Chapter – V

CHAPTER 5

MATLAB SIMULATION FOR VECTOR CONTROL

OF PROTOTYPE SIX PHASE INDUCTION MOTOR

5.1 INTRODUCTION

As discussed in previous chapter vector control demands two axis (d-q) model of three phase induction motor. This is required because the motor is run like separately excited dc motor. In the case of induction motor, the control is usually performed in the reference frame d-q (d- direct axis, q- quadrature axis) attached to the rotor flux space vector. That's why the implementation of vector control requires information on the modulus and the space angle (position) of the rotor flux space vector [55, 56]. Before actual control of six phase induction motor, mathematical modeling of the prototype is carried out in Matlab software. Then simulation of vector control of six phase induction motor is carried out and the results are compared with equivalent three phase induction motor.

5.2 MODELING OF SIX PHASE INDUCTION MOTOR

The equations that describe the behavior of the six-phase induction motor when expressed in the arbitrary reference frame are listed in equations shown below:

$$V_{q1} = r_1 I_{q1} + p\lambda_{q1} + w_k \lambda_{d1} \qquad (1)$$

$$V_{d1} = r_1 I_{d1} + p\lambda_{d1} - w_k \lambda_{q1} \qquad (2)$$

$$V_{01} = r_1 I_{01} + p\lambda_{01} \qquad (3)$$

$$V_{qr} = r_r I_{qr} + p\lambda_{qr} - (w_k - w_r)\lambda_{dr} \qquad (4)$$

$$V_{dr} = r_r I_{dr} + p\lambda_{dr} - (w_k - w_r)\lambda_{qr} \qquad (5)$$

$$V_{0r} = r_r I_{0r} + p\lambda_{0r} \qquad (6)$$

$$V_{q2} = r_2 I_{q2} + p\lambda_{q2} + w\lambda_{d2} \qquad (7)$$

$$V_{d2} = r_2 I_{d2} + p\lambda_{d2} - w\lambda_{q2} \qquad (8)$$

$$V_{02} = r_2 I_{02} + p\lambda_{02} \qquad (9)$$

where ω_k is the speed of the reference frame,

and ω_r is the rotor speed.

5.2.1 Expressions for rotor and stator flux linkages

$$\lambda_{q1} = (L_{l1} - L'_{lm})I_{q1} + L'_{lm}(I_{q1} + I_{q2}) + L_m(I_{q1} + I_{q2} + I'_{qr}) \qquad (10)$$

$$\lambda_{d1} = (L_{l1} - L'_{lm})I_{d1} + L'_{lm}(I_{d1} + I_{d2}) + L_m(I_{d1} + I_{d2} + I'_{dr}) \qquad (11)$$

$$\lambda_{01} = L_{l1}I_{01} + L'_{lm}(I_{01} + I_{02}) \qquad (12)$$

$$\lambda_{q2} = (L_{l2} - L'_{lm})I_{q2} + L'_{lm}(I_{q1} + I_{q2}) + L_m(I_{q1} + I_{q2} + I'_{qr}) \qquad (13)$$

$$\lambda_{d2} = (L_{l2} - L'_{lm})I_{d2} + L'_{lm}(I_{d1} + I_{d2}) + L_m(I_{d1} + I_{d2} + I'_{dr}) \qquad (14)$$

$$\lambda_{02} = L_{l2}I_{02} + L'_{lm}(I_{01} + I_{02}) \qquad (15)$$

$$\lambda_{qr} = L'_{lr}I_{qr} + L_m(I_{q1} + I_{q2} + I'_{q2}) \qquad (16)$$

$$\lambda_{dr} = L'_{lr}I_{dr} + L_m(I_{d1} + I_{d2} + I'_{d2}) \qquad (17)$$

$$\lambda_{0r} = L'_{lr}I_{0r} \qquad (18)$$

5.2.2 Electromagnetic torque and mechanical model of motor

$$T_e = (\tfrac{3}{2}\tfrac{p}{2})\left[\lambda_{md}\left(I_{Q1} + I_{Q2}\right) - \lambda_{mq}\left(I_{d1} + I_{d2}\right)\right] \qquad (19)$$

