CHAPTER 5
RESULTS AND DISCUSSION

5.1 GENERAL

In this chapter, analysis of the performance of induction motor drive controlled using Indirect Vector control method is carried out and various performance checks are observed under different operating condition. The performance of IVCIM has been analysed using various intelligent controllers and compared with conventional PI controller.

5.2 SIMULATION RESULTS OF INDIRECT VECTOR CONTROL

An indirect vector control of induction motor was implemented through simulation and hardware and realised on a 3 HP, 415 volt, 50 Hz, 1440 rpm motor.

Induction motor simulation was tested under various operating conditions. These operating conditions were chosen to make sure that drive can work satisfactory under worst working conditions. The drive was tested for following conditions:

A. Machine was started then gradually load was applied.
B. Machine was started then reference speed was changed.
C. Machine was started and then both load and reference speed was changed in running conditions.
D. Machine was started as a motor under no load and then condition of reverse braking was checked.

The variation of stator current, stator voltage, reference and actual speed of motor along with variation of electromagnetic torque is discussed in upcoming sections. In each case, the load torque and speed is varied independently and it is observed that the through indirect vector control of induction motor an independent variation of speed and torque is achieved.

5.2.1 Performance analysis with Proportional Integral Controller (PI)

The dynamic behavior of Indirect Vector controlled Induction motor, was studied initially through a conventional PI speed controller, where the actual speed of the motor was sensed through a techogenerator and the output voltage of techogenerator was sensed through a voltage sensor. For the speed variation in the range of 1200-1440 rpm, the voltage sensor provides a voltage in the range of 68-78 V respectively. The actual speed is compared with voltage corresponding to reference speed and the difference is processed by PI controller.

5.2.1.1 Performance of IVCIM under starting and sudden switching of loads

In Simulation, initially the motor is run at no load up to t=0.4 sec. After this a load of 4 N-m is applied on the motor. The motor speed is set at a reference speed of 150 rad/sec with a rated rms voltage of 230V.

It is observed that the speed transition from zero to rated speed takes place in just over 0.05 sec. The starting current is initially higher and eventually reduces to steady state at 3.5 Amps. Again at time t= 0.6 sec, load was increased to 6 N-m. On application of load of 6 N-m, there is a momentary dip in the speed which is regulated by PI controller in 0.1 second and finally motor attains speed of 150 rad/sec and current eventually achieves steady state value of 6 Amp.

Figure 5.1 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.

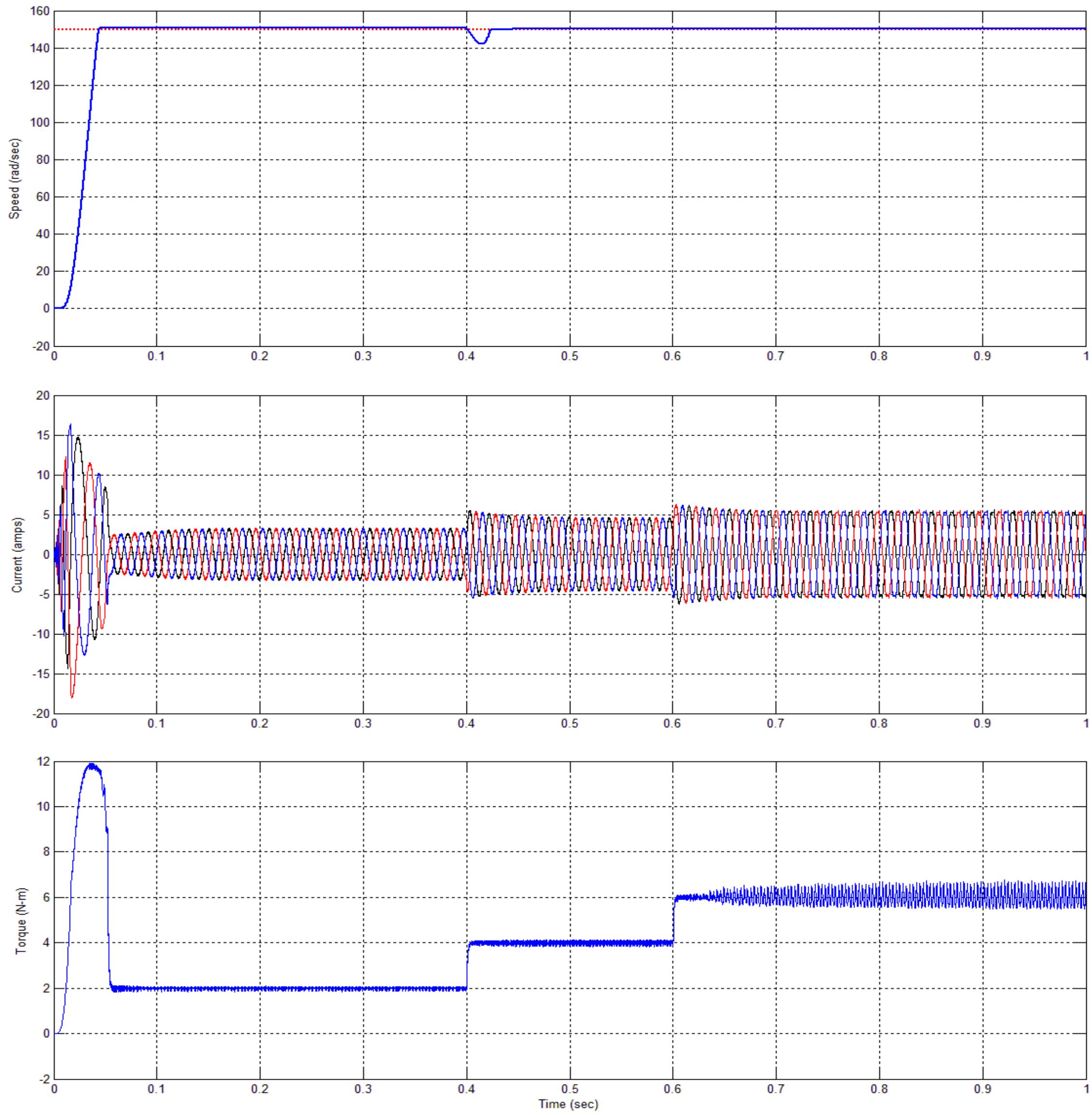


Figure 5.1 Dynamic performance of IVCIM under variable load condition

5.2.1.2 Performance of IVCIM under sudden change of speed

In Simulation, initially the motor is run at a load of 4 N-m with reference speed of 100 radian/sec up to t=0.4 sec. After this, reference speed is changed to 125 radian/sec and 150 radian/sec at time t=0.5 sec and t=0.6 sec.

It is observed that speed transition from zero to 100 takes place in 0.05 seconds and speed transition from 100 to 125 takes place in 0.0076 seconds. During the speed transitions, stator line currents have high value which eventually reduces to steady state current of 4.9 Amps. The transition in developed electromagnetic torque is observed during speed transitions.

Figure 5.2 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.

