Three Phase Induction Motor Drive based on Vector Control using Pi Controller

Preeti Shankhwar[1], Prashant Singh[2]
Electrical & Electronics Engg. TITS, Bhopal[1, 2] India
e-mail preeti.shankhwar@gmail.com[1], prashantmits@gmail.com[2]

Abstract— **This paper proposes a PI (Proportional Integral) controller with FOC (field Oriented Control) applied in three-phase induction motor control. Conventional vector control method was used two PI current controllers which is replaced by a single FOC with PI controller included speed controller. The aim of this paper is to reduce the quantity of controllers, low current ripple and obtain constant speed by using sensor less field oriented control method.. The proposed schem is simulated by using Matlab /Simulink software.**

Keywords— **PI (Proportional Integral) controller, FOC(field Oriented Control) or Vector Control , PWM (Pulse Width Modulation).Id(reference direct axis current), Id*(actual direct axis current),Iq(actual quadrature axis current), Iq*(reference quadrature axis current.**

I. INTRODUCTION

Variable speed ac drive have been used in the past to perform relatively undemanding roles in application which preclude the use of dc motor, which was environmentally limited and having a high cost, fast switching frequency statics inverter. The lower cost of ac motor has also been a decisive economic factor in multi motor system. However as a result of the progress in the field of power electronics which is cheaper and more effective power converters, and a single motor ac drives complete favorably on a purely economic dc drives[see Reference1].

Among the various ac drive system, those which contain the cage induction motor have a particular cost advantage. Induction motors are relatively rugged and having lower cost machines. That's why much attention has to given to their control for various applications with different control requirements. Squirrel cage induction machine, the cage motor is simple and is one of the cheapest machines available at all power ratings. Have many advantages when compared with DC machine. First of all, it has lower cost And compact structure and insensitive to environment. Furthermore, it does not require periodic maintenance like DC motors. However, because of it is non-linear and dynamically coupled structure, an induction machine has complex control method than DC motors [2].

Recent development based on drive controlled techniques, power switches, fast switching and lower cost microcontrollers became induction motors alternatives of DC motors in industry , while all speed sensor-less technique eliminate the use of mechanical speed sensor, they require stator current & voltage signal as input. These require at least two current sensors and two voltage sensor on stator side. Further the output of same are current sensor can be used for current regulation in drive based controller. In this scheme control strategy is based on controlling speed, torque & current regulation without using mechanical sensor. Unlike closed loop observer it requires only less computation & less dependent on machine parameter. Like field oriented control is provide with variable in synchronously rotating frame. The benefits of speed sensor-less control are the increased reliability of overall system with removal of mechanical sensors ,reducing size, cost and sensor noise also. The speed sensor has many drawbacks which is very inconvenient-

1) Higher costs (especially for low power drives) and higher complexity
2) Installation more complex.
3) Reduced mechanical robustness.
4) Highly costly to maintenance.
5) Reduced immunity to electro-magnetic noise.
6) Lower overall reliability.

The need for tacho less speed control of induction machines has become widely recognized because of the cost and fragility of a mechanical speed sensor due to the difficulty arises of installing the sensor in many applications. That's why mostly industries experts agree that the next generation of commercial drives will include some sort of sensor less torque control. With the invention of FOC complexity of induction motor can be constructed as a dc motor by performing simple transformation. In a similar manner like dc machine, an induction motor has armature winding is also on the rotor, whereas the field is to be generated by currents in the stator winding. However the rotor current is not directly derived from an external source but result from the emf induced in the winding as a result of the relative motion of the rotor conductor with respect to the stator field and armature current. In other words, the stator current is the source of both the magnetic field and armature current. Squirrel cage motor is most commonly used motor. Only the stator current can be directly controlled, while the rotor winding is directly not accessible .The Optimal torque arises condition are not inherent due to the absence of a fixed physical disposition between the stator and rotor field, and the torque equation is non linear. It is independent and efficiently controlled of the field and torque is not as simple and straightforward as in the dc motor [2].

