International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 3, March - 2014

MPSOC Design Approach of FPGA Based Controller For Induction Motor Drive

Gayathri.V
PG Student, Department of ECE
East Point College of Engineering and Technology
Bangalore, India

Arun Kumar. M
Associate Prof, Department of ECE
East Point College of Engineering and Technology
Bangalore, India

***Abstract*— Modern embedded control systems require high performance digital devices to answer their growing complexities. The high of FPGA has made it an appropriate solution for motor drive application. This paper presents a speed control strategy for a three phase induction motor. Firstly the induction machine is mathematically modeled and the transformation is with respect to rotor flux. Secondly a matlab/simulink model is designed and developed based on the principle of vector control. Thirdly the induction motor is fed from a three hose inverter bridge. The triggering pulses required for the inverter are generated using state vector pulse width modulation technique. The svpwm is realized on the same chip. Finally the developed model is simulated using matlab.**

Keywords*— *IVOC- Indirect Vector oriented control, FPGA- Field Programmable Gate Array, State Vector PWM,MPSOC-Multi Process Systen On Chip.

I. INTRODUCTION

In the last years, several research studies proved that FPGA is an appropriate alternative to implement digital controllers in several application areas, such as motion control, power electronics, and motor control over pure software solutions and analog solutions Control of AC induction machines using the vector control techniques is becoming more popular nowadays. The objective of vector control of induction machine is to allow an induction machine to be controlled just like a separately excited dc machine. When the dynamic equations for an induction machine is transformed by means of rotating transformation methods into a reference frame that coincides with rotor flux, the results become similar to that of a DC machine. This allows AC machine to be controlled just like a DC machine. This method of decoupling the variables and controlling them independently is termed as vector control. The Pulse Width Modulation (PWM) Technique called "Vector Modulation", which is based on space vector theory, is the most important development in the last few years. Although, several of PWM methods have been created in the past, the vector modulation technique appears to be the best alternative for a three phase switching power converter. Since the concept of multilevel PWM converter was introduced, various modulation strategies have been developed and studied in detail, such as multilevel sinusoidal PWM, multilevel selective harmonic elimination and space vector modulation. Among these strategies, the space vector PWM (SVPWM) [14][15] stands out because it offers significant flexibility to optimize switching waveforms and is well suited for digital implementation. The IVOC with space vector pwm controller is modeled in matlab/simulink and the simulation result is presented in this paper.

II. MATHEMATICAL MODEL OF THREE PHASE INDUCTION MOTOR

Induction machine 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 loads), but also due to their varied modes of operation both under steady state and dynamic state. The basic purpose of using d-q model[13][6] approach to control the motor parameters independently i.e. torque and flux of the induction motor. By this modeling approach, all of the machine parameters are assessable for control and verification purposes. As long as equations are known, any drive or control algorithm can be modeled in Simulink.

A. D-Q Modelling of Three Phase Induction Motor

The induction machine d-q or dynamic equivalent circuit is shown in Fig. 1 & 2 .The modeling equations are as given below.

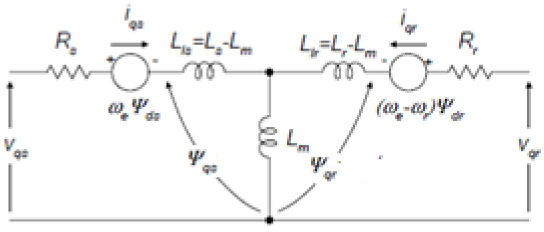


Fig. 1 Quadrature Axis Equivalent Circuit

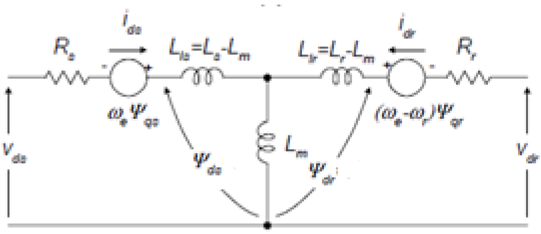


Fig. 1 Direct Axis Equivalent Circuit

Stator voltage equations[6][8][13]

$$V_{qs}=R_s\, i_{qs} + \frac{d\psi_{qs}}{dt} + \omega\, \psi_{ds} \qquad (1)$$

$$V_{ds}=R_s\, i_{ds} + \frac{d\psi_{ds}}{dt} + \omega\, \psi d_{qs} \qquad (2)$$