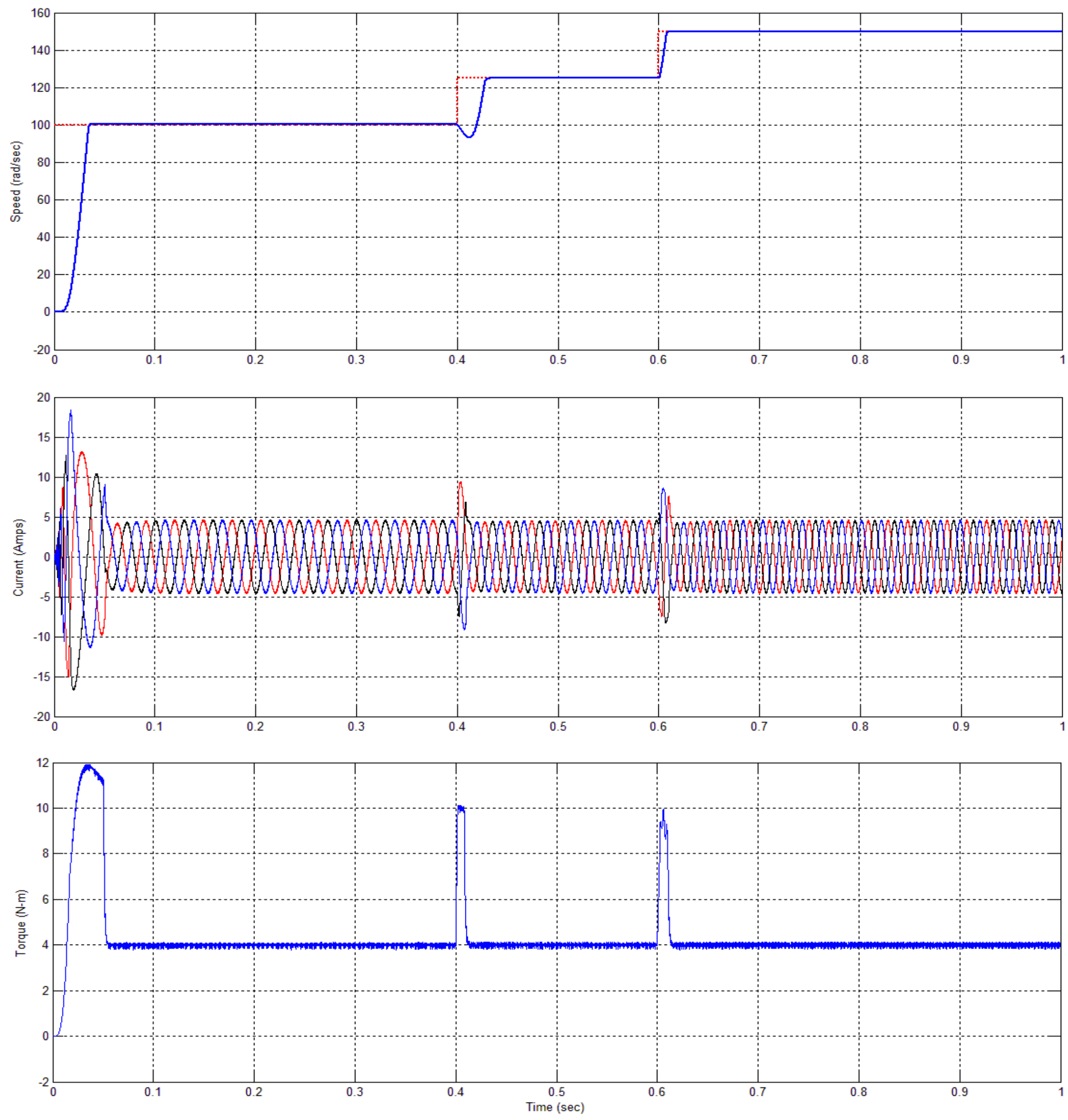


Figure 5.2 Dynamic performance of IVCIM under variable speed condition

5.2.1.3 Performance of IVCIM under sudden load change and change in reference speed

In Simulation, initially the motor is run at a load of 2 N-m with reference speed of 100 radian/sec up to t=0.4 sec. After this, reference speed is changed to 125 radian/sec and 150 radian/sec at time t=0.5 sec and t=0.6 sec. A load of 5 N-m is applied at t=0.5 sec.

It is observed that speed transition from zero to 100 rad/sec takes 0.045 seconds and speed transition from 100 to 125 takes place in 0.01 second respectively.

On application of load of 5 N-m, there is a momentary dip in speed which is recovered in just 0.1 seconds and the motor once again settles at the rated speed of 125 rad/sec with offset 2 rad/sec.

The transitions in currents are more during first speed transition and current eventually attains steady state value of 5.08 Amps. Figure 5.3 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.