The concept of the steady state torque control of an induction motor is extended to transient states of operation in the high performance, indirect controlled ac drive system based on the field operation principle. The FOC defines condition for decoupling the field control from the torque control. A FOC motor work as a separately exited dc motor in two aspects:

(1)Both the magnetic field and torque developed in motor can be controlled independently.

(2) Optimal condition for the torque production for the torque production, resulting in the maximum torque occurs in the motor in steady state and in transient condition of operation. Many speed estimation algorithms and speed sensor less control schemes have been developed during the past few years. One of the major problems with the terminal quantities-based flux observers designed in the past is their sensitivity to the machine parameters, specifically, to rotor resistance for the current model observer and to stator resistance in case of the voltage model flux observer. To overcome these problems various control techniques have been tried to improve the rotor flux estimation. This has been developed using high frequency measurements based on machine salient, rotor slotting and irregularities [7].

II. PROPORTIONAL CONTROL

A proportional controller attempts to perform better than the On-off type by applying power in proportion to the difference in temperature between the measured and the set-point. As the gain is increased the system responds faster to changes in set-point but becomes progressively under damped and unstable. The final obtained temperature placed below the setting-point for this system because some difference is required keep the heater supplying power.

A. *Sensorless Field Oriented Control*

Field oriented control method applied to an ACIM is based on the decoupling between the current components used for magnetizing flux generation and for torque generation. The decoupling allows the induction motor to be controlled as a simple DC motor. The field oriented control implies the translation of coordinates from the fixed reference stator frame to the rotating reference rotor frame. This translation makes possible the decoupling of the stator current's components, which are responsible for the magnetizing flux and the torque generation. through measurement or it can be estimated using other available parameters such as phase currents and voltages. The term "sensor less" control indicates the lack of speed measurement sensors.

When exceeding the nominal motor speed, the rotor flux must be weakened. A mechanical speed increase will require an increase of the stator currents frequency, but this must be done with respect to the simple equation, V/Hz = ct. Since the voltage cannot be increased over the nominal value, the increase of speed must be done in detriment of torque produced, keeping the constant power curve. In closed loop field oriented control, when exceeding the nominal motor speed, the Id and Iq control loops saturate, limiting the motor flux. The field weakening algorithm will decrease the Id current as the motor speed is increase thus removing saturation.

B. *Mathematical Model of the Induction Motor*

During the entire report, a complex vector notation and some reference frame conversions are used. Since this is quite essential to the understanding of the rest of the theory.

C. *Torque Production*

If a IM's rotor is initially stationary, its conductor will be subjected to a sweeping magnetic field, produced by stator's current, inducing current in the short-circuit rotor with same frequency. The interaction of air gap flux and rotor mmf produces torque. At synchronous speed, the rotor cannot have any induced currents and; therefore, torque cannot be produced. At any other speed, there is a difference between the rotating field (synchronous) speed and the shaft speed, which is called slip speed. The slip speed will induce current and torque in the rotor.

The rotor will move in the same diction as that of the rotating magnetic field to reduce the induced current. We define slip as:

$$S = \frac{N_e - N_r}{N_e} = \frac{\omega_e - \omega_r}{\omega_e} = \frac{\omega_{sl}}{\omega_s} \quad (1)$$

Where ωe = stator supply frequency (r/s), ωr = rotor electrical speed (r/s), and ωsl = slip frequency (r/s). The rotor current is induced at slip frequency. Since the rotor is moving at speed ωr and it current wave is moving at speed ωsl relative to the rotor, the rotor mmf wave moves at the same speed as that of the air gap flux wave the torque expression can be derived as..

$$T_e = \left(\frac{P}{2}\right) lr\, B_p\, F_p \sin\delta \quad (2)$$

Where P = number of poles, l = axial length of the machine, r = machine radius, Bp = peak value of air gap flux density, Fp = peak value of rotor mmf , and δ is defined as the torque angle.