Rotor voltage equations[6][8][13]

$$V_{qr}=R_r\, i_{qr} + \frac{d\psi_{dr}}{dt} + (\,\omega e\text{-}\omega r)\, \psi_{dr} \qquad (3)$$

$$V_{dr}=R_r\, i_{dr} + \frac{d\psi_{dq}}{dt} + (\,\omega e\text{-}\omega r)\, \psi_{qr} \qquad (4)$$

Stator flux equations[6][8][13]

$$\Psi_{qs}=L_s\, i_{qs}+L_m\, i_{qr} \qquad (5)$$

$$\Psi_{ds}=L_s\, i_{ds}+L_m\, i_{dr} \qquad (6)$$

Rotor flux equation[6][8][13]s

$$\Psi_{qr}=L_r\, i_{qr}+L_m\, i_{qs} \qquad (7)$$

$$\Psi_{dr}=L_r\, i_{ds}+L_m\, i_{ds} \qquad (8)$$

Stator current equations [6][8][13]

$$I_{ds} = \frac{1}{X_{ls}}(\Psi_{ds} - \Psi_{md}) \qquad (9)$$

$$I_{qs} = \frac{1}{X_{ls}}(\Psi_{qs} - \Psi_{mq}) \qquad (10)$$

Rotor current eqution[6][8][13]

$$I_{dr} = \frac{1}{X_{ls}}(\Psi_{dr} - \Psi_{md}) \qquad (11)$$

$$I_{qr} = \frac{1}{X_{ls}}(\Psi_{qr} - \Psi_{mq}) \qquad (12)$$

Torque eqution [6][8][13]

$$Te=1.5P\ (\psi ds\ iqs - \psi qs\ ids) \qquad (13)$$

$$Te - TL = J\ (P/2)\frac{d\omega_r}{dt} \qquad (14)$$

$$\frac{d\omega_r}{dt} = P/2J\ (Te\text{-}TL) \qquad (15)$$

Where

$$L_s = L_{ls} + L_m \qquad (16)$$

$$L_r = Ll_r + L_m \qquad (17)$$

d: direct axis
q:quadrature axis
s: stataor variable
r:rotor variable
ω_e =stator angular electrical frequency,
ω_r= rotor angular electrical speed.
Ψ_{ij} = is the flux linkage (*i*=*q* or *d* and *j*=*s* or *r*),
P: number of poles,
J: moment of inertia,
Te: electrical output torque,
TL (or *Tl*) : load torque,

III. BLOCK DIAGRAM OF IVOC

Fig.3 shows the block diagram of an indirect vector control system for an induction motor. The dq frame is fixed to the rotor flux position which is defined by the angle. The rotor position is sensed by a position detector and used in conversion from dq to abc.The induction motor is fed by a current-controlled three phase inverter bridge. The stator currents are regulated by state vector pulse width modulation technique which generates inverter drive signals for the inverter switches.

