Diyala Journal of Engineering Sciences

ISSN 1999-8716
Printed in Iraq

Vol. 10, No. 2, pp. 27-38, June 2017

OPEN LOOP &CLOSED LOOP VECTOR CONTROL of VFD THREE PHASE VERSION INDUCTION MOTOR DRIVES

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(Received: 22/3/2016; Accepted: 12/6/2016)

ABSTRACT: - In this paper, a design of a vector control algorithm for a three-phase induction motor. The three phase AC induction motors are a popular in manufacturing industries as it has many benefits. It is quite simple and minimum cost is favourable, it does not have brushes and requires minimum maintenance. In order to achieve variable speed operations in a three-phase AC induction motor by open and closed loop vector control technique to improve the motor's performance, is used because this technique has higher efficiency, accurate control of the motor's speed and torque. To analyse vector control, by converting the three phase Quantities into 2-axes system called the d- q transformation. The d-q axes can be chosen to be stationary or rotating. MATLAB/ SIMULINK is used as tool to simulate the model of (IM) and applying the control technique on it. In open and closed loop vector control, by use of PWM inverter, voltage supply can vary as well as the supply frequency such that the ratio v/f remains constant so that the flux remains constant as well.
Key words: Closed loop control, Open loop control, D-Q transformation, Induction Motors, Vector control, V/f.

I. INTRODUCTION

The induction motor (IM), which is the most widely used motor type in the engineering business industry, has been favoured because of its simplicity and rugged structure, low in cost and reliability, and self-starting capability. Induction motors are used in applications that do not need fast dynamic response. In the field of motor control, vector control is considered one of the most important species which added the possibility of induction motors to accomplish control or to have similar performance as the DC motors.

They have limited commutate capability under high speed, and high voltage operational conditions [(1)]. As well as not being able to use them in corrosive environment. These problems can be solved by the application of alternating current motors. Variable speed AC drives have served in the past to perform relatively undermining roles in applications which keep the utilization of DC motors, either due to the workplace or commutated points of confinement. Further, because of push ahead in the field of power hardware, this increases the demand for less expensive and more successful power converters nourishing AC drives [(2)].

Modern control known as power electronics gives the ability to control on ACIM of the type of so-called closed-loop control with sensor for the shift. In order to understand the starting of the induction motor and the performance of his case, we must analyze and study through the use of appropriate simulation of the system that will help us, and also to understand the stability of electrical machinery and behaviour of motor problems in various operating conditions. To do this, accurate analysis and simulation are very important to minimize costly replication of designs [(3)].

Induction motors have performed the main part of many speed control systems and found use in several industrial applications [4]. The advances in microprocessor and power electronics give permission to implement modern techniques for induction machines such as field oriented control [5]. Slip frequency controls [6]. Then a modern speed Ac machine system is equipped with adjustable frequency drive for speed control of electric machine. Speed of machine of machine is controlled by converting fixed voltage and frequency to adjustable values on machine side. The three phase inverter circuit changes the DC input voltage to three phase variable frequencies Variable voltage output [7]. Three phases Ac are rectified into DC and then filtered to minimize the ripple current. This controlled DC is converted into controlled pulses by means of voltage to frequency converter. These controlled pulses are fed to Inverter Bridge for producing variable voltage variable frequency output [9]. This output is constituted to induction motor for controlling its speed [8].

In this paper, the usage and the importance of implement a variable speed drive for maintaining the constant speed of a three phase induction motors and flux controller is given.

II. DESCRIPTION OF THE INDUCTION MOTOR DRIVE

In this paper, the 3-phase induction motor is connected to a 3-phase inverter bridge. The power inverter has 6 switches that are controlled in order to generate 3-phase AC output from the DC bus. PWM signals, generated from the microcontroller, control these 6 switches. Switches IGBTH1 through IGBTH3, which are connected to DC+, are called upper switches. Switches IGBTL1 through IGBTL3, connected to DC-, are called lower switches. The amplitude of phase voltage is determined by the duty cycle of the PWM signals. While the motor is running, three out of six switches will be on at any given time; either one upper and two lower switches or one lower and two upper switches. The switching produces a rectangular shaped output waveform that is rich in harmonics. The inductive nature of the motor’s stator windings filters this supplied current to produce a 3-phase sine wave with negligible harmonics. When switches are turned off, the inductive nature of the windings oppose any sudden change in direction of flow of the current until all of the energy stored in the windings is dissipated, as shown in Fig. (1).[9]

III. VECTOR CONTROL or FOC

Vector Control One of the excellent control theories of torque (T) control in IM. Dc motor had significantly more than the other types of AC induction machine. Dc derive can be provide torque control through the direct control of the armature current consider the main advantages of it. While the AC drive used pulse width modulation (PWM) to provide adjustable frequency sinusoidal current of AC machine stator. This was the best way for speed control. This paper presents a most excellent control strategy for (IM) derive which is concentrated in open loop & closed loop vector control[2]. It is based on various criteria involved in basic control characteristic and dynamic performance.

IV. MODEL OF VECTOR CONTROL DRIVE

1- O.L. VECTOR CONTROL

As shown in Fig. (1). AC source is supplied the induction pass through the power electronic circuit. It is called Open Loop control System because there is no feedback in this system. One of the most important methods to speed control is (VVVF) or V/f in open loop. IM control is complex due to its nonlinear characteristics. Therefore we used the (VVVF) as a suitable method for applications requirements or the need for high accuracy of speed control.