D. *Three-Phase Transformations*

In the study of generalized machine theory, mathematical transformations are often used to decouple variables, to facilitate the solutions of difficult equations with time varying coefficients, or to refer all variables to a common reference frame.The most commonly used transformation is the polyphase to orthogonal two phase (or two-axis) transformation. For the n-phase to two-phase case, it can be expressed in the form:

$$[f_{xy}] = [T(\theta)]\,[f_{1,2\ldots\ldots n}] \quad (3)$$

Where,

$$[T(\theta)] = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\frac{p}{2}\theta \cos\left(\frac{p}{2}\theta - \alpha\right) \ldots\ldots & \cos\left(\frac{p}{n}\theta - (n-1)\alpha\right) \\ \sin\frac{p}{2}\theta \sin\left(\frac{p}{2}\theta - \alpha\right) \ldots\ldots & \sin\left(\frac{p}{n}\theta - (n-1)\alpha\right) \end{bmatrix} \quad (4)$$

and θ is the electrical angle between the two adjacent magnetic axes of a uniformly distributed n-phase windings.

The coefficient $\sqrt{\frac{2}{n}}$, is introduced to make the transformation power invariant.

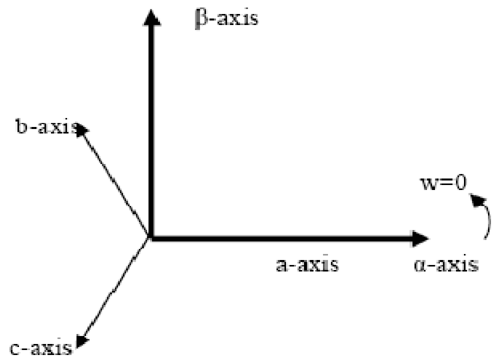

Figure (1) Relationship between the αβ, abc quantities.

E. Clark Transformations

The Clark transformation is basically employed to transform three-phase to two-phase quantities. The two-phase variables in stationary reference frame are sometimes denoted as α and β. As shown in Fig. the α axis coincides with the phase-a axis and the β axis lags the α axis by 90.

$$[f_{\alpha\beta 0}] = [T_{\alpha\beta 0}]\,[f_{abc}] \tag{5}$$

Where the transformation matrix, $T_{\alpha\beta 0}$ is given by:

$$[T_{\alpha\beta 0}] = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \sqrt{\frac{3}{2}} & -\sqrt{\frac{3}{2}} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{6}$$

The inverse transformation is

$$[T_{\alpha\beta 0}]^{-1} = \frac{2}{3}\begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \sqrt{\frac{3}{2}} & 1 \\ -\frac{1}{2} & -\sqrt{\frac{3}{2}} & 1 \end{bmatrix} \tag{7}$$

F. Park Transformations

The Park's transformation is a well-known transformation that converts the quantities to to-phase synchronously rotating frame. The transformation is in the form of:

Where the dq0 transformation matrix is defined as :

$$[T_{dq0\,(\theta_d)}] = \begin{bmatrix} \cos\theta_d & \cos\left(\theta_d - \frac{2\pi}{3}\right) & \cos\left(\theta_d + \frac{2\pi}{3}\right) \\ -\sin\theta_d & -\sin\left(\theta_d - \frac{2\pi}{3}\right) & -\sin\left(\theta_d + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{8}$$

Where θ_d is transformation angle, the relationship between them θ_d and θ_q is:

$$\theta_q = \theta_d + \frac{\pi}{2} \tag{9}$$

One can show that $[T_{dq0}]$ and $[T_{qd0}]$, are basically the same, except for the ordering of the d and q variables. Both of the alternatives are shown in Fig 2(a), (b).

Where Lls is the per phase stator winding leakage inductance, Llr is the leakage inductance of per phase rotor winding and Lss is stator winding self inductance, Lrr is the self inductance of the rotor winding, Lsm is the mutual inductance between stator windings, Lrm is the mutual inductance between rotor windings, and Lsr is the peak value of the stator to rotor mutual inductance.