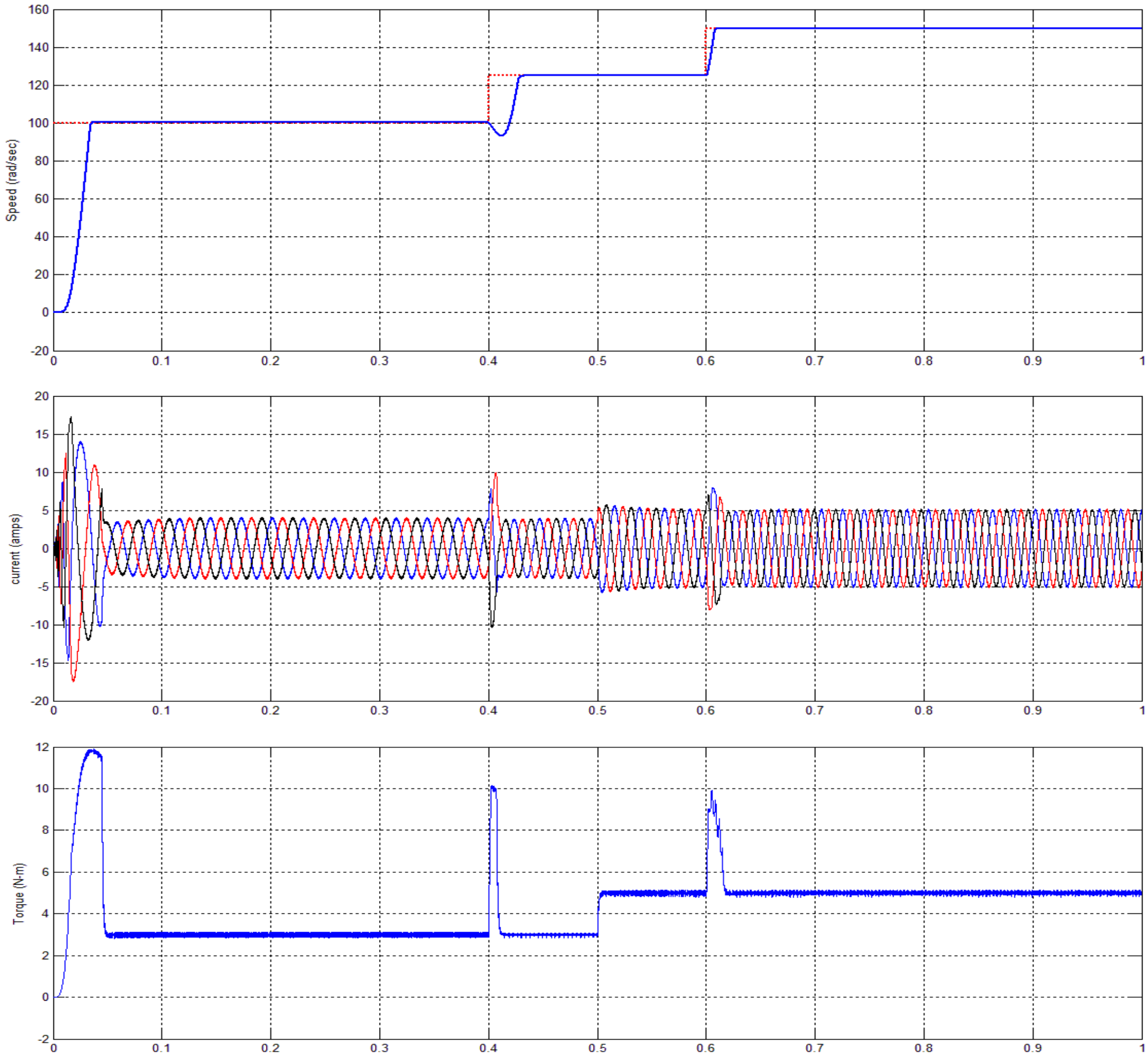


Figure 5.3 Dynamic performance of IVCIM under variable speed & variable load condition

5.2.1.4 Performance of IVCIM under sudden reversal of speed

In this condition, machine was started at 100 rad/sec and reference speed was changed without changing the load on the machine. Under this operating condition, reference speed was changed to -100 rad/sec from 125 rad/sec at t=0.6 sec.

It is observed that the speed transition from zero to 100 radian/seconds take place in 0.49 seconds and speed transition from 125 rad/sec to -125 rad/sec take place in 0.38 seconds. Fluctuations in developed electromagnetic torque are observed during speed changes which are mitigated in very less time by PI controller.