1.1 Pulse width modulation:

Fig. (2) shows the modulation signal by means of the angle δ. The equations (1-3) show that the three phase PWM.

$$VA = Vsin(wt + \delta) \quad (1)$$

$$VB = Vsin\left(wt + \delta - \frac{2\pi}{3}\right) \quad (2)$$

$$VC = Vsin\left(wt + \delta + \frac{\pi}{3}\right) \quad (3)$$

1.2 Power electronics converter:

PE converter has three phase rectifier (Ac-Dc) and inverter (DC- adjustable AC) with variable voltage. The inverter consists of six power switches that can be (MOSFET), (GTO), or (IGBT), being dependent on the drive power limit and the inverter switching frequency. The Fig.(1) shows up in a streamlined graph of a 3ph-inverter [9].

1. 3 (abc- xy) Transformation:

Vector control was used in this paper, transformation 3phase into 2 axes used to make the control is easy. The equations (4-11) shows that as following:

$$i1x = \frac{2}{3}\left[i1A - \frac{1}{2}(i1B + i1C)\right] = i1A \quad (4)$$

$$i1y = \frac{1}{\sqrt{3}}[(i1B - i1C)] \quad (5)$$

$$u1x = u1A \quad (6)$$

$$u1y = \frac{1}{\sqrt{3}}[(u1B - u1C)] \quad (7)$$

$$u1A = (uAB - uCA)/3 \quad (8)$$

$$u1B = (uBC - uAB)/3 \quad (9)$$

$$u1C = (uCA - uBC)/3 \quad (10)$$

$$u1x = \frac{uAB - uCA}{3} = 0.333(uAB - uCA) \quad (11)$$

$$u1y = \frac{2uBC - uAB - uCA}{3\sqrt{3}} = 0.1924(2uBC - uAB - uCA) \quad (12)$$

2- C.L. VECTOR CONTROL of IM

In closed-loop Vector control the speed of the rotor is deliberately using a sensor and it is comparable to the reference speed. The difference is seen as the error and the error is fed to a proportional controller. The PI controller sets the inverter frequency. The input data that we have to provide VSI is the frequency and through the inverter the output voltage will change as we need all of this operation to remain in the V/f ratio constant.

A Simulink/ MATLAB block was built and chosen the input of the starting Load Torque and speed. The motor frequency was calculated to make the motor operate in the stable zone. The corresponding voltage is determined. During the operation the rotor speed increased (0- synchronous speed). Values of the motor torque were stored. The actual speed of the rotor compared with the reference speed to prove the enhancement control. The resulting difference was regarded as the error and original frequency was corrected. Output voltage is changed and the V/f ratio kept constant. As showed in Fig. (3).

2.1 Hysteresis Current Regulator:

Three hysteresis controllers were built to act the current regulator. By using Asynchronous Machine block, we got the actual current from the measurement block. It compares with reference current in hysteresis type relay. As shown in Fig.(4).

2.2 Flux Calculation:

The equations (13-15) show the Flux Calculation. As shown in Fig. (5).

$$phir = \frac{Lm*Id}{(1+Tr\,.s)} \quad (13)$$

$$Tr = \frac{Lr}{Rr} \quad (14)$$

$$Lr = LI'r + Lm \quad (15)$$

Where

Lr is Rotor Inductance (mH)
Lm is Magnetizing Inductance (mH)
Rr is Rotor Resistance (Ohm)

2.3 Teta Calculation:

Fig. (6) Shows the calculation of the rotor flux position (θe) by the Teta Calculation block, and the equations (16-17) shows that.

Teta= electrical angle= integ (wr+wm) (16)

$$wr = Rotor\ frequency\ \left(\frac{rad}{sec}\right) = \frac{Lm*Iq}{(Tr*Phir)} \quad (17)$$

Wm= $Rotor\ mechanical\ speed\ \left(\frac{rad}{sec}\right)$

2.4 d-q to abc transformation blocks

The equations (18-21) shows that the transformation 2 axes into 3phase. As shown in Fig (7) and Fig(8).

$$\begin{pmatrix} ia(t) \\ ib(t) \\ ic(t) \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos(\theta e) & -sin(\theta e) \\ cos(\theta e + \frac{4\pi}{3}) & -sin(\theta da + \frac{4\pi}{3}) \\ cos(\theta e + \frac{2\pi}{3}) & cos(\theta e + \frac{2\pi}{3}) \end{bmatrix} \begin{pmatrix} ids \\ iqs \end{pmatrix} \quad (18)$$

$$ia = \sqrt{\frac{2}{3}}\ (cos(\theta e)id - sin(\theta e)iq) \quad (19)$$

$$ib = \sqrt{\frac{2}{3}}\ (cos(\theta e + 4.18879)id - sin(\theta e + 4.18879)iq) \quad (20)$$

$$ic = \sqrt{\frac{2}{3}}\ (cos(\theta e + 2.094395)id - sin(\theta e + 2.094395)iq) \quad (21)$$

2.5 abc to d-q Transformation Blocks

To convert the three phase current into 2 axis (dq) current the (abc –dq) transformation used, to develop the model and that’s can be in stator or rotor as following. For stator there is a relationship between phase winding variables to abc (abc to d-q).

$$\begin{pmatrix} isd \\ isq \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos(\theta e) & cos(\theta e - \frac{2}{3}) & cos(\theta e - \frac{4\pi}{3}) \\ -sin(\theta e) & -sin(\theta e - \frac{2}{3}) & cos(\theta e - \frac{4\pi}{3}) \end{bmatrix} \begin{pmatrix} ia(t) \\ ib(t) \\ ic(t) \end{pmatrix} \quad (22)$$

So

$$id = \sqrt{\frac{2}{3}}\ (cos(\theta e)ia + cos(\theta e - 2.094395)ib + cos(\theta e - 4.18879)ic) \quad (23)$$

$$id = \sqrt{\frac{2}{3}}\ (-sin(\theta e)ia - sin(\theta e - 2.094395)ib - sin(\theta e - 4.18879)ic) \quad (24)$$

V. SIMULATION RESULTS AND DISCUSSION

A. Open loop control (O.L.C)

Simulation was carried out for constant v/f control of induction motor drives using PWM technique for an open loop system. The rates parameters of the IM used for simulation are as follows:

380V, 50Hz, fs= 2.1 kHz, 4pole, 3Ph ,Rs=0.55Ω, D.C voltage = 282.84V, Ls=93.38mH, Rr=0.78Ω, Lr=93.36mH ,Lm=90.5mH,mi=0.83,J=0.019KG-M2,B=.000051, TL=10.32N-m;

Figure (11), show the output phase voltages of PWM and xy voltage after transformation from 3axes to 2 axes. For IM with open loop control.

Fig(12) , shows the 3 axes current ,abc current and 2 axes dq currents, and xy current .

Fig.(13), shows torque under OL control, speed & flux of IM with open loop control . Speed with PWM more than speed without it with same VDC.

B. Closed loop control (C.L.C)

The Vector Control System based on the stator flux orientation can be consider as a one of precise methods to make the simulation of speed control IM possible. This is possible as it consist of more than four modules such as PI controller module connected to Pulse width modulator module to feeds the inverter module, flux controller, observer modules, and Speed Regulator Module.

As results of the torque of IM after applied method of controller is varied to its stator terminals. New electromagnetic torque after applied method of controlled by the motor is varied. Vector Control method uses for small Induction motors (squirrel-cage).

A MATLAB/Simulink was developed to observe the variation in torque-speed characteristics of a three phase Induction motor with variable stator voltage. Stator current drawn high with low frequency when motor starting works to cover the new starting torque after applied method of control that may be consider as a necessary torque, during this procedure IM pick up speed to reduce the magnitude of current and make the frequency is increased. The stator current and a new electromagnetic torque has ripples but a minor due to switching in hysteresis current controller Fig. (14) shows the actual waveforms and Fig. (15) shows the developed waveforms.

C. PI Controller Effects

The input of the PI controller is the difference between the given speed and the practical speed (e) as shown in equation (25). Fig. (19) shown General system block with PI controller. PI controller used to make the system stable i.e. the overshot after PI installation is less than overshot after PI installation. Fig.(13) shown that the overshot on speed, and Fig.(17) shown the Te& wm relationship after PI controller.

$$\mathrm{U} = \left[\mathrm{Kp}\left(\mathrm{s} + \frac{\mathrm{Ki}}{\mathrm{Kp}}\right)\right] * \mathrm{e} \qquad (25)$$

Where

$$\mathrm{e} = \mathrm{input} - \mathrm{output}$$

VI. CONCLUSION

In this paper, the vector control model of the IM uses direct vector control framework with open and closed loop speed and flux. In view of the sufficient investigation of induction motor mathematical model and vector rule, simulation was done by Matlab/Simulink environment. The results illustrate validity of this model, and it is observed that the torque ripples is low in Vector control induction motor, steady tracking has high accuracy, and the torque has short-lived response attributes, all of which are steady with the hypothetical analysis of vector control VF speed regulation. In the mean time this system strategy for simulation model is straightforward and convenient, which gives powerful intends to the recognition and debugging in practical motor control system.

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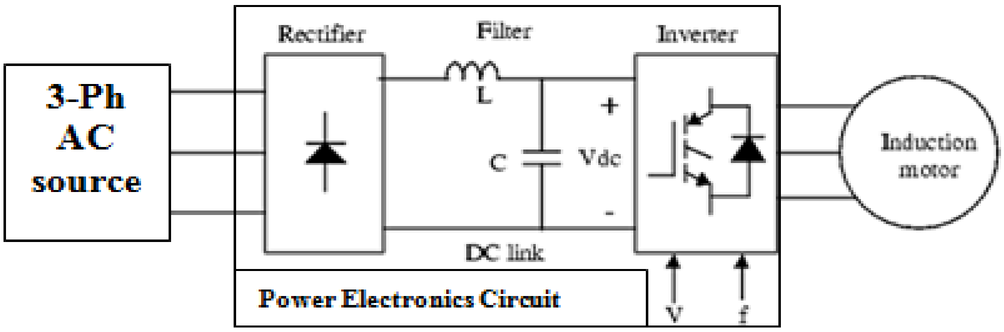

Fig.1 Block diagram of power electronics converter with induction motor drive.

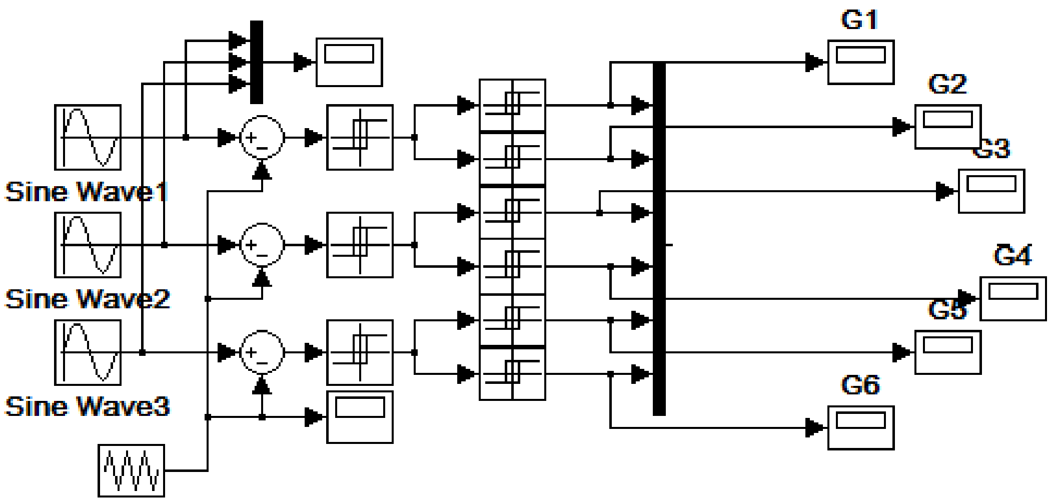

Fig. 2 Pulse modulation circuit by Matlab- Simulink.

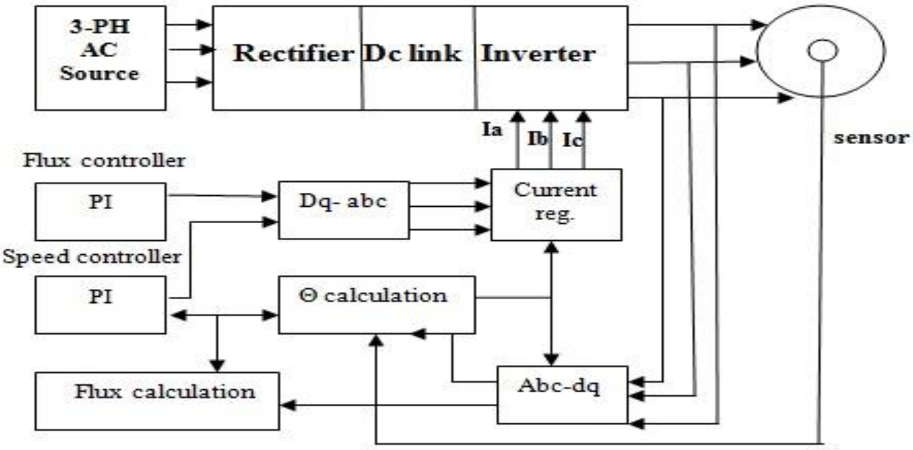

Fig.3 block diagram of Vector Control System

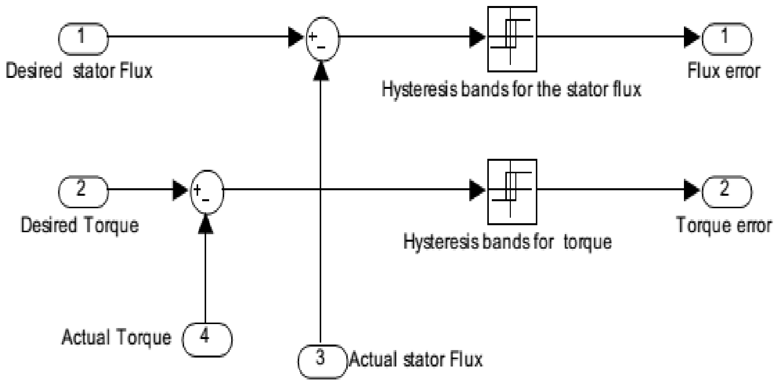

Fig. 4. Hysteresis Current Regulator circuit

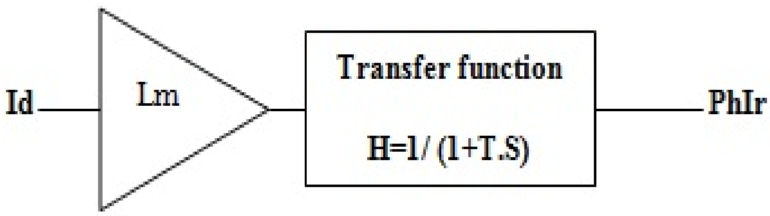

Fig.5. Flux Calculation block

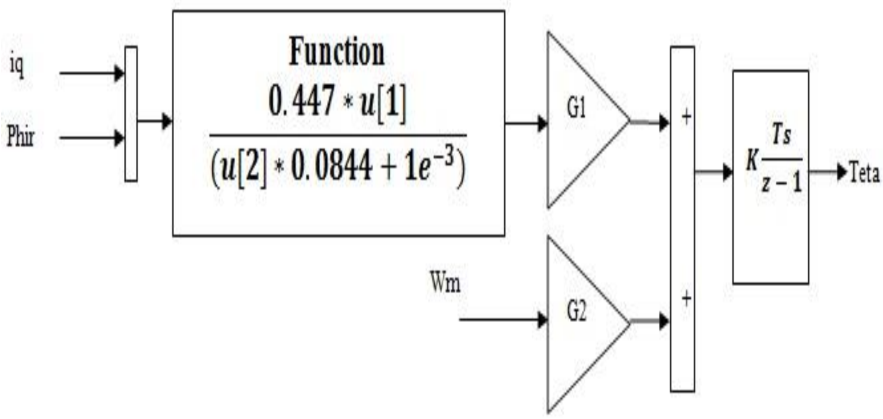

Fig.6. Teta Calculation diagram.

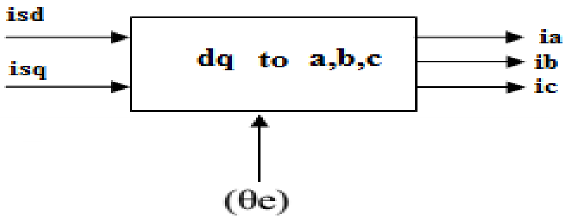

Fig.7. isd-isq to ia,ib,ic transformation Block.

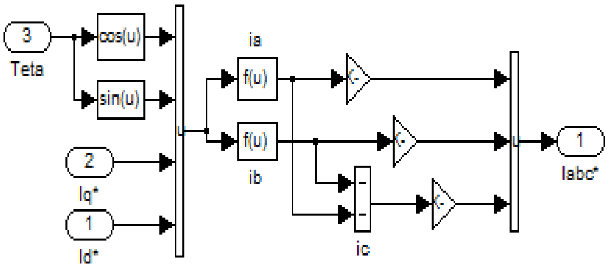

Fig.8. d-q to abc transformation Simulink Block.

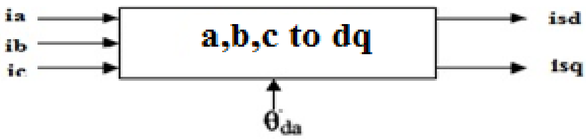

Fig.9. abc to d-q Transformation Block.

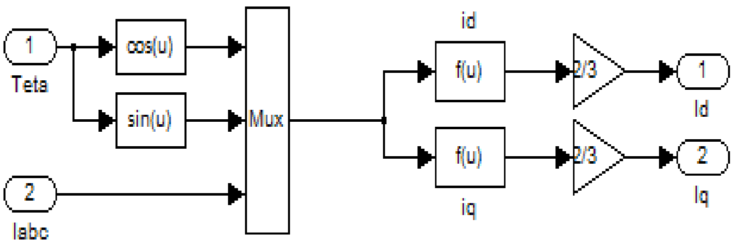

Fig. 10. abc to d-q Transformation Simulink Block.

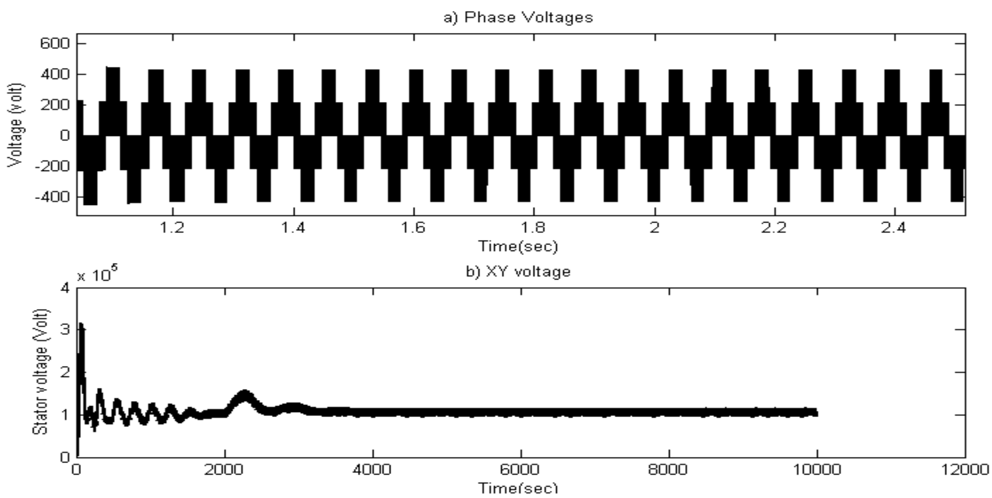

Fig. 11. (a) Phase voltages, b) XY voltage.

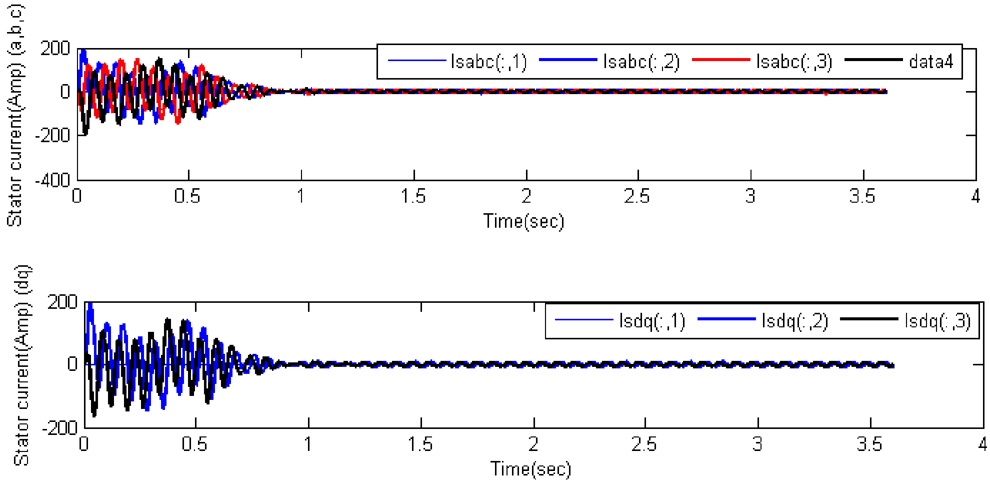

Fig.12. abc currents for stator

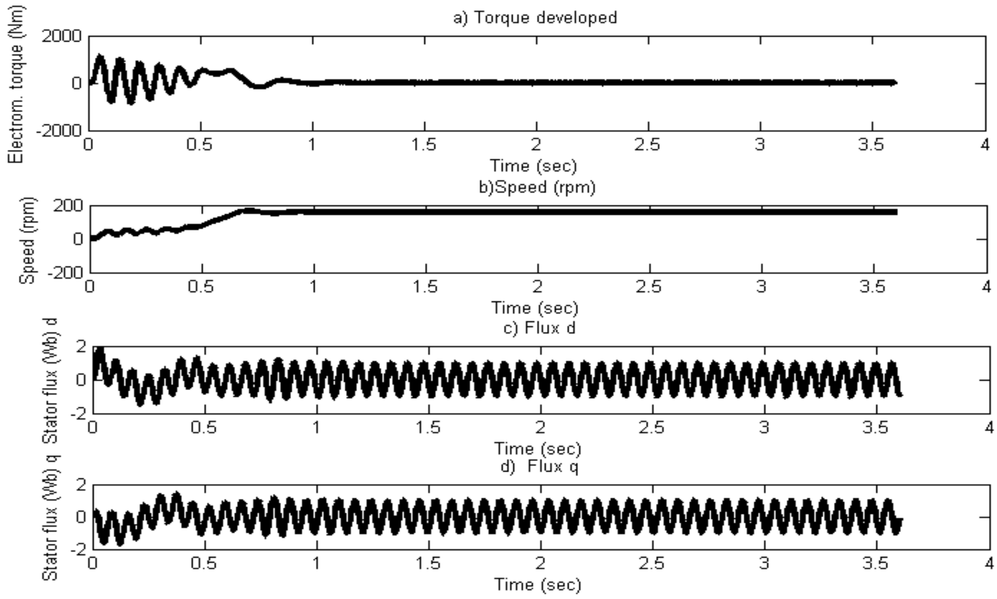

Fig.13. a) Torque developed, b) Speed , and c) Flux d-axis, and d) Flux q-axis of IM.

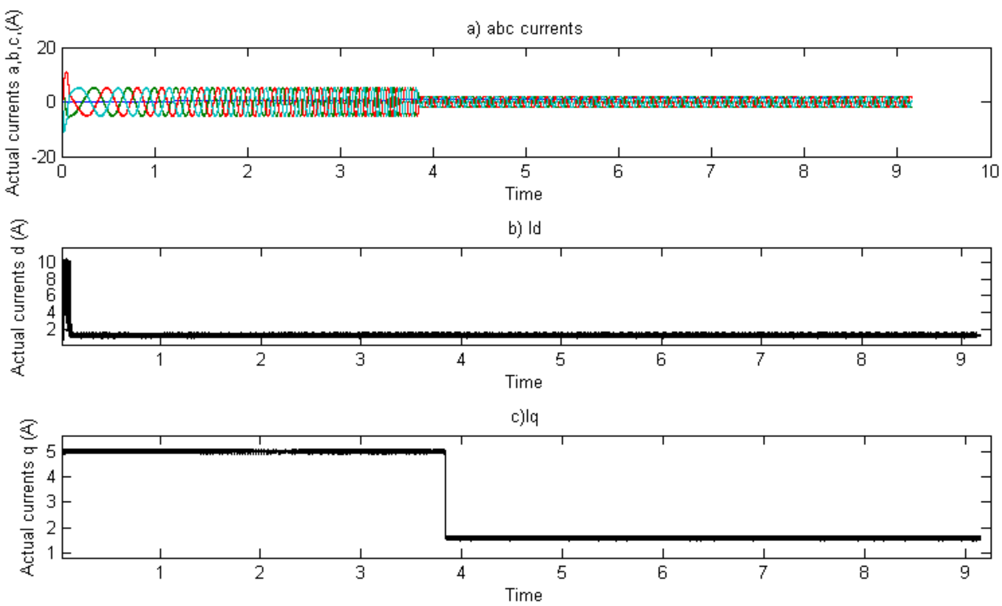

Fig.14 . a) Actual currents a,b,c ,b) Actual current Id, and c) Actual current Iq.

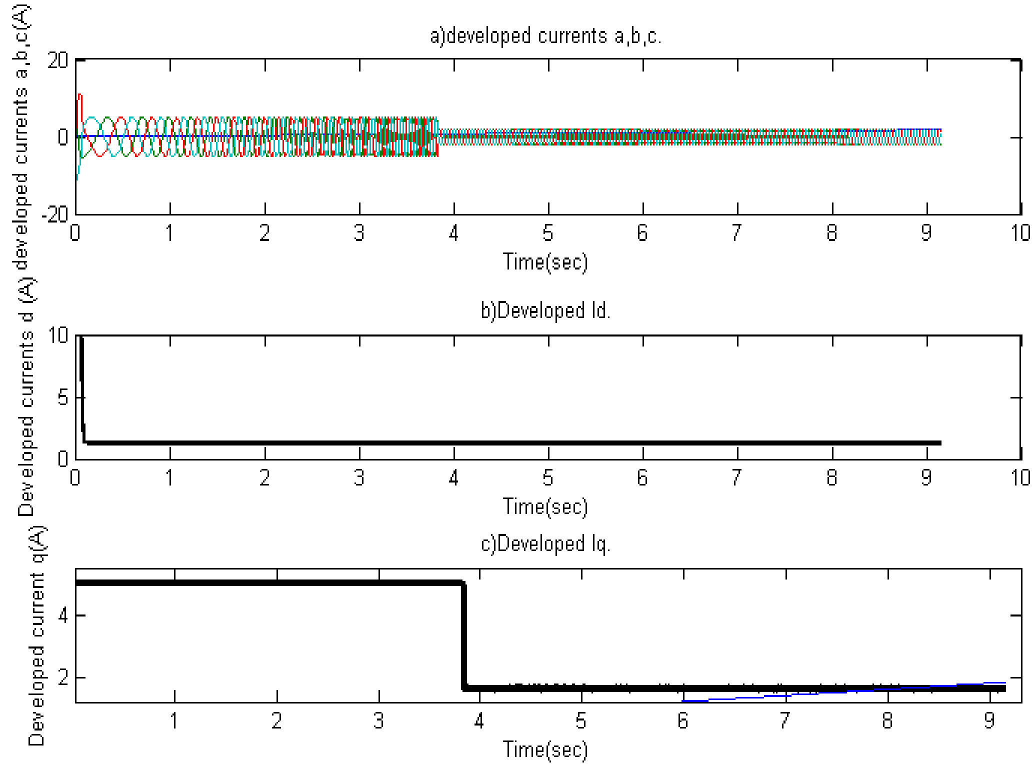

Fig. 15. a) Developed currents a,b,c ,b) Developed current Id, and c) Developed current Iq.

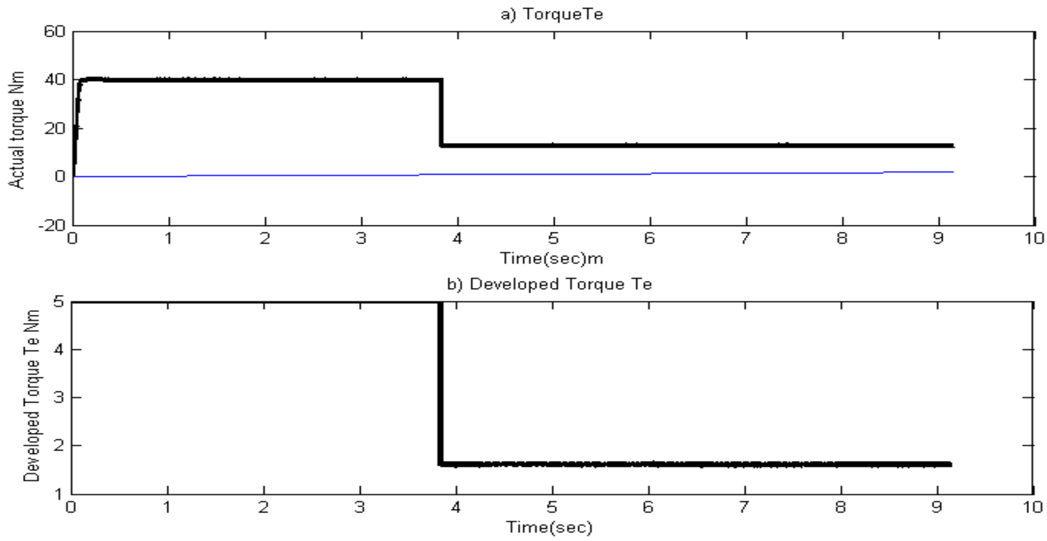

Fig.16. a) Actual Torque ,and b) Developed Torque.

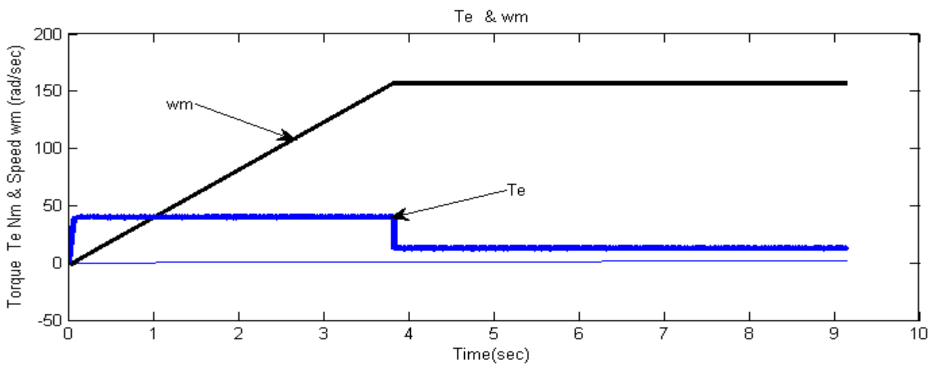

Fig.17. Te& wm relationship.

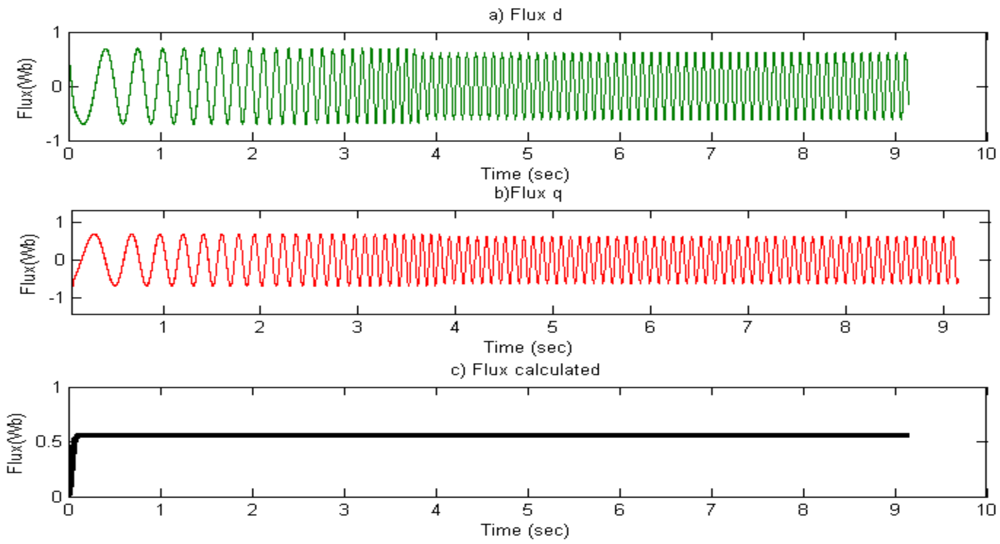

Fig.18. a) Flux d-axis ,b) Flux q-axis, and c) Flux calculated.

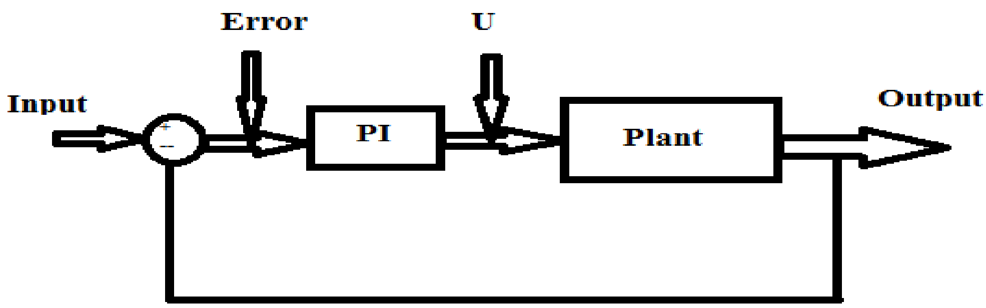

Fig.19 General System Block with Pi Controller.

السيطرة ألاتجاهية (المسار المفتوح والمسار المغلق) لسواقات المحرك الحثي ثلاثي الاطوار

الخلاصة

في هذاالبحث تصميم خوارزمية لنظام سيطرة على محرك حثي ثلاثي الاطوار. المحركات الحثية ثلاثية الاطوار تعتبر من الانواع المعروفة و المفضلة في العديد من الصناعات , لكونها ذات كلف اقتصادية مناسبة جدا من حيث الصيانة وايضا لعدم احتوائها على الفرش الكاربونية (التي تستهلك وتحتاج للتبديل بشكل متكرر).الهدف من هذا البحث هو تحسين اداءالمحرك الحثي ثلاثي الاطوار من حيث السيطرة على السرعة (العمل بسرع مختلفة) والعزم,عن طريق تصميم خوارزمية لنظام سيطرة اتجاهية (مسار مغلق ومسار مفتوح) .من اجل اجراء التحليل الرياضي لنظام السيطرة الاتجاهية تم تحويل الاطوار الثلاثة الى محورين يدعى تحويل (D–Q) في هذا التحويل يمكننا تطبيقه على المحورين الدوار والمتحرك حسب طريقة العمل المراد العمل عليها. MATLAB/ SIMULINK استخدم كاداة لمحاكاة التصميم المقترح للمحرك الحثي وقد تم تطبيق نظريات السيطرة عليه مع PWM INVERTER. النتائج اثبتت كفاءة طرق السيطرة المستخدمة على المحرك الحثي ثلاثي الاطوار من حيث ان نسبة الفولتية الى التيار بقيت ثابتة.