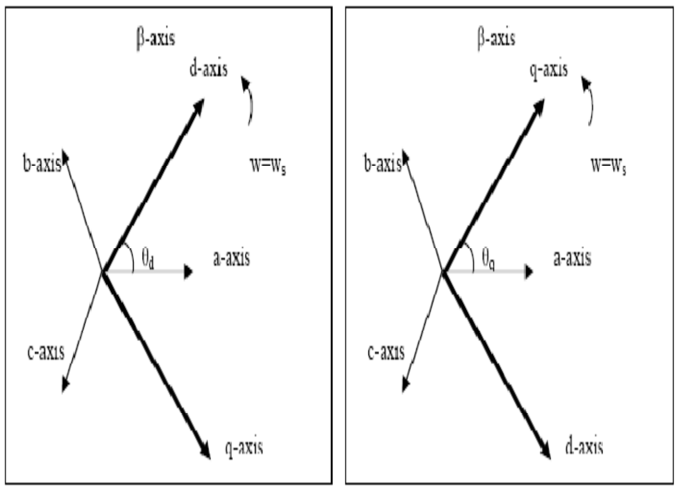

Fig. 2. Relationship between the αβ, abc quantities

III. PROPOSED SCHEME WORK

This scheme based on FOC with PI controller technique which perform an important role for controlling the Induction motor Speed and Torque and current. This scheme used DC source and gives a particular voltage to PWM inverter, which convert DC into AC and supplied to the Induction Motor. In D C source six pulses are generated, 1000 V is limited value for operating D C source, has supplied to the inverter and results are shown on scope. Simulink model of PI controller based induction motor drive shown in below.