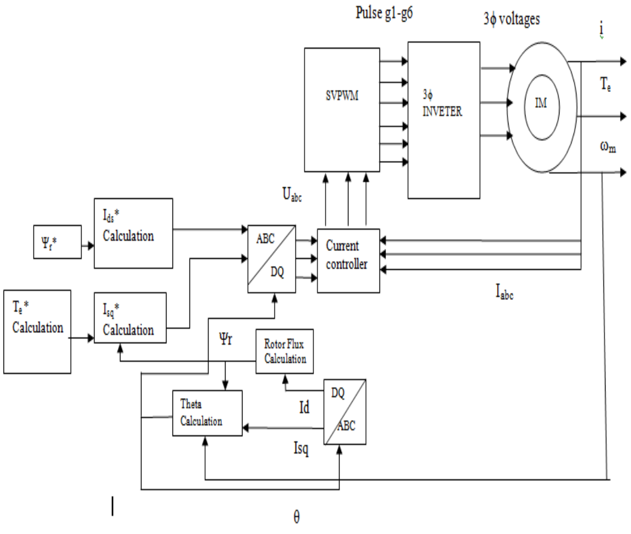


Fig. 3 Block Diagram of IVOC

IV. DEVELOPMENT OF IVOC SIMULINK MODEL

The simulink model developed as shown in the fig below. In this system, rotor reference frame is chosen as the reference frame for transforming the dynamic equations of the induction motor. The induction motor is fed by a current-controlled three phase inverter bridge. The stator currents are regulated by by svpwm which generate drive signals for the inveter switches which is converted to Sa, Sb, and Sc.The torque is controlled by the quadrature-axis component of the stator current iqs*. The rotor flux is controlled by the direct-axis component ids*.The motor speed is regulated by a control loop which produces the torque control signal iqs*. The iqs* and ids* current references are converted into phase current references ia*, ib*, and ic* for the current regulators.

A) Simulink model of IVOC:

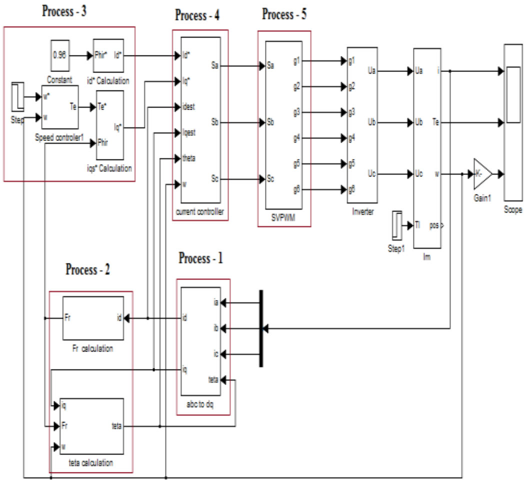


Fig.4 Simulink Model of IVOC

B) Descripition of individual processes

Process - 1

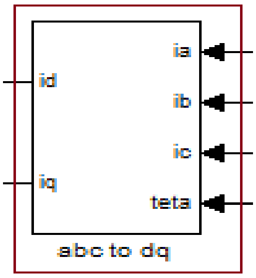


Fig: 5 Process 1

abcto αβ transformation (Clarke's transformation):

The transformation of three phase to two is done using clarks and parks transformation.The transformation equations are implemented in the abc todq convertion block and the eqations are as below

$$i_\alpha = \sqrt{\frac{2}{3}}\left(i_a - \frac{1}{2} i_b - \frac{1}{2} i_c\right) \quad (18)$$

$$i_\beta = \sqrt{\frac{2}{3}}\left(0 + \frac{\sqrt{3}}{2} i_b - \frac{\sqrt{3}}{2} i_c\right) \quad (19)$$

αβ to dq axes (Parks transformation)

$$i_d = i_\alpha cos\Theta + i_\beta sin\Theta \quad (20)$$

$$i_q = -i_\alpha sin\Theta + i_\beta cos\Theta \quad (21)$$

Process - 2

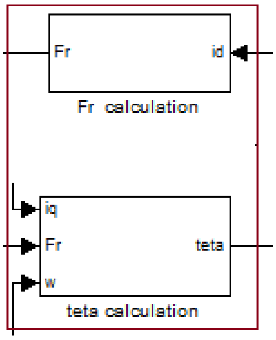


Fig: 6 Process 2

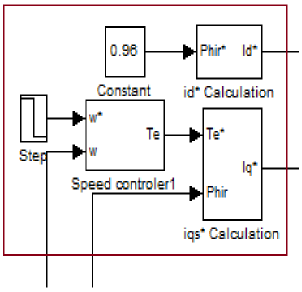
F$_r$ (flux) calculation:

$$F_r = i_d L_m R_r \left(\frac{1}{L_{rs} + R_r}\right) \quad (22)$$

$$\Theta = \int (\omega_m + \omega_{sl})\, dt \quad (23)$$

$$\omega_{sl} = \frac{L_m R_r}{\hat{\psi}_r L_r} i_{qs} \quad (24)$$

Process - 3



Fir: 7 Process 3

Speed controller block

In the speed controller block PI controller is implemented and the reference torque is calculated by implementing the torque equation given below