$$J\frac{2}{P}\frac{dWr}{dt} = T_{em} - T_L \qquad (20)$$

5.2.3 Current expressions in terms of flux linkages

The equations that describe the electrical and mechanical behavior of the machines contain mixed variables (flux linkages and current). Above equations can be simplified by algebraic manipulations of equations (1)-(18). Thus, the currents when solved in terms of flux linkages are obtained as:

$$I_{d1} = \frac{1}{lx}\left[(L_{12}+L_{lm})\,\lambda_{d1} - L_{12}\lambda_{md} - L_{lm}\lambda_{d2} - L_{ldq}(\lambda_{q2}-\lambda_{q12})\right] \qquad (21)$$

$$I_{q1} = \frac{1}{lx}\left[(L_{12}+L_{lm})\,\lambda_{q1} - L_{12}\lambda_{mq} - L_{lm}\lambda_{q2} + L_{ldq}(\lambda_{d2}-\lambda_{d12})\right] \qquad (22)$$

$$I_{d2} = \frac{1}{lx}\left[(L_n+L_{lm})\,\lambda_{q2} - L_n\lambda_{md} - L_{lm}\lambda_{d1} + L_{ldq}(\lambda_{q1}-\lambda_{mq})\right] \qquad (23)$$

$$I_{q2} = \frac{1}{lx}\left[(L_n+L_{lm})\,\lambda_{q2} - L_n\lambda_{mq} - L_{lm}\lambda_{q1} + L_{ldq}(\lambda_{q1}-\lambda_{md})\right] \qquad (24)$$

$$I'_{qr} = \frac{\lambda_{qr}-\lambda_{mq}}{L'_{tr}} \qquad (25)$$

$$I'_{dr} = \frac{\lambda_{dr}-\lambda_{md}}{L'_{tr}} \qquad (26)$$

$$\lambda_{md} = L_D[\lambda_{d1}L12 + \lambda_{d2}L_{l1} - L_{idq}(\lambda_{q2} - \lambda_{q1})] \tag{27}$$

$$\lambda_{mq} = L_Q[\lambda_{q1}L12 + \lambda_{q2}L_{l1} + L_{idq}(\lambda_{d2} - \lambda_{d1})] \tag{28}$$

Where

$$L_D = [\frac{L_A}{L_m} + (L_{l1} + L_{l2})]^{-1} \tag{29}$$

$$L_A = L_{l1}L_{l2} + L_{lm}(L_{l1} + L_{l2}) \tag{30}$$

$$L_Q = [\frac{L_A}{L} + (L_{l1} + L_{l2})] \tag{31}$$

Substituting equations (21)-(28) into (1) – (8) and solving the equation in the rotor reference frame, (i.e. ω_k becomes ω_r) the integral form of the machine voltage and torque equations with flux linkage as state variables is given as:

$$\lambda_{d1} = \int[V_{d1} + \omega_r\lambda_{q1} - \frac{R_1}{L_\lambda}\{(L_{l2} + L_m)\lambda_{d1} - L_{l2}\lambda_{md} - L_m\lambda_{d2} - L_{idq}(\lambda_{q2} - \lambda_{mq})\}] \tag{32}$$

$$\lambda_{q1} = \int[V_{q1} + \omega_r\lambda_{d1} - \frac{R_1}{L_\lambda}\{(L_{l2} + L_m)\lambda_{q1} - L_{l2}\lambda_{mq} - L_{lm}\lambda_{q2} - L_{idq}(\lambda_{d2} - \lambda_{md})\}] \tag{33}$$

$$\lambda_{d2} = \int[V_{d2} + \omega_r\lambda_{q2} - \frac{R_1}{L_\lambda}\{(L_{l1} + L_m)\lambda_{l2} - L_{l1}\lambda_{md} - L_{lm}\lambda_{d1} + L_{idq}(\lambda_{q1} - \lambda_{mq})\}] \tag{34}$$