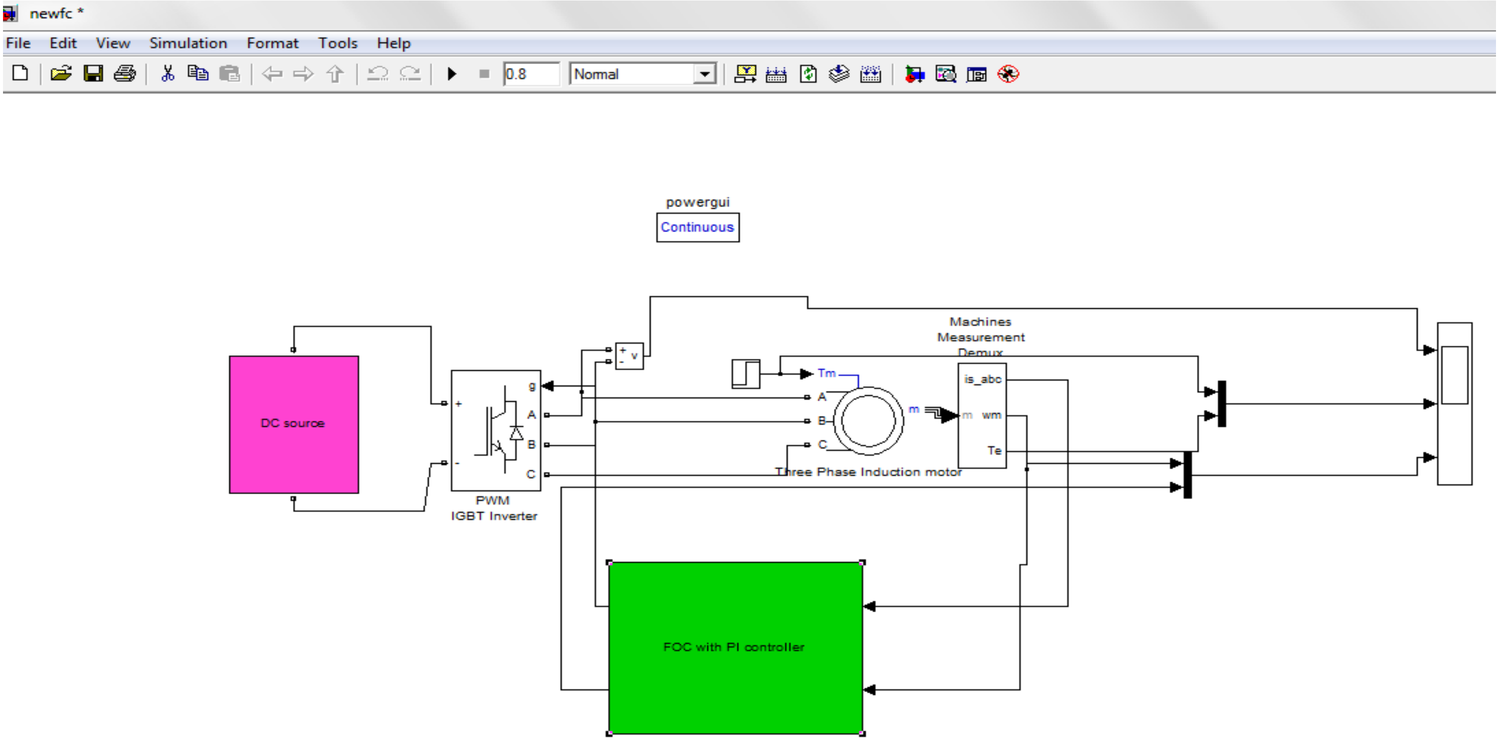

Fig. 3. Proposed Simulink model of PI controller based Induction motor based drive.

A. *Induction Motor Control Strategy by Rotor Reference Frame*

In Simulink model Rotor reference frame theory are used Id (direct axis) and Iq(quadrature axis) is used for improving the voltage pulse by placing field winding on Id (direct axis) and armature winding on Iq (quadrature axis) pulse Iabc is the three phase reference current which is converted into two phase current by Clark transformation and Iabc reference current and Iabc* actual current are compared by current controller.

Results are find out by Scope which shows current ,flux and torque and again two phase current is converted into three phase by Inverse Parks and Iabc* actual current is find out.Id* actual direct axis current and Iq* actual quadrature axis current and teta (torque) is obtained. Actual speed, actual torque and reference speed is find out by Speed controller which is shown by Scope .So constant voltage are supplied by closed loop foc with PI controller and given to the induction motor and by this method speed is controlled according to system requirement.