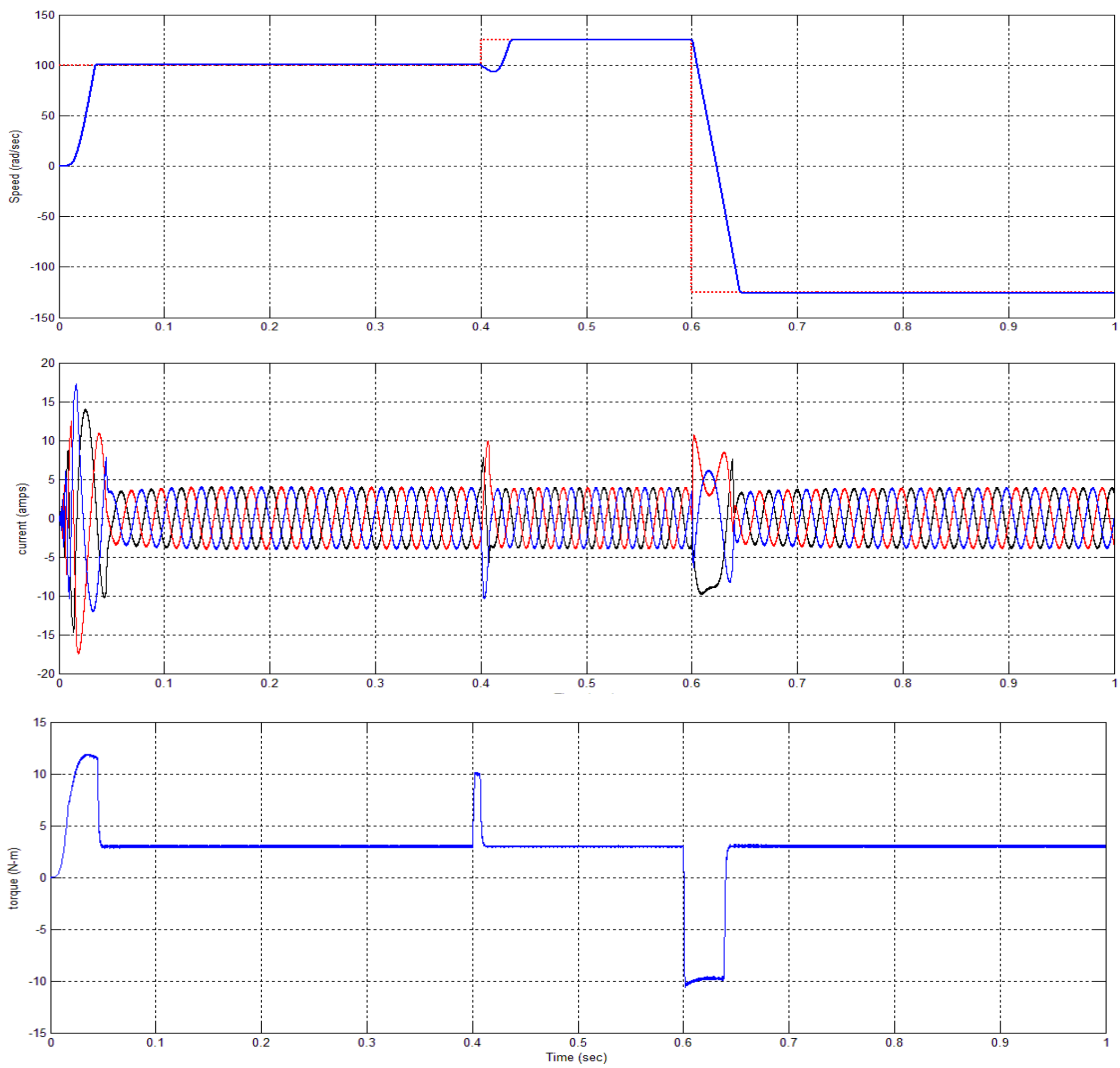


Figure 5.4 Dynamic performance of IVCIM under condition of reverse braking

5.2.2 Performance analysis with Fuzzy Logic Controller (FLC)

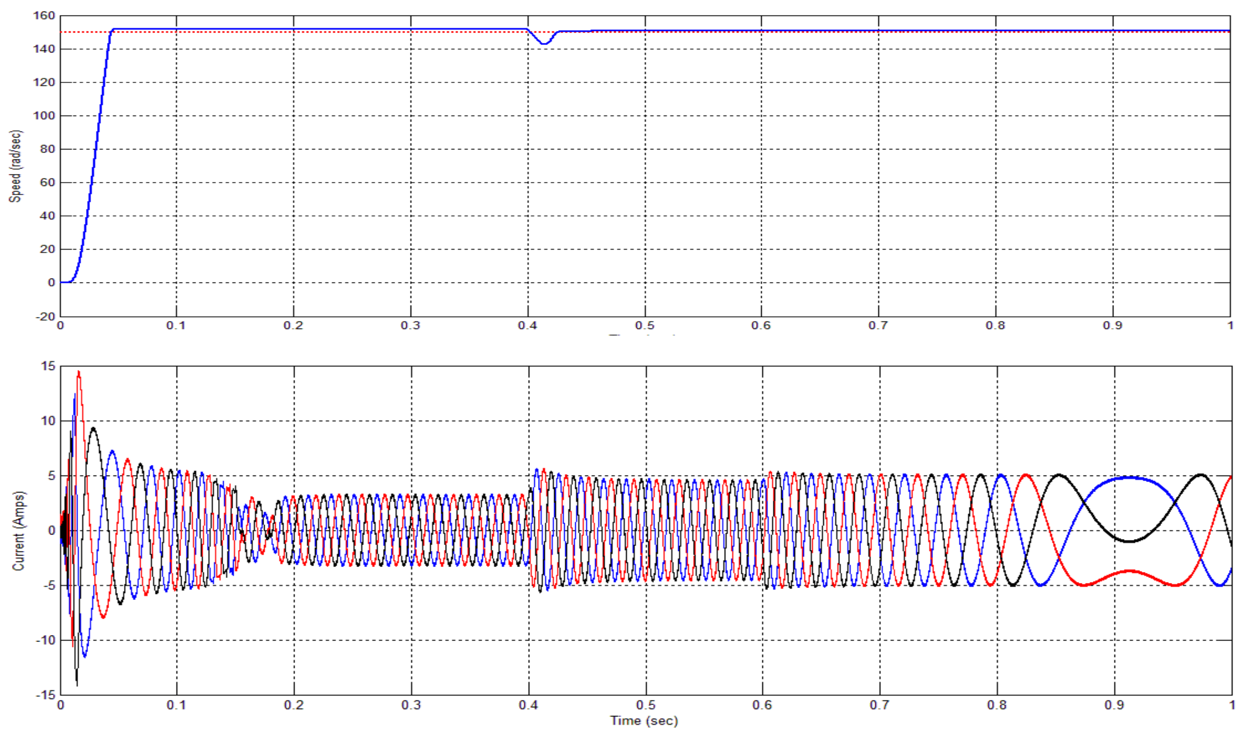
The dynamic performance of IVCIM is analyzed using a Fuzzy Logic Controller also. The FLC speed controller is developed using rule base discussed in the previous chapter. The operating conditions are kept the same as that for the simulation using PI controller to analyze the performance of the two control schemes under same operating conditions.

5.2.2.1 Performance of IVCIM under starting and sudden switching of loads

In Simulation, initially the motor is run at no load up to t=0.4 sec. After this a load of 4 N-m is applied on the motor. The motor speed is set at a reference speed of 150 rad/sec with a rated rms voltage of 230V.

It is observed that the speed transition from zero to rated speed takes place in 0.2 sec. The starting current is initially higher and eventually reduces to steady state at 3.7 Amps. Again at time t= 0.6 sec, load was increased to 6 N-m. On application of load of 6 N-m, there is a momentary dip in the speed which is regulated by PI controller in 0.15 second and finally motor attains speed of 150 rad/sec and current eventually achieves steady state value of 5.8 Amp.

Figure 5.5 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.



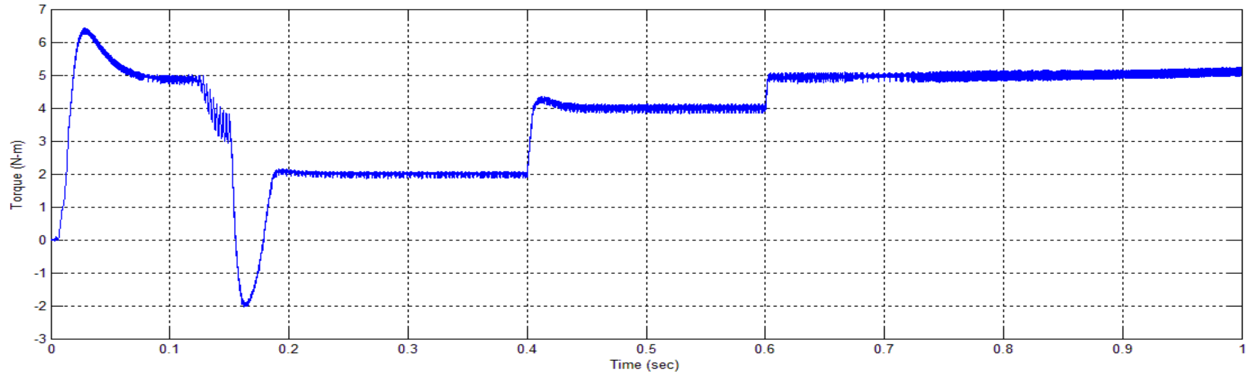


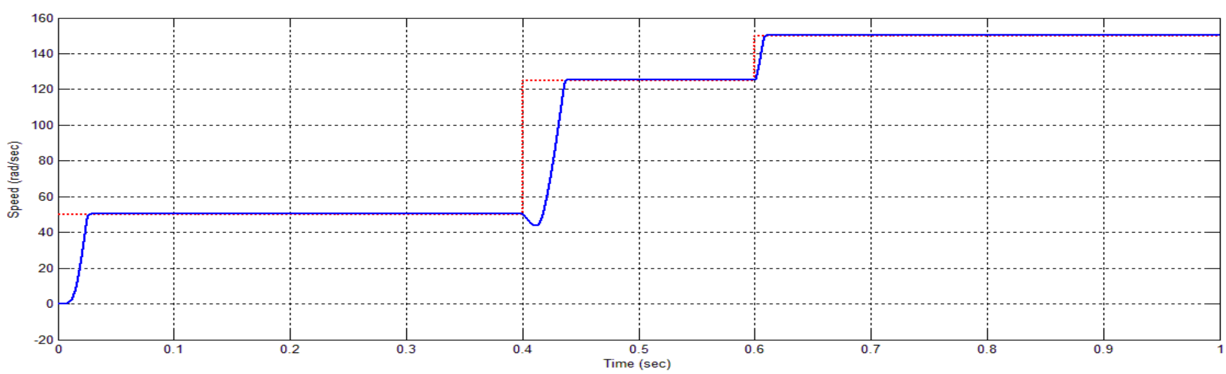
Figure 5.5 Dynamic performance of IVCIM under condition of variable load

5.2.2.2 Performance of IVCIM under sudden change of speed

In Simulation, initially the motor is run at a load of 4 N-m with reference speed of 100 rad/sec up to t=0.4 sec. After this, reference speed is changed to 125 radian/sec and 150 radian/sec at time t=0.5 sec and t=0.6 sec.

It is observed that speed transition from zero to 100 takes place in 0.03 seconds and speed transition from 100 to 125 takes place in 0.015 seconds. During the speed transitions, stator line currents have high value which eventually reduces to steady state current of 4.9 Amps. The transition in developed electromagnetic torque is observed during speed transitions.

Figure 5.6 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.