(T$_e$* calculation):

$$T_e^* = (\,Kp\,(\omega * - \omega) + \int Ki(\omega * - \omega)) \quad (25)$$

i$_q$* calculation :

$$i_q^* = (2/3)\,(2/P)\,(Lr/Lm)\,(Te/phir) i_q^* \quad (26)$$

$$i_d^* = (phir^*/L_m) \quad (27)$$

$$(Lm = 61.31mH)$$

Process - 4

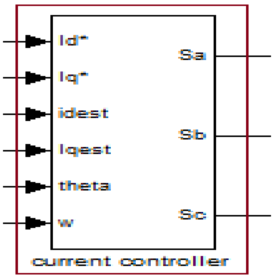


Fig: 8 Process 4

Fig. 8 represents the current controller blocks the estimated currents and the reference currents are compared and the required voltages are computed using the following equations.

Sub blocks of process – 4

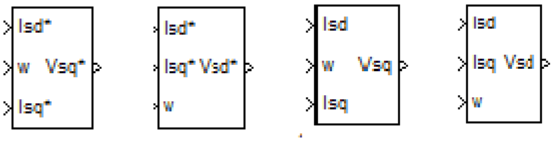


Fig: 8.1 Sublocks of process 5

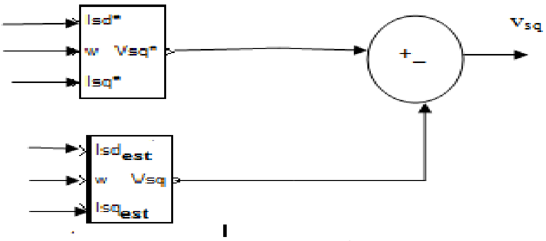


Fig: 8.1.1 estimation of V$_{sq}$

$$v_{sq} = R_s i_{sd} + \sigma L_s \frac{di_q}{dt} + \omega L_s i_{sd} \qquad (28)$$

$$v^*_{sq} = R_s i^*_{sd} + \sigma L_s \frac{di^*_s}{dt} + \omega L_s i^*_d \qquad (28.1)$$

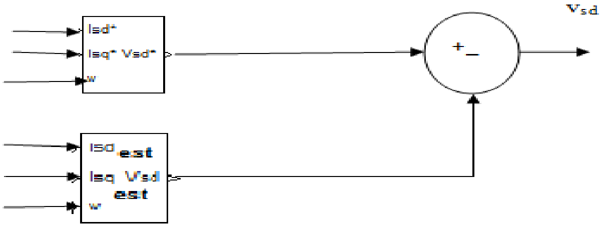


Fig. 8.1.2 Estimation of V_{sd}

$$v^*_{sd} = R_s i^*_{sd} - \omega_s [L_s - \frac{L_m^2}{L_r}] i^*_{sq} \qquad (29)$$

$$v_{sd} = R_s i_{sd} - \omega_s [L_s - \frac{L_m^2}{L_r}] i_{sq} \qquad (29.1)$$

v_{dq} tov_{abc} transformation block:
The the two phase to three phase conversion is obtained clark and parks transformation.The equations are as given below.