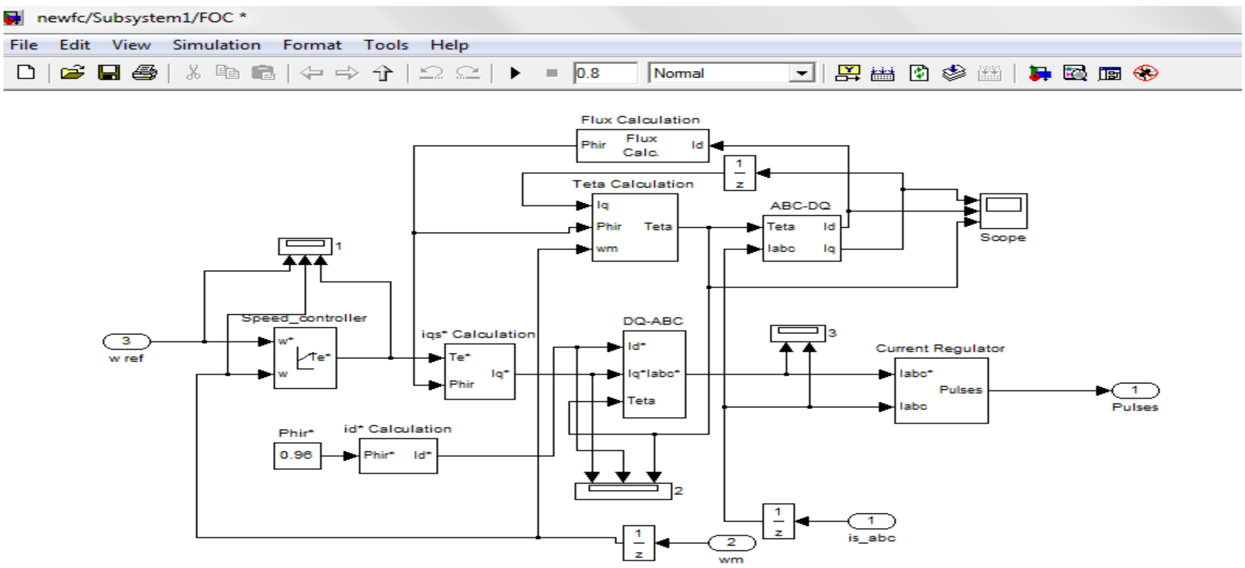

Fig. 4. Simulink model for Induction motor Control strategy by Rotor Reference Frame.

B. Result Analysis and Discussion

The Simulation results are used MATLAB software 7.9 version,have taken to analysis the effective result of the proposed strategy. The proposed scheme of reconstructed technique and feedback output signal sis illustrated by a simulation which is shown in the block diagram of Figure(3).The Induction motor data is used in the simulation strategy is shown in appendix. Flux is set to its rated value of 0.96 W b and the dc voltage is 400 V. Speed is used 1430 RPM. The load torque is 0.32417s in case 4.The initial value of state vector is set to zero.The sampling time has set as to 2e - 6.

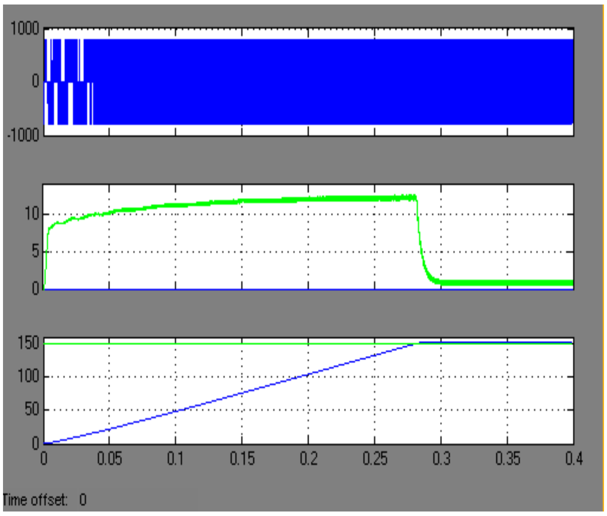

Fig.5.Simulink results with (a) Voltage Vs Time and(b) TorqueVs Time and (c) Speed Vs Times of I/m motor drive.

In figure (6) this characteristics of induction motor firstly current has shown above 50 Ampere at the starting of squirrel cage induction motor current is high and this time as soon as motor attain normal speed current will be starting reduced so this time torque will be high and after some time when motor gain high speed this time torque will be very low but flux has constant in complete operation.

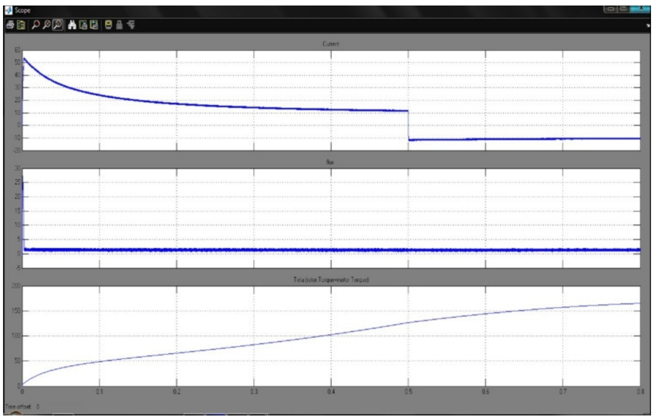

Fig. 6.Simulink Result of Induction motor (a) Current Vs Time and (b) Flux Vs Time and (c) Torque Vs Time.