$$\lambda_{q2} = \int[V_{q2} + \omega_r\lambda_{d2} - \frac{R_{12}}{L_\lambda}\{(L_{l1} + L_{lm})\lambda_{q2} - L_{l1}\lambda_{mq} - L_{lm}\lambda_{q1} - L_{idq}(\lambda_{d1} - \lambda_{md})\}] \tag{35}$$

$$\lambda_{dr} = \int\frac{r'_r}{L'_r}(\lambda_{dr} - \lambda_{md}) \tag{36}$$

$$\lambda'_{dr} = \int\frac{r'_r}{L'_r}(\lambda_{qr} - \lambda_{mq}) \tag{37}$$

$$\omega_r = \frac{P}{2J}\int[T_{em} - T_L]dt \tag{38}$$
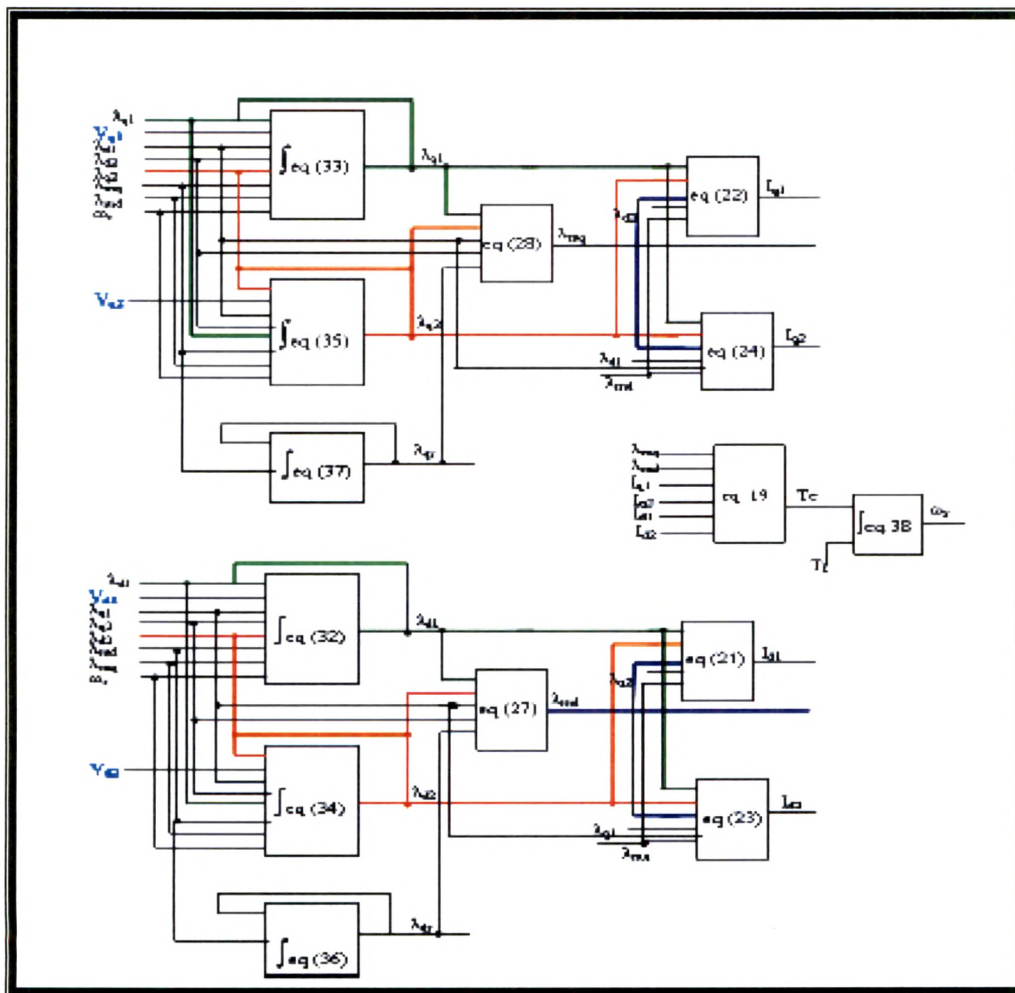
$$\theta_r = \int\omega_r\,dt \tag{39}$$