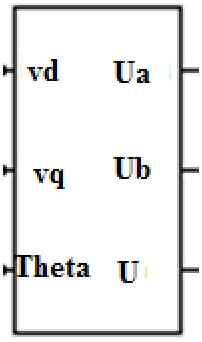


Fig. 9 dq to abc transformation

d-q to αβ transformation:

$$v_{\alpha} = v_d cos\theta - v_q sin\theta$$

$$V_{\beta} = sin\theta + v_q \, cos\theta$$

αβ to abc transformation:

$$v_a = v_{\alpha} \sqrt{\frac{2}{3}} \qquad (30)$$

$$v_b = \sqrt{\frac{2}{3}} \left(-\frac{1}{2} v_{\alpha} + \frac{\sqrt{3}}{2} v_{\beta} \right) \qquad (31)$$

$$v_c = \sqrt{\frac{2}{3}} \left(-\frac{1}{2} v_{\alpha} - \frac{\sqrt{3}}{2} v_{\beta} \right) \qquad (32)$$

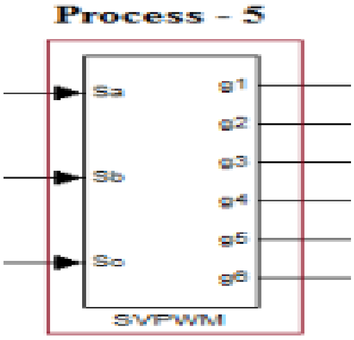


Fig. 10 Process 5

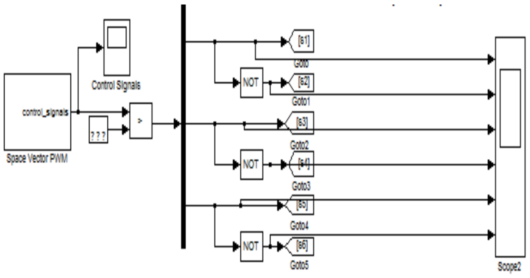


Fig. 10.1 Sub block of process 10

Three phase inverter :

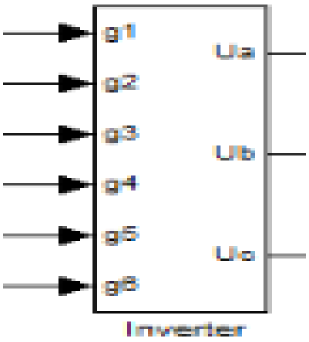


Fig. 11 Inverter Bridge

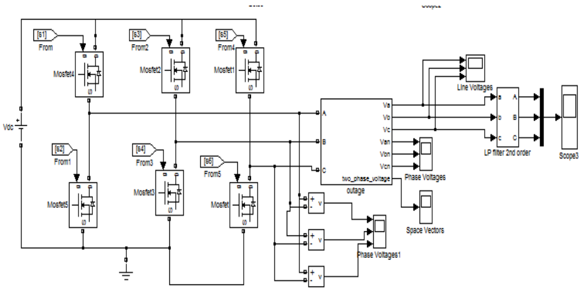


Fig. 11.1: Sub blocks of Inverter Bridge

Induction motor d-q block:

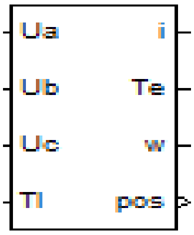


Fig:12 Induction motor dq block

$$i_a = i_d \quad (33)$$

[6][8][13]

$$i_b = -\frac{1}{2} i_d + \frac{\sqrt{3}}{2} i_q \quad (34)$$

[6][8][13]

$$i_c = \frac{1}{2} i_d + \frac{\sqrt{3}}{2} i_q \quad (35)$$

[6][8][13]

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\frac{L_m}{L_r}\right)(F_d i_q - F_q i_d) \quad (36)$$ [6][8][13]

$$\omega = [\int(Te - Ti)](\frac{P}{J}) \quad (37)$$ (36) [6][8][13]

C) Principle of SVPWM:

In vector coordinates, the combinations of three-phase inverter output voltages form eight space vectors as depicted in figure 5.There are six nonzero space vector forming an origin centered hexagon, and the circle is the maximum trajectory of the regular sinusoidal outputs in linear modulation. This figure also illustrates the PWM output patterns in the six regions (denoted as sector I-VI) separately. In accordance with three phase to two phase transformation , the three phase inputs (Va, Vb, Vc)are transformed into (Vα , Vβ) as the reference vectors. [15][16][17]