In figure(7) this characteristics of induction motor Iabc which is Reference current of Park's transformation is converted Three phase to Two phase and again converted two phase to three phase by Inverse Park's transformation and find Iabc* actual current which is shown in below characteristic.

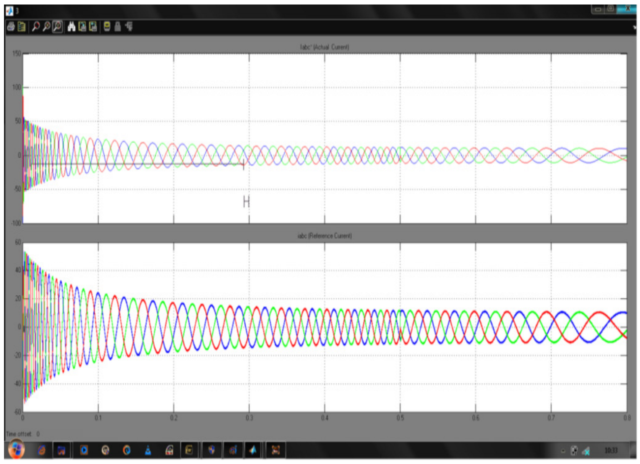

Fig. 7.Simulink Result Of Induction Motor (a) Iabc* (Actual current) Vs Time and (b) Iabc (Reference current) Vs Time.

In figure (8) Simulink result are shown first reference speed are constant and in second characteristics actual speed are gradually increases and torque is also constant.

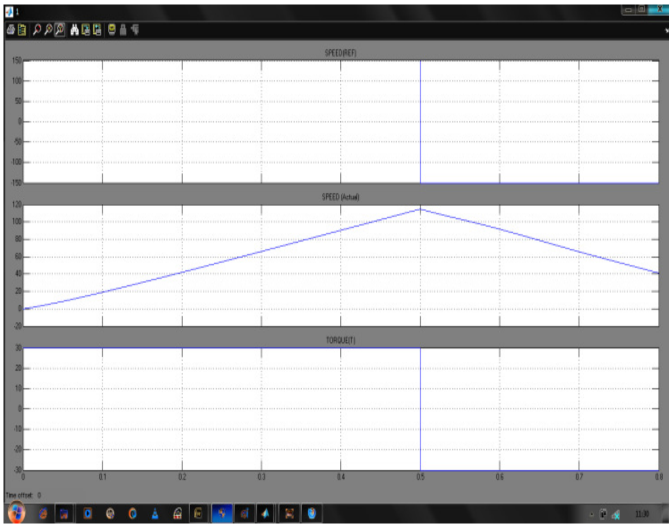

Fig. 8.Simulink Result of Induction motor (a) Reference Speeds Vs Time and (b) Actual speed Vs Time and (c)Torque Vs Time.

In figure (9) this characteristics of induction motor firstly current has shown current is high at the starting and obtained Iq* and in second characteristics Id* actual direct axis is obtained which is constant and in third characteristics teta (torque) is obtained which is low at the starting when current is high means current is inversely proportional to torque.

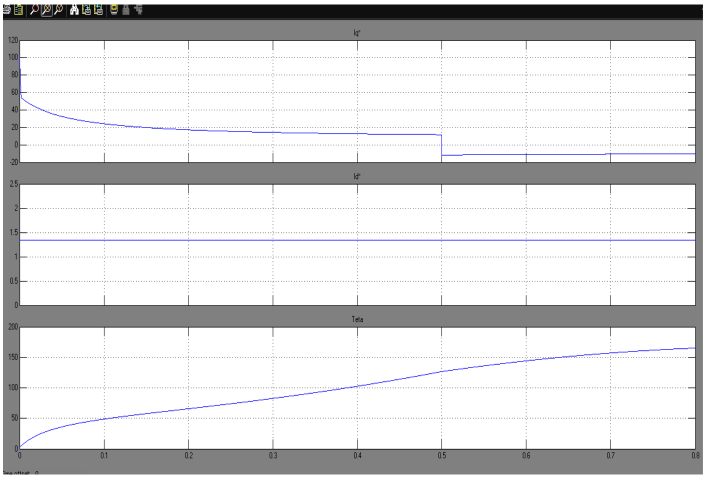

Fig. 9. Simulink results of Induction motor (a) Iq* Vs Time and (b) Id* Vs Time and (c) Teta Vs Time of Inverse Park.