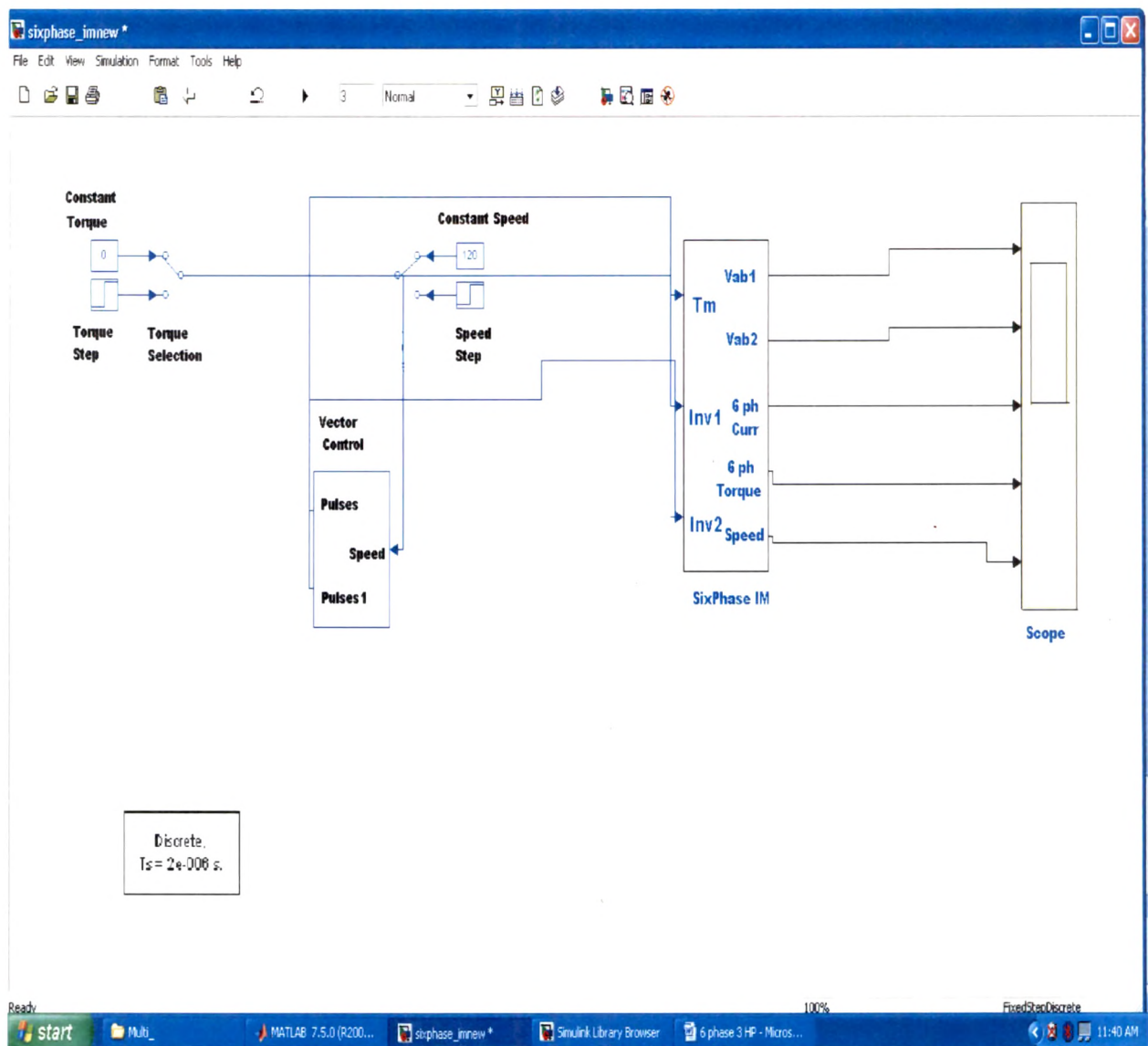Figure 5.1 Flow diagram of the electrical part for the simulation of the six-phase