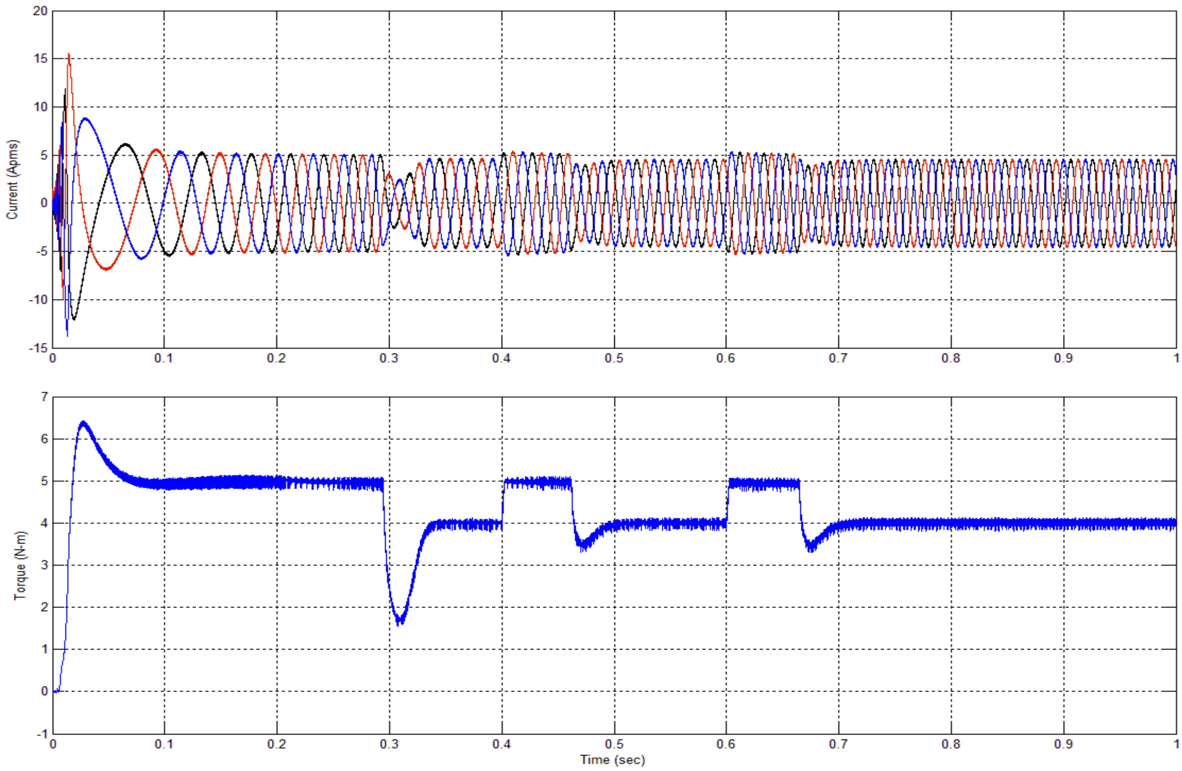


Figure 5.6 Dynamic performance of IVCIM under condition of variable speed condition

5.2.2.3 Performance of IVCIM under sudden load change and change in reference speed

In Simulation, initially the motor is run at a load of 2 N-m with reference speed of 100 radian/sec up to t=0.4 sec. After this, reference speed is changed to 125 radian/sec and 150 radian/sec at time t=0.5 sec and t=0.6 sec. A load of 5 N-m is applied at t=0.5 sec.

It is observed that speed transition from zero to 100 rad/sec takes 0.15 seconds and speed transition from 100 to 125 takes place in 0.09 second respectively.

On application of load of 5 N-m, there is a momentary dip in speed which is recovered in just 0.02 seconds and the motor once again settles at the rated speed of 125 rad/sec with offset 0.6 rad/sec.

The transitions in currents are more during first speed transition and current eventually attains steady state value of 4.9 Amps. Figure 5.7 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.

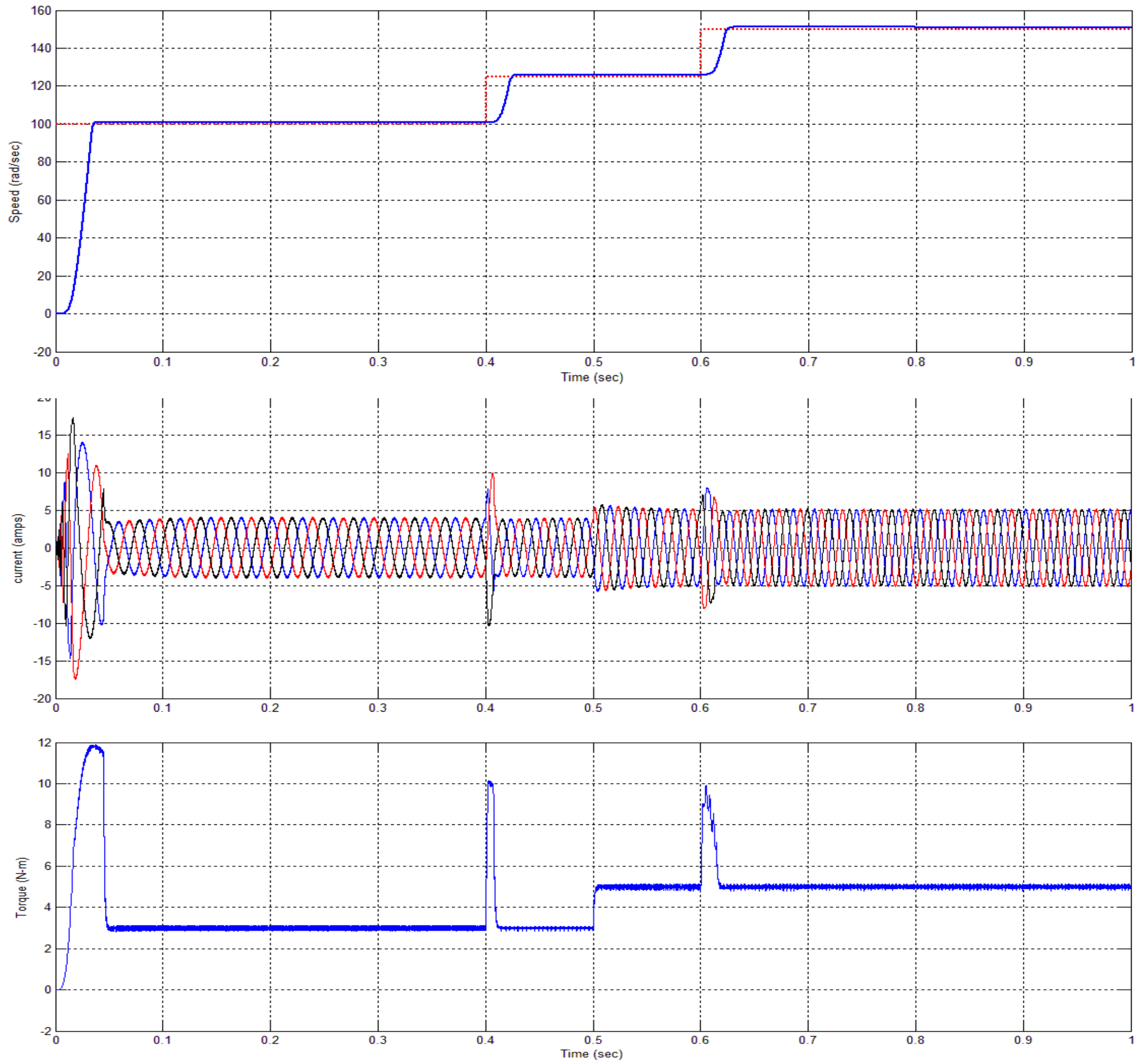


Figure 5.7 Dynamic performance of IVCIM under condition of variable speed and load

5.2.2.4 Performance of IVCIM under sudden reversal of speed

In this condition, machine was started at 100 rad/sec and reference speed was changed without changing the load on the machine. Under this operating condition, reference speed was changed to -100 rad/sec from 125 rad/sec at t=0.6 sec.