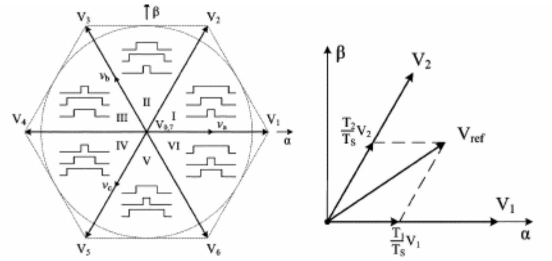


Fig. 13 Basic Eight Switching Vectors and Vector Representation of Sector I.

Table.1 Voltage Vectors, Switching Vectors, Phase voltages and the Line to Line Vectors

Voltage Vectors	Switching Vectors			Line to neutral voltage			Line to line voltage		
	a	b	c	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_{ca}
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

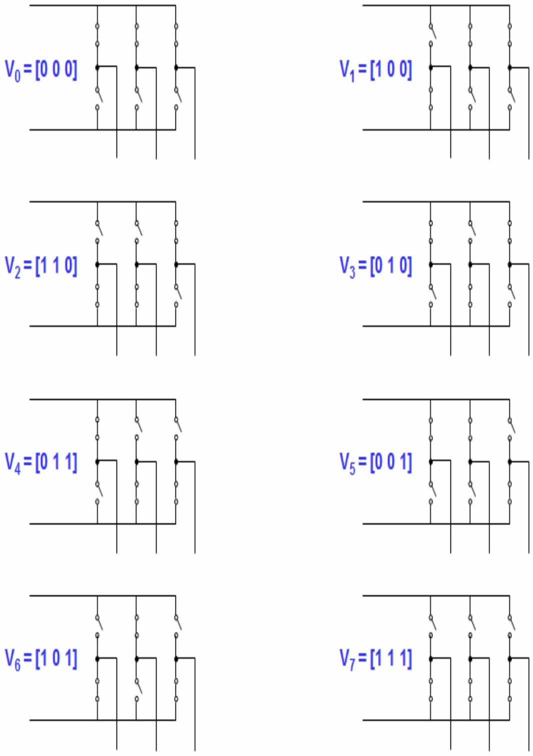


Fig. 14 The eight inverter voltage sequence.

V) Results

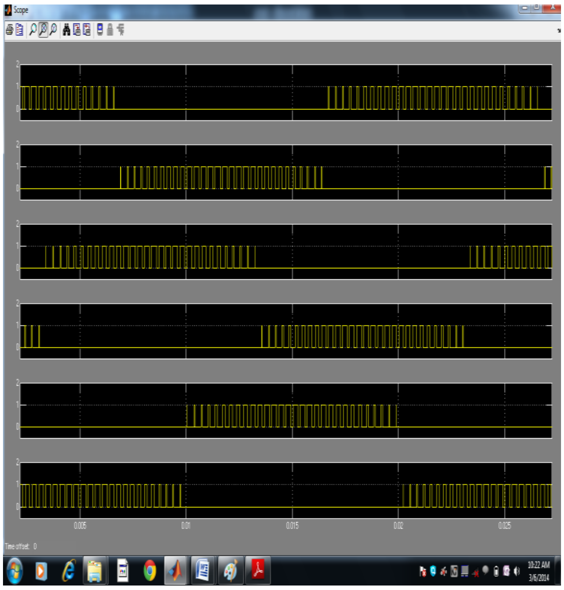


Fig. 15SVPWM simulation output pulses.