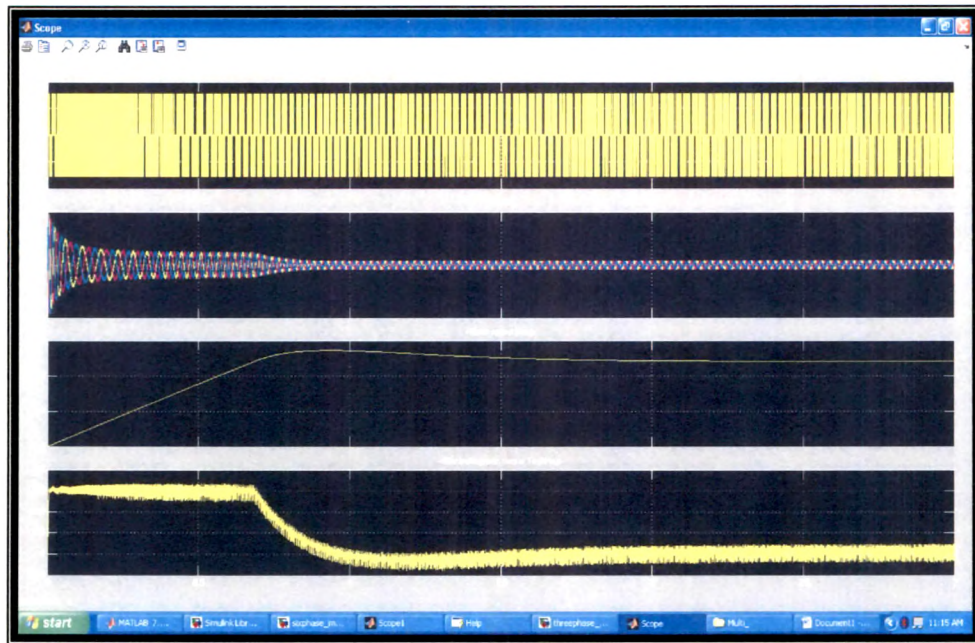Figure 5.2 Simulated circuit of six phase 3 HP IM vector control

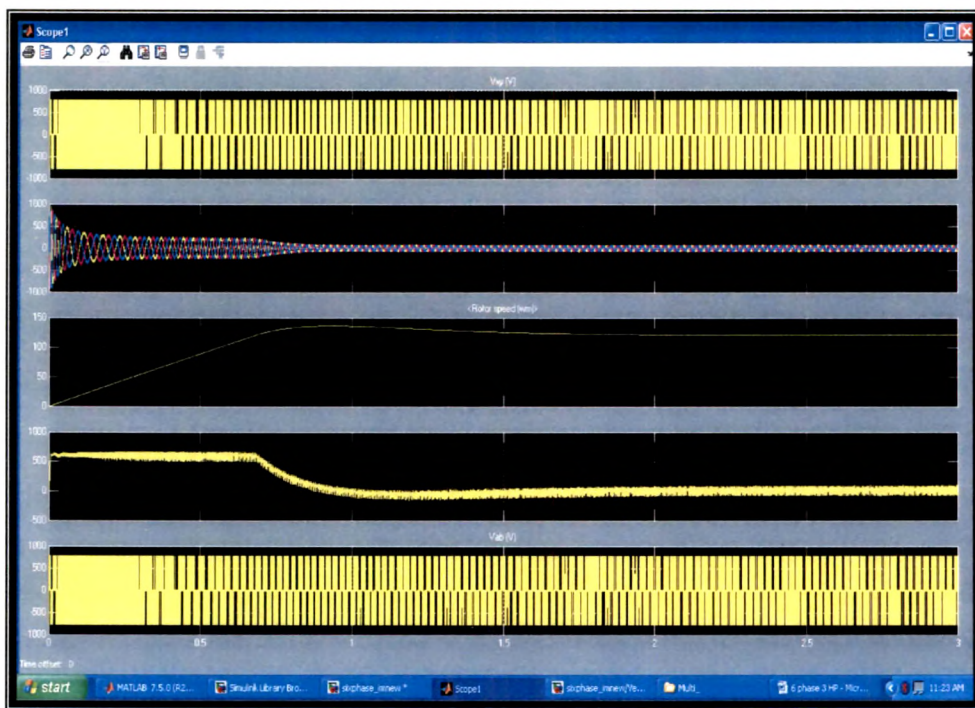Figure 5.3 Simulation results of three phase, 3HP, 200V, 50 Hz IM