It is observed that the speed transition from zero to 100 radian/seconds take place in 0.05 seconds and speed transition from 100 rad/sec to -100 rad/sec take place in 0.038 seconds. Fluctuations in developed electromagnetic torque are observed during speed changes which are mitigated in very less time by FLC controller. Figure 5.8 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions

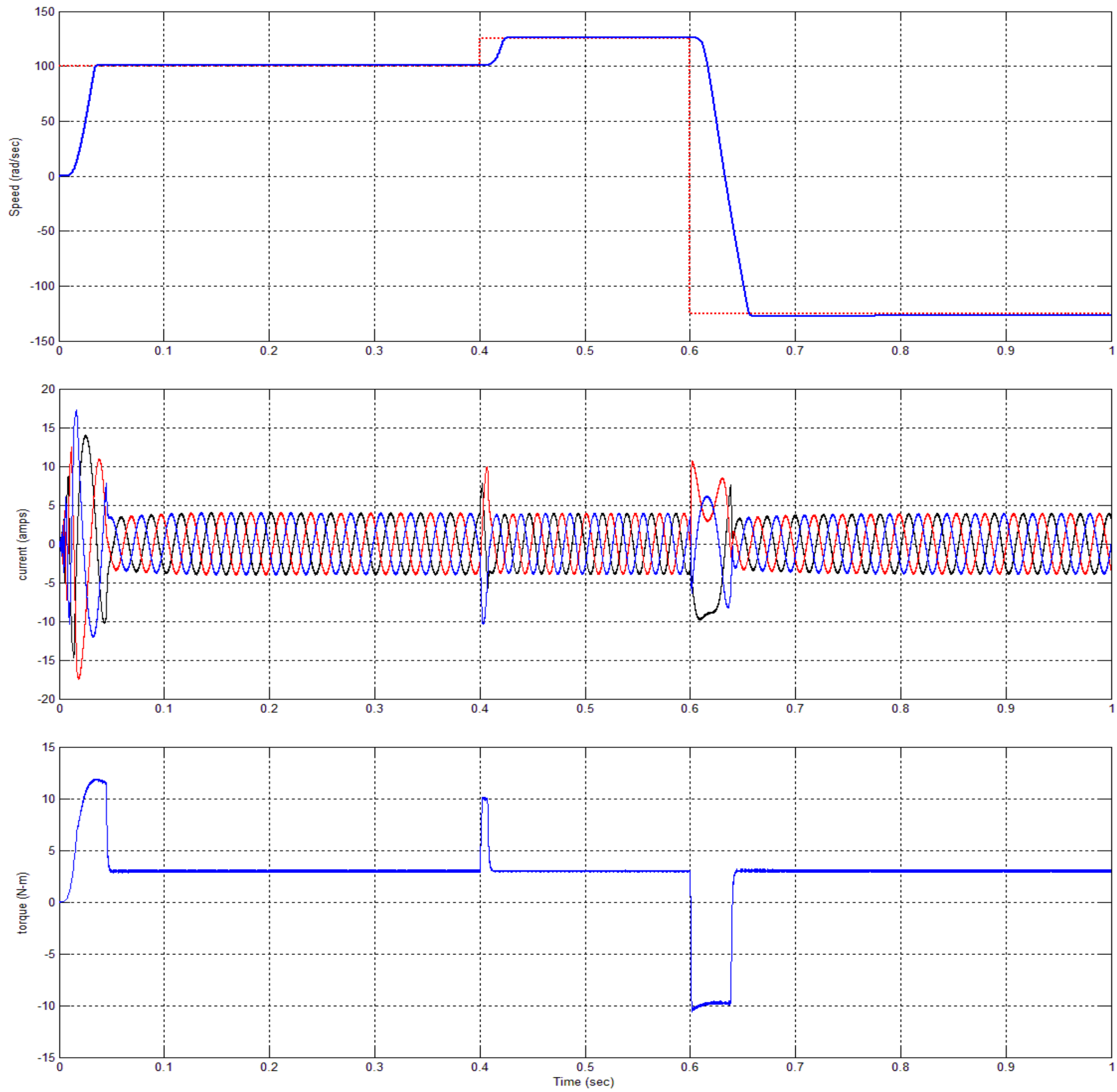


Figure 5.8 Dynamic performance of IVCIM under condition of reverse braking

5.2.3 Performance analysis with ANFIS Controller

The performance of Induction motor drive with indirect vector control implemented using ANFIS controller was analysed. The ANFIS controller was trained using the data obtained from conventional PI controller The operating conditions are kept the same as that for the simulation using PI controller to analyze the performance of the two control schemes under same operating conditions.

5.2.3.1 Performance of IVCIM under starting and sudden switching of loads

In Simulation, initially the motor is run at no load up to t=0.4 sec. After this a load of 4 N-m is applied on the motor. The motor speed is set at a reference speed of 150 rad/sec with a rated rms voltage of 230V.

It is observed that the speed transition from zero to rated speed takes place in just over 0.16 sec. The starting current is initially higher and eventually reduces to steady state at 3.57 Amps. Again at time t= 0.6 sec, load was increased to 6 N-m. On application of load of 6 N-m, there is a momentary dip in the speed which is regulated by PI controller in 0.015 second and finally motor attains speed of 150 rad/sec and current eventually achieves steady state value of 6.1 Amp.

Figure 5.9 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.

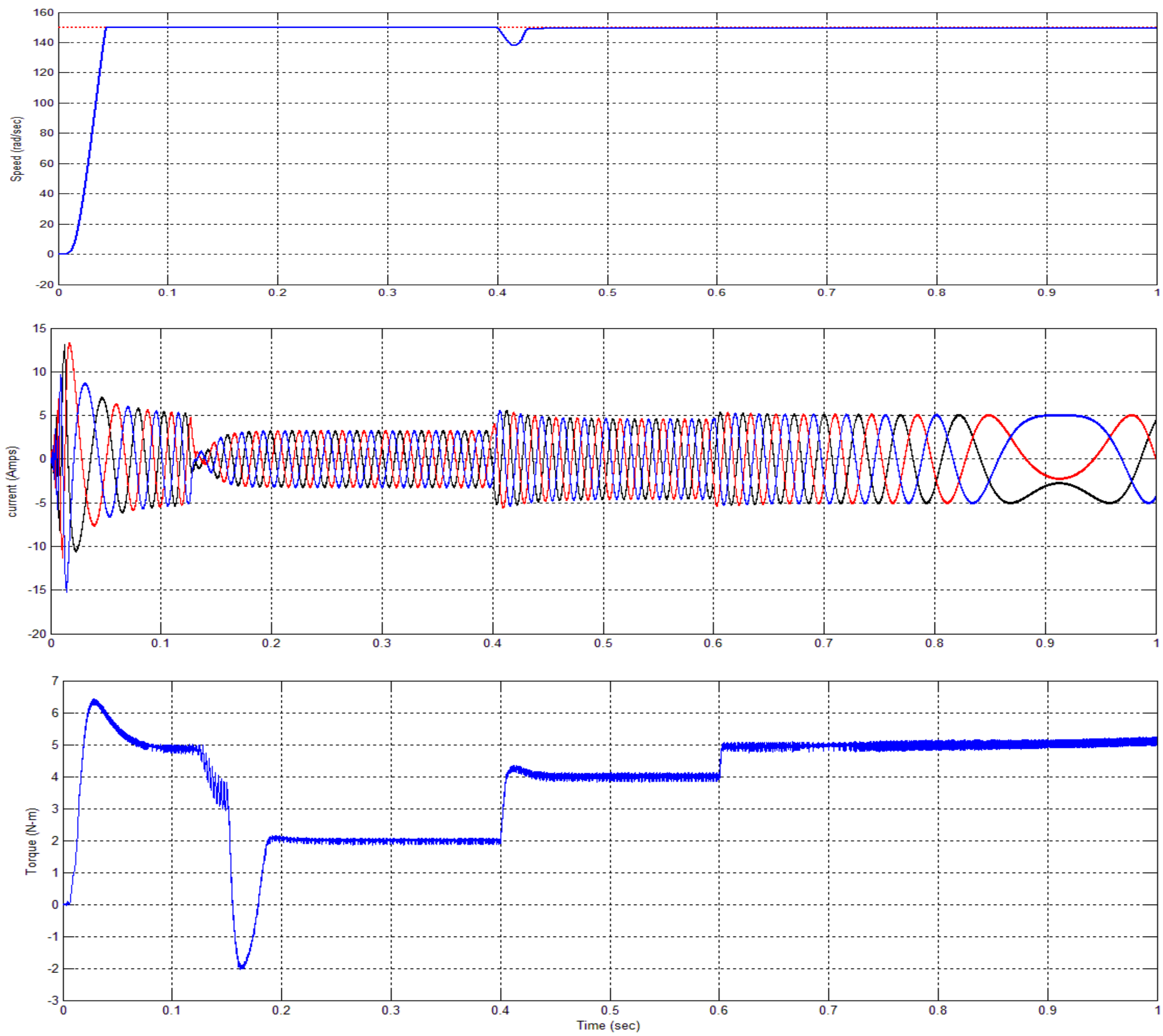


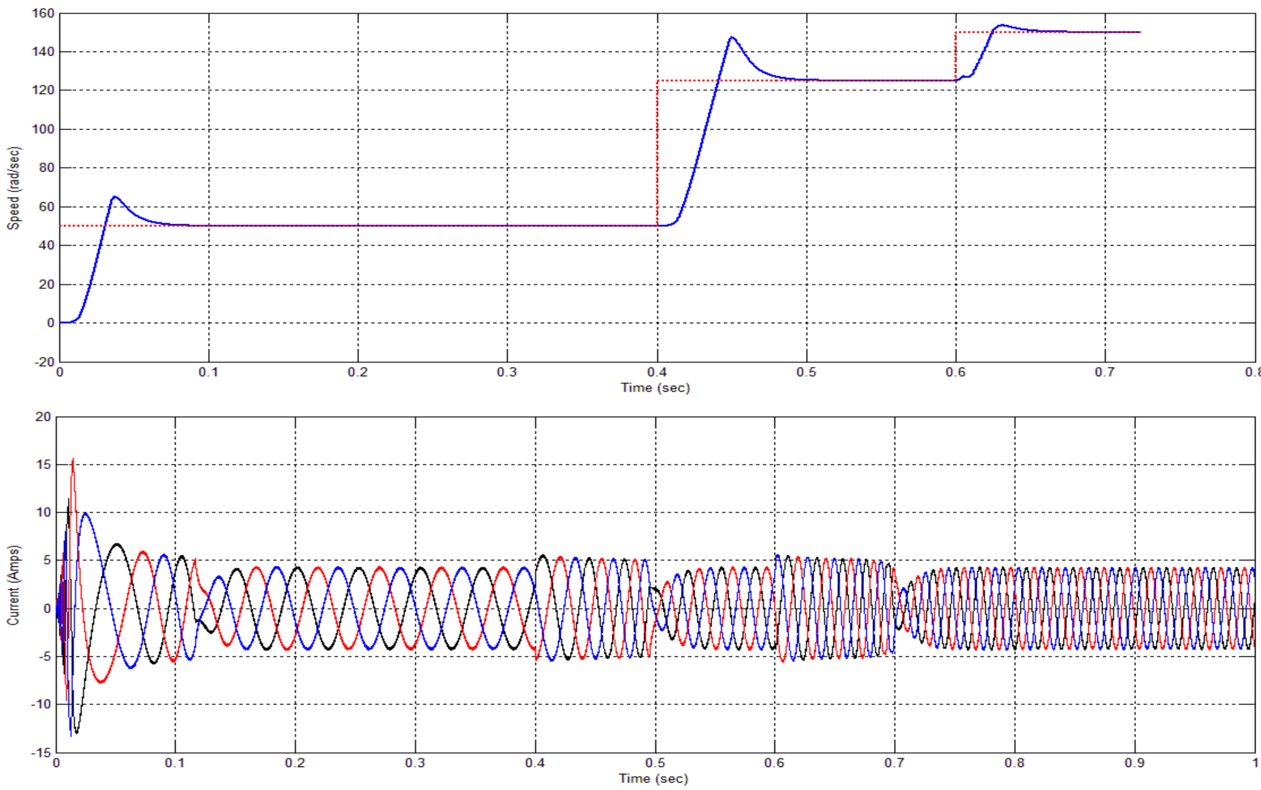
Figure 5.9 Dynamic performance of IVCIM under variable load

5.2.3.2 Performance of IVCIM under sudden change of speed

In Simulation, initially the motor is run at a load of 3 N-m with reference speed of 50 rad/sec up to t=0.4 sec. After this, reference speed is changed to 100 radian/sec and 125 radian/sec at time t=0.4 sec and t=0.6 sec.

It is observed that speed transition from zero to 100 takes place in 0.13 seconds and speed transition from 100 to 125 takes place in 0.14 seconds. During the speed transitions, stator line currents have high value which eventually reduces to steady state current of 4.85 Amps. The transition in developed electromagnetic torque is observed during speed transitions.

Figure 5.10 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.



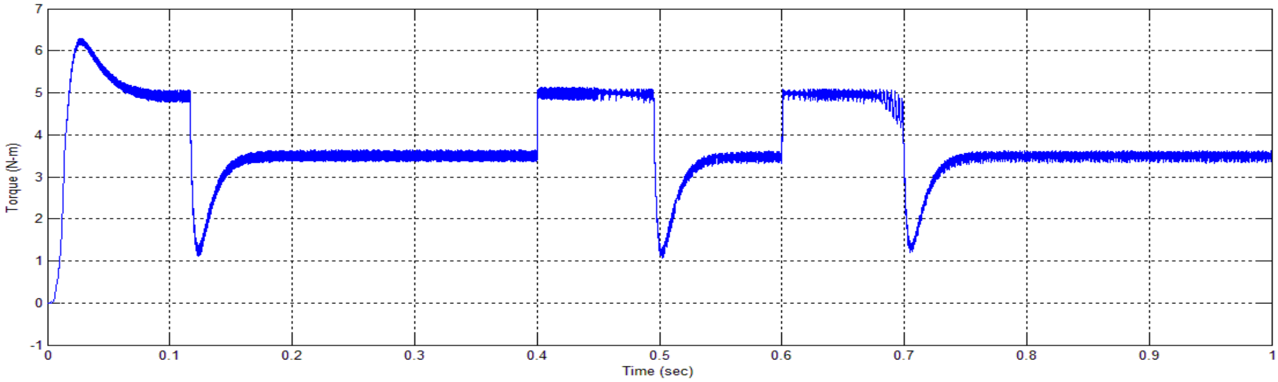


Figure 5.10 Dynamic performance of IVCIM under variable load

5.2.3.3 Performance of IVCIM under sudden load change and change in reference speed

In Simulation, initially the motor is run at a load of 3.5 N-m with reference speed of 50 radian/sec up to t=0.4 sec. After this, reference speed is changed to 100 radian/sec and 150 radian/sec at time t=0.5 sec and t=0.6 sec. A load of 5 N-m is applied at t=0.5 sec.

It is observed that speed transition from zero to 50 rad/sec takes 0.1 seconds and speed transition from 50 to 100 takes place in 0.048 second respectively.

On application of load of 5 N-m, there is a momentary dip in speed which is recovered in just 0.02 seconds and the motor once again settles at the rated speed of 150 rad/sec with offset 0.6 rad/sec.

The transitions in currents are more during first speed transition and current eventually attains steady state value of 5.05 Amps. Figure 5.11 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions.

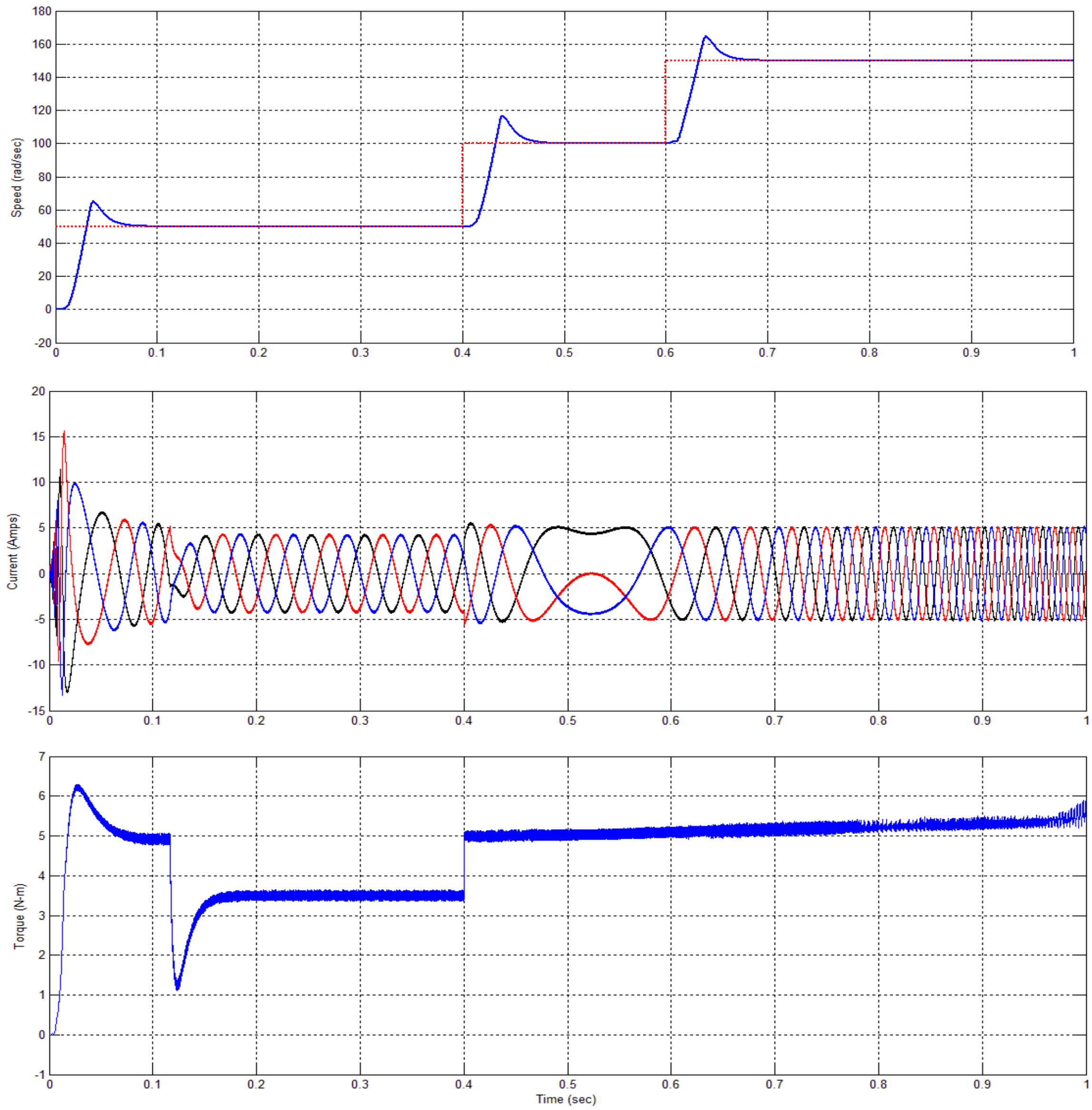


Figure 5.11 Dynamic performance of IVCIM under variable speed and load

5.2.3.4 Performance of IVCIM under sudden reversal of speed

In this condition, machine was started at 50 rad/sec and reference speed was changed without changing the load on the machine. Under this operating condition, reference speed was changed to -100 rad/sec from 100 rad/sec at t=0.6 sec.

It is observed that the speed transition from zero to 50 radian/seconds take place in 0.16 seconds and speed transition from 100 rad/sec to -100 rad/sec take place in 0.182 seconds. Fluctuations in developed electromagnetic torque are observed during speed changes which are mitigated in very less time by ANFIS controller. Figure 5.12 shows the variation of the speed, line current (i_{abc}) and electromagnetic torque developed by the motor for above operating conditions