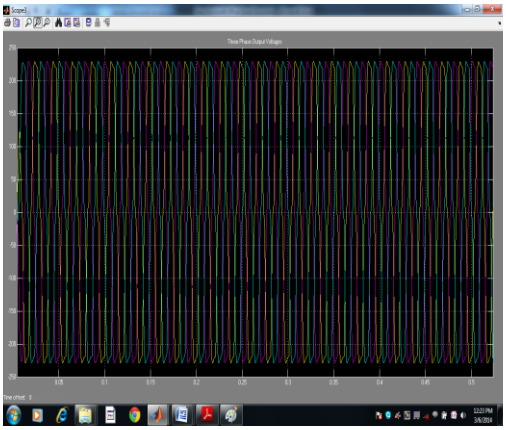


Fig.16 Three pase bridge rectifier output

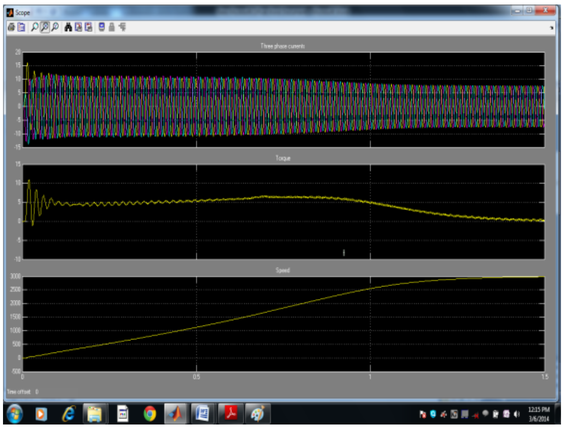


Fig. 17 The induction motor output

VII) THREE PHASE STATOR CURRENTS

ii) Torque
iii) Speed

VI) CONCLUSION.

The IVOC simulink model for a three phase induction motor was developed and simulated using matlab/Simulik.

VII) FUTURE SCOPE

The simulink model developed can be coded in hardware description language and implement on FPGA and can be applied to any real time system.

REFERENCES

[1] Slim Benthoman,Ahmed KrimBen Salem, Hedi, “MPSOCDesign Approach of FPGA Based Controller for Induction Motor Drive”

[2] Sifat Shah,A,Rashid MKL Bhatti “Direct Quadrature (D-Q) modeling 0f 3-phase IM using matlab simulink”

[3] P.Pillai,Senior member IEEE,V Levin, “Mathematical Models For Induction Machines”

[4] Park and clarkes transformation on the TMS320C2xx – Texas instruments

[5] Burak Ozpineci1, Leon M. Tolbert,”Simulink implementation of IM machine model-A modular approach”

[6] Ashutosh Mishra1, Prashant Choudhary2 “Speed Control Of Acosta, M Vilargat,Travieso,M Dourte, “Matlab based simulation toolbox for the study and design of induction motor foc speed drives”

[7] An Induction Motor By Using Indirect Vector Control Method”

[8] Generalized theory of electrical machines by - Dr.P.S Bimhra

[9] Electrical machines by - Nagrath Kothari

[10] Electrical machines by - J.B Gupta

[11] Electrical machines by - As hfaq hussain

[12] Electrical machines by - Mulukutla S.Sarma & Mukesh K. Pathak

[13] Advanced power electronic and AC drives - Bimal .K Bose

[14] Implementation of SVPWM in FPGA through Matlab/Simulink Environment. K Vinoth Kumar et. Al. / International Journal of Engineering Science and Technology.

[15] Space Vector Pulse Width Modulation Schemes for Two-Level Voltage Source inveter P.Tripura1, Y.S.Kishore Babu2, Y.R.Tagore2 1 Vignan’s Nirula Institute of Technology & Science for Women, EEE Dept.,Guntur,A.P.,INDIA Matlab/Simulink

[16] Implementation of SVPWM in FPGA through Environment. K Vinoth Kumar et. Al. / International Journal of Engineering Science and Technology.

[17] SV PWM Pattern Generator using Field Programmable Gate Array Implementation Prawin Ange l ,Michael 1, Dr. N. Devarajan 22009 International Conference on Machine Learning and Computin IPCSIT vol.3 (2011) © (2011) IACSIT Press, Singapore