C. APPENDIX

TABLE.1

INDUCTION MOTOR DATA

PARAMETERS	VALUES
Rated voltage	400V
Rated current	0.3436 A
Rs	2.1 Ohm
Lm	0.71469 H
Ls	0.7329H
L’r	0.7328 H
R’r	2.2605 Ohm
P	4

IV. CONCLUSION

The aim of the paper was to give constant speed by sensorless FOC method. It is simple to be implement & requiring less controller.The proposed controller is modeled & simulated in matlab using simulink.A simulation result shows that the method can effectively enhance the speed & torque characteristic & satisfy the performance requirement of the system.

REFERENCES

[1] Sawa, T.; Kume, T, Motor drive technology- history and visions for the future Power Electronics specialist Conference, 2004 Conference, 2004. PESC 04 2004 IEEE 35th Annual,2004,Page(s):2-9,Vol.1.

[2] Aydeniz, M.G.; Senol, I.; “A novel approa to sensorless control of induction motors” Electrical and Electronics Engineering, 2009. ELECO 2009, Page(s): I-179 - I-183

[3] Lai, Y.S.; Liu, C.N.; Chang, K.Y.; Luo, Y.C.; Lee, C.I.; Liu, C.H.; “Sensor less vector controllers for induction motor drives” Power Electronics and Drive Systems, 1997. Proceeding 1997 International Conference, Page(s): 663 - 669 vol.2.

[4] Critchley, D.R.; Jones, R, “High performance AC motor controller” Control of Induction Motors, IEE Colloquium on , 1989 , Page(s): 5/1 - 5/3.

[5] Kalilah, S.A,“Improved torque and speed estimation in sensorless induction motor drive” Universities Power Engineering Conference, 2004. UPEC 2004. 39th International Page(s): 538 - 544 vol. 1.

[6] Derdiyok, A.,“Speed-Sensorless Control of Induction Motor Using a Continuous Control Approach of Sliding Mode and Flux Observer”,Volume: 52 , Issue: 4 , 2005 , Page(s): 1170 – 1176.

[7] Vaclavek, P.; Blaha, P, “Lyapunov-function-based flux and speed observer for AC induction motor sensorless control and parameters estimation” Industrial Electronics, IEEE Transactions on Volume: 53 , Issue: 1, : 2005 , Page(s): 138 – 14 .

[8] Mohamed Boussak,kamel jarray, “A High-Performance Sensorless Indirect Stator Flux Orientation Control of Induction Motor Drive”, IEEE Transactions On Industrial Electronics,Vol. 53, No. 1, February 2006,Page(S):41-49 .

[9] Kwon, Y. A.; Kim, S. K. “A High-Performance Strategy for Sensorless Induction Motor Drive Using Variable Link Voltage” Power Electronics, IEEE Transactions on ,Volume: 22 , Issue: 1 , 2007 , Page(s): 329 – 33.

[10] Garcia, G.O.; Stephan, R.M.; Watanabe, E.H, “Comparing the indirect field-oriented-control with a scalar method”, Industrial Electronics, Control and Instrumentation, 1991. Proceedings. IECON '91., 1991 International Conference on Page(s):475-480,vol.1.

[11] Iqbal, A.; Khan, M.R, “Sensorless control of a vector controlled three-phase induction motor drive using artificial neural network” Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India, 2010 Joint International Conference on 2010 , Page(s): 1 – 5.

[12] Mitronikas, E.D.; Safacas, A.N.“An improved sensorless vector-control method for an induction motor drive.