequency.

B- Synchronous rotating reference frame: When the reference frame rotating at synchronous speed, the stator and rotor rotating at different speeds relative to it. But when the reference frame rotating at the same speed as the stator and rotor speed field MMF waves[3], the stator and rotor DQ quantities are constant quantities, whereas the actual variables are at system frequency and slip frequencies respectively. Figure (10) shows how the stator q- axis current gradually reduces from 60 Hz frequency at the instant of switching to the equivalent of a steady DC when at rated speed.

5-CONCLUSIONS:

In this paper two main objectives have been done, firstly building dynamical modeling and simulation for three phase induction, two different rating machines tested and the results compared and verified.
Secondly two different speed reference frames(stationary and synchronous) studies and compared, the following conclusion regarding this part has been concluded, when a single induction machine is being studied its preferred to use stationary reference frame, however when multi-machines or control design is desired the synchronous reference frame is preferred in the analysis of the three phase induction machine.

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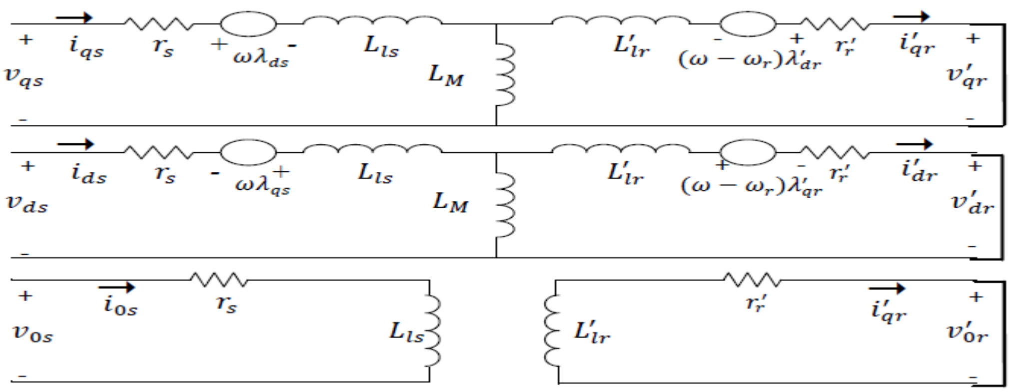

Figure (1): The dq0 equivalent of induction motor.

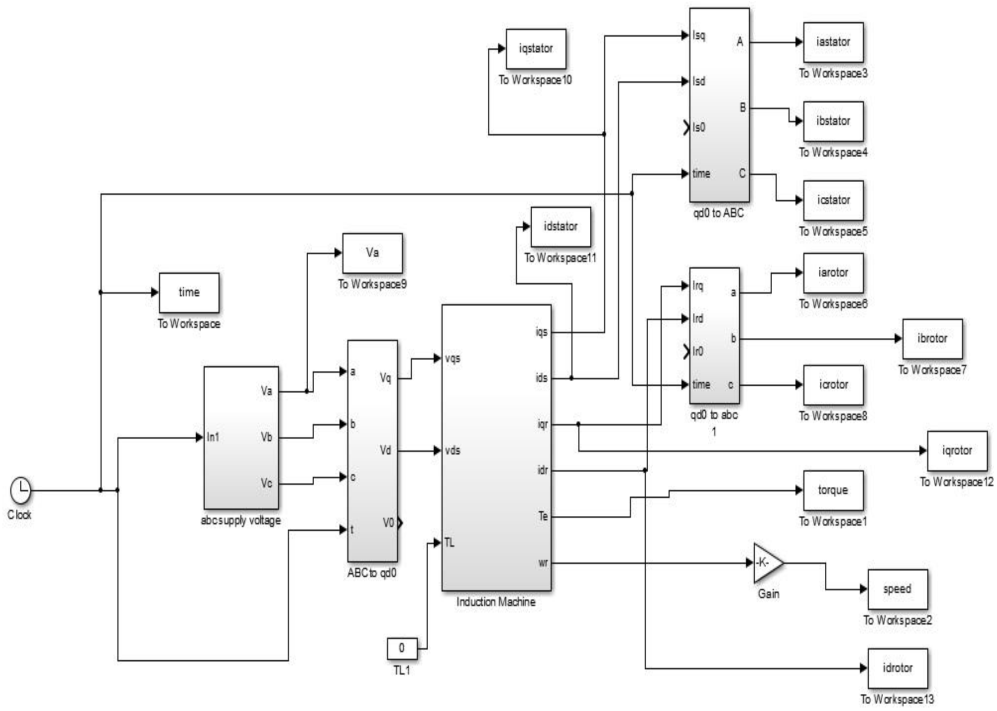

Figure (2): The 3-phase induction motor MATLAB/SIMULINK model

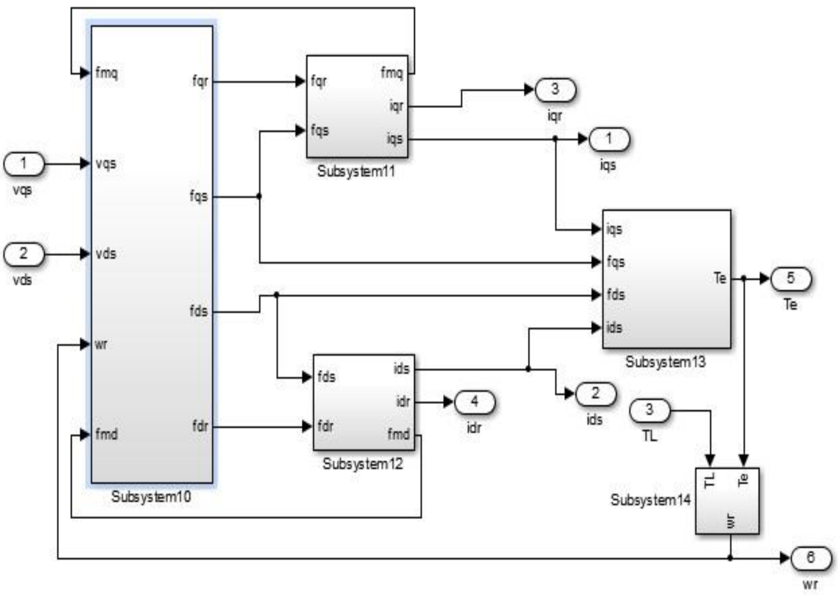

Figure (3): The internal parts inside the induction motor dq0 model.

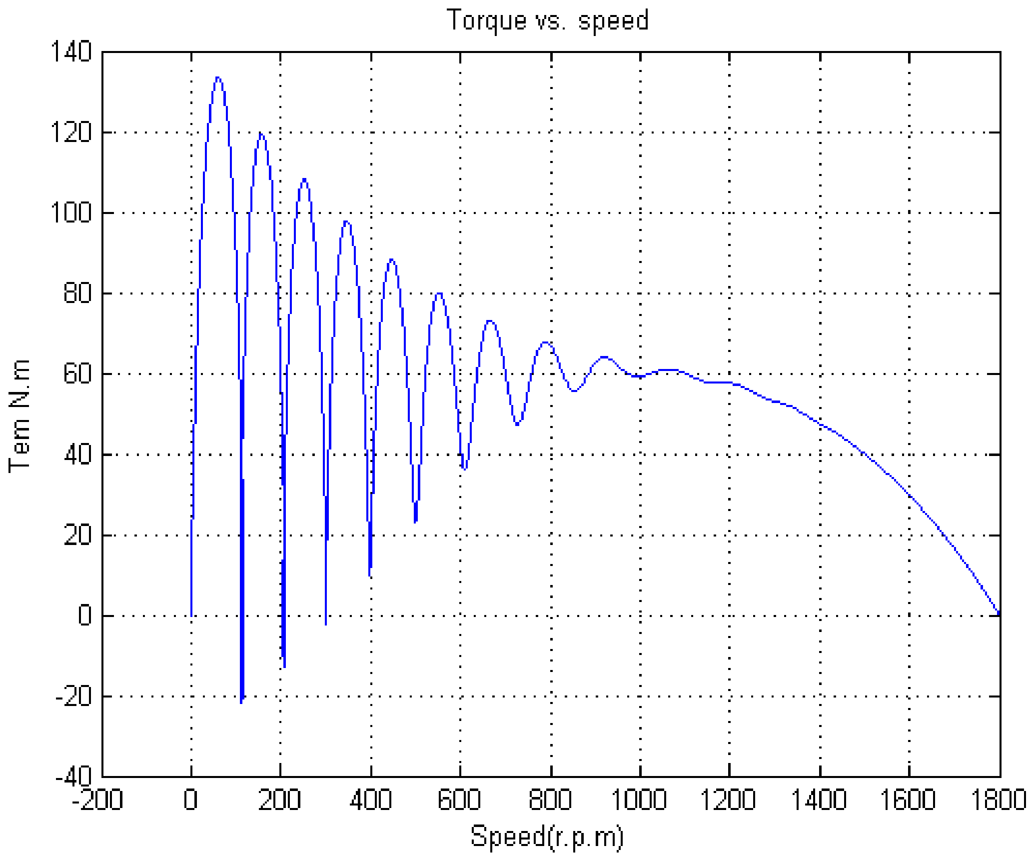

Figure (4): Torque speed characteristics for the 3 hp induction motor.

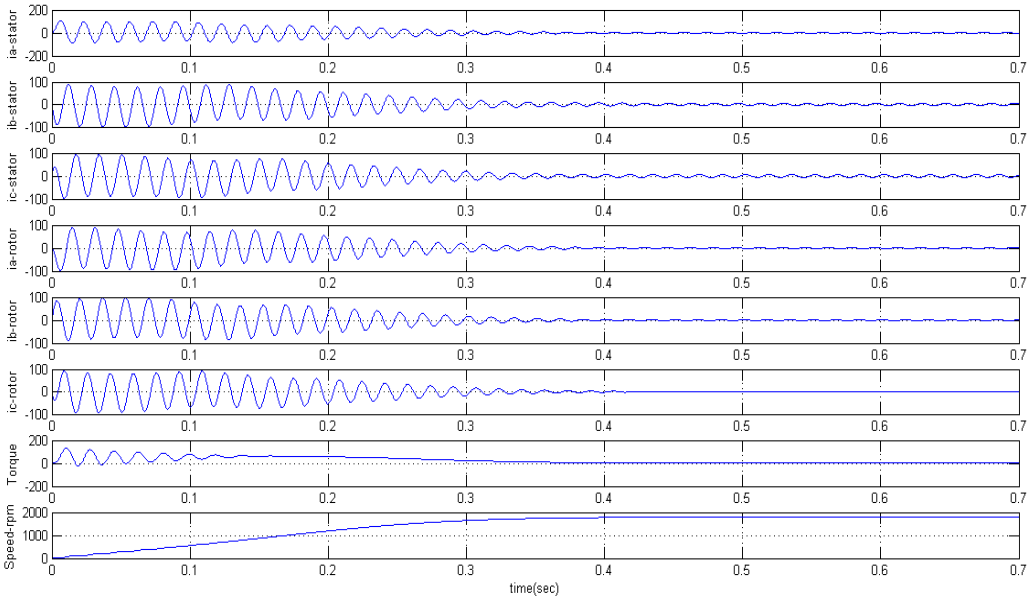

Figure (5): 3hp machine different variables during free acceleration.

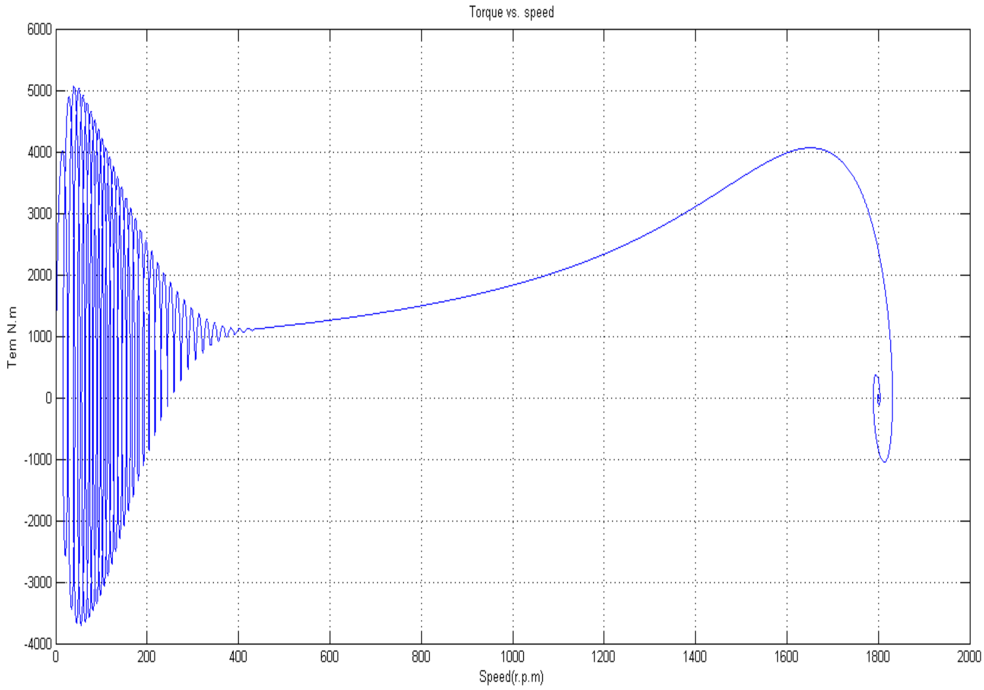

Figure (6): 500 hp torque vs. speed characteristics.

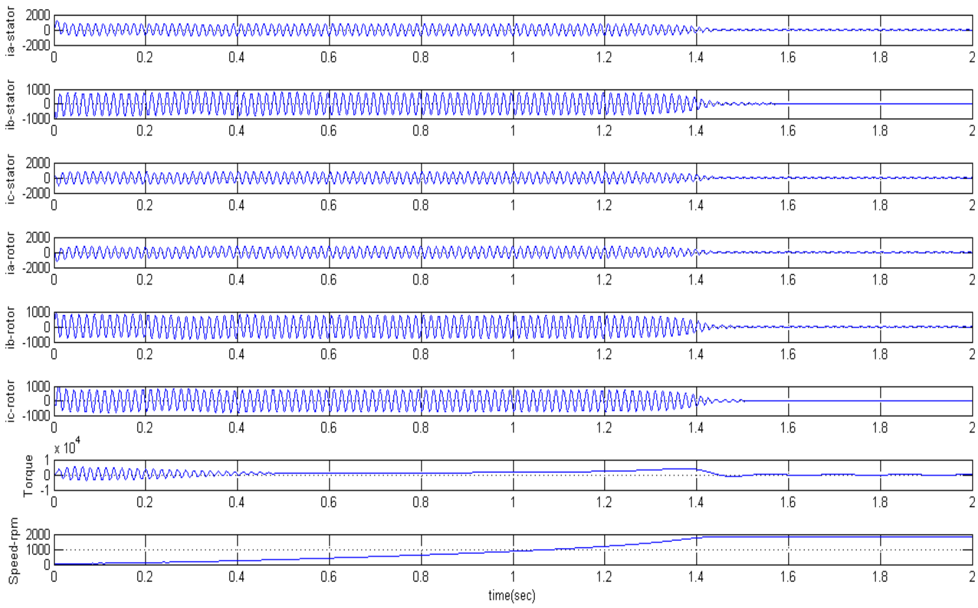

Figure (7): 500 hp different variables during free acceleration working mode.

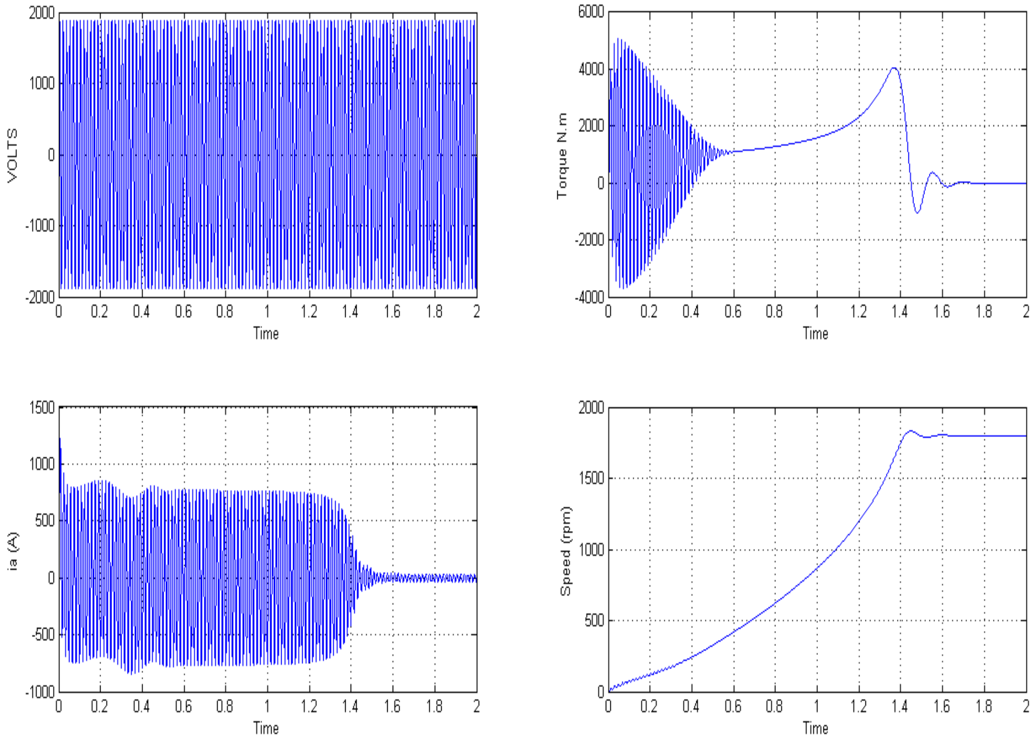

Figure (8): Predicted starting up performance of a 500 hp induction motor.

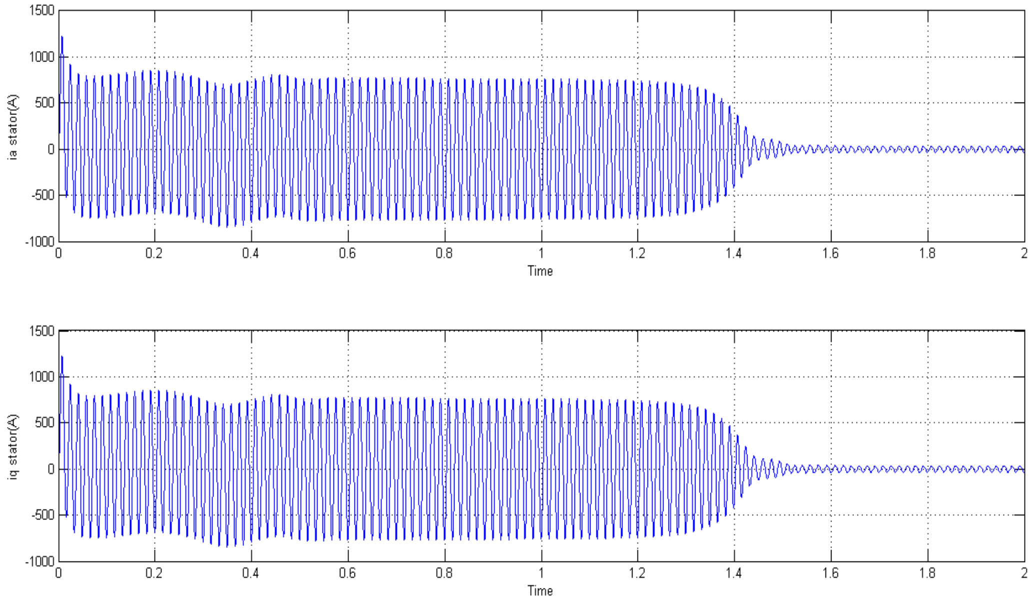

Figure (9): phase A stator current vs. iq current

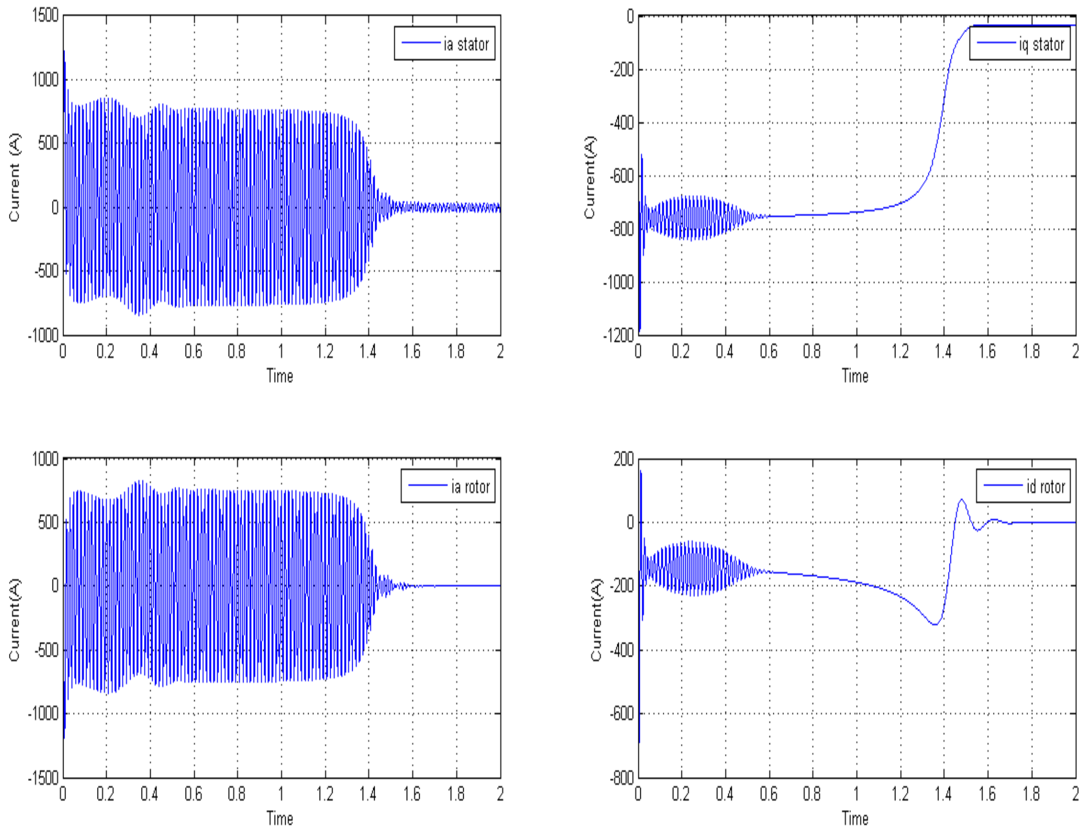

Figure (10): Starting up current using the synchronous rotating reference frame.

تحليل الكميات العابرة لمكائن الحث ثلاثية الاطوار باستخدام نظرية الاحداثيات المتعامدة وباستخدام المحورين الساكن والمحور المتحرك بالسرعة التزامنية

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الخلاصة

ان تحليل المكائن الحثية يعتبر موضوعا جاذبا للكثير من الدراسات والبحوث, ليس فقط لكونها تمثل الاداة الاكثر استخداما وبالتالي الاكثر استهلاكا للطاقة الكهربائية ضمن المنظومة الكهربائية(تمثل احمال المحركات الحثية ما يعادل 80% من الاحمال الكلية في الشبكة الكهربائية كمعدل), وانما ايضا لطبيعة التحليل المعقد لهذه المكائن اذا ما اردنا نظرة تفصيلية عميقة لدراسة سلوكها في مختلف اطوار عملها وخصوصا في حالة تغير الاحمال او عند بدء الاشتغال.

عند بدء عمل المحرك الحثي فانه يسحب كمية كبيرة من التيار تفوق بعدة مرات الكمية المسحوبة بعد استقرار عمل المحرك, ان هذه الفترة العابرة مهمة جدا لكون التيارات المسحوبة تسبب اضطرابا في فولتية التجهيز خصوصا في حالة المحركات الكبيرة, وكذلك تحدث ظاهرة التذبذب في العزم للماكنة وهذا بالإجمال قد يسبب تأثيرات سلبية على الفولتية المجهزة وبالتالي على الاحمال المرتبطة بنفس المنظومة.

أن معادلات الفولتية والتيار والعزم التي تصف السلوك الديناميكي للماكنة الحثية تعتمد على قيم متغيرة مع الزمن وهذا يسبب تعقيدا كبيرا في تحليل السلوك الديناميكي لهذه المكائن.

ان نظرية الاحداثيات المتعامدة تمثل طريقة بالغة الفعالية والقوة لتحليل السلوك الديناميكي والعابر لعدة انواع من المكائن ومنها المكائن الحثية.

في هذا البحث تمت عملية استخدام نظرية المحاور المتعامدة العامة لغرض محاكاة سلوك المكائن الحثية ثلاثية الاطوار وفي محورين مصدريين مختلفي السرعة, المحور الاول هو المحور الساكن والثاني هو المحور المتحرك بالسرعة التزامنية والتي تمثل سرعة تردد الفولتية التي يعمل عليها المحرك الحثي.

من خلال عمل نموذج حاسوبي في بيئة برنامج ال MATLAB/Simulink تمت محاكاة كاملة لسلوك المحرك الحثي ولمحركين مختلفي السعة الاول 3 احصنة والثاني 500 حصان. كما تمت دراسة اثر اختيار سرعة المحور المصدري في استقاء المعلومات من المحاكاة الحاسوبية وتبيان الفرق بين الحالتين.