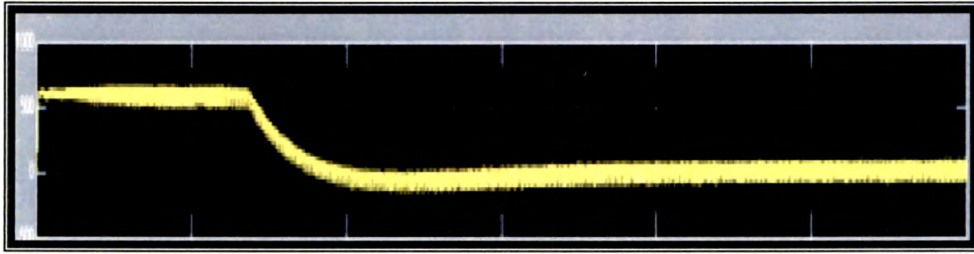Figure 5.4 Simulation results of six phase,3HP,200V, 50Hz IM
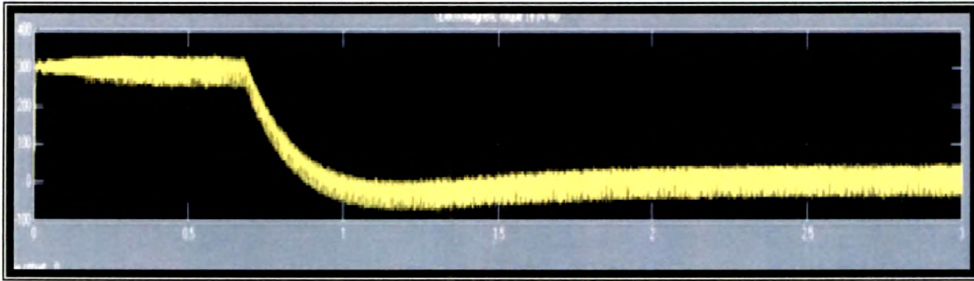
Figure 5.5 Six phase IM torque

Figure 5.6 Three phase IM torque

5.3 DISCUSSION:

Rectified voltage is fed to the two voltage source inverters and then output of two inverters, is given to six phase induction motor. Six phase induction motor is modeled using above equations.

The figures 5.3 and 5.4 show the Simulation output of six phase and three phase induction motors respectively.

From the waveforms of torque of six phase and three phase induction motor (figures 5.5 and 5.6) it is clear that the starting torque of six phase induction motor is about 550 N-m for say from 0 to 0.8 sec., the speed is increasing from zero to 140 rps approximately. When rated speed is reached, the torque reduces

to zero as seen from the waveform. Similarly the starting torque of three phase motor is about 350 N-m for 0 to 0.8 sec, when rated speed is reached the torque reduces to zero. Thus the six phase motor torque is almost 1.6 times more than three phase induction motor torque. Thus higher starting torque is obtained as compared to three phase motor. The rating of three phase and six phase motor are same.

Also figure 5.7 show the output of six phase induction motor for step change in speed and torque. It shows the waveform of V_{ABC} (Voltage of set ABC), Six phase current, Speed, Torque and V_{XYZ} (Voltage of set XYZ) respectively. With the step change of speed, at start, i.e at nearly zero speed the torque is highest and when rated speed is reached the torque reduces to zero. When again speed reduces to zero, torque increases.

It is clear from the output waveform that the torque of six phase IM is about 1.6 times more than that of three phase motor of same size. Also the torque pulsations are reduced in six phase IM due to elimination of $6n \pm 1$ harmonics.
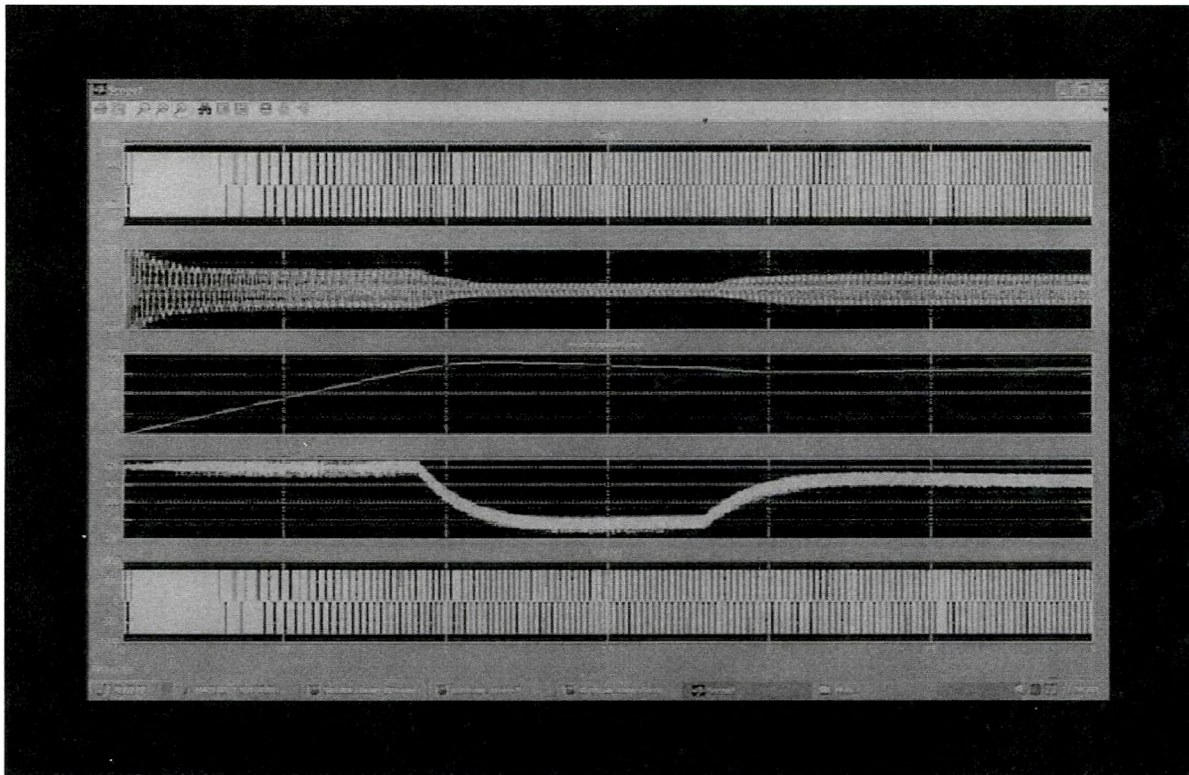
Figure 5.7 Six phase, 3 hp IM output waveform for change in step of torque

5.4   CONCLUSION:

In this chapter mathematical modeling and Matlab simulation of prototype six phase induction motor is discussed. Before actual control of six phase induction motor, which needs two separate three phase SVPWM inverters, software simulation helps in deciding parameters. Thus 1.6 times more torque of six phase induction motor as compared to equivalent three phase induction motor is obtained. Also torque pulsations are reduced in case of six phases.

Harmonics are reduced because all the harmonics of the order (6n$\pm$1) where n = 1, 3, 5, 7------- get cancelled because of 30 degrees phase displacement. Reduced torque pulsations are observed because of harmonic reduction. (Figure 5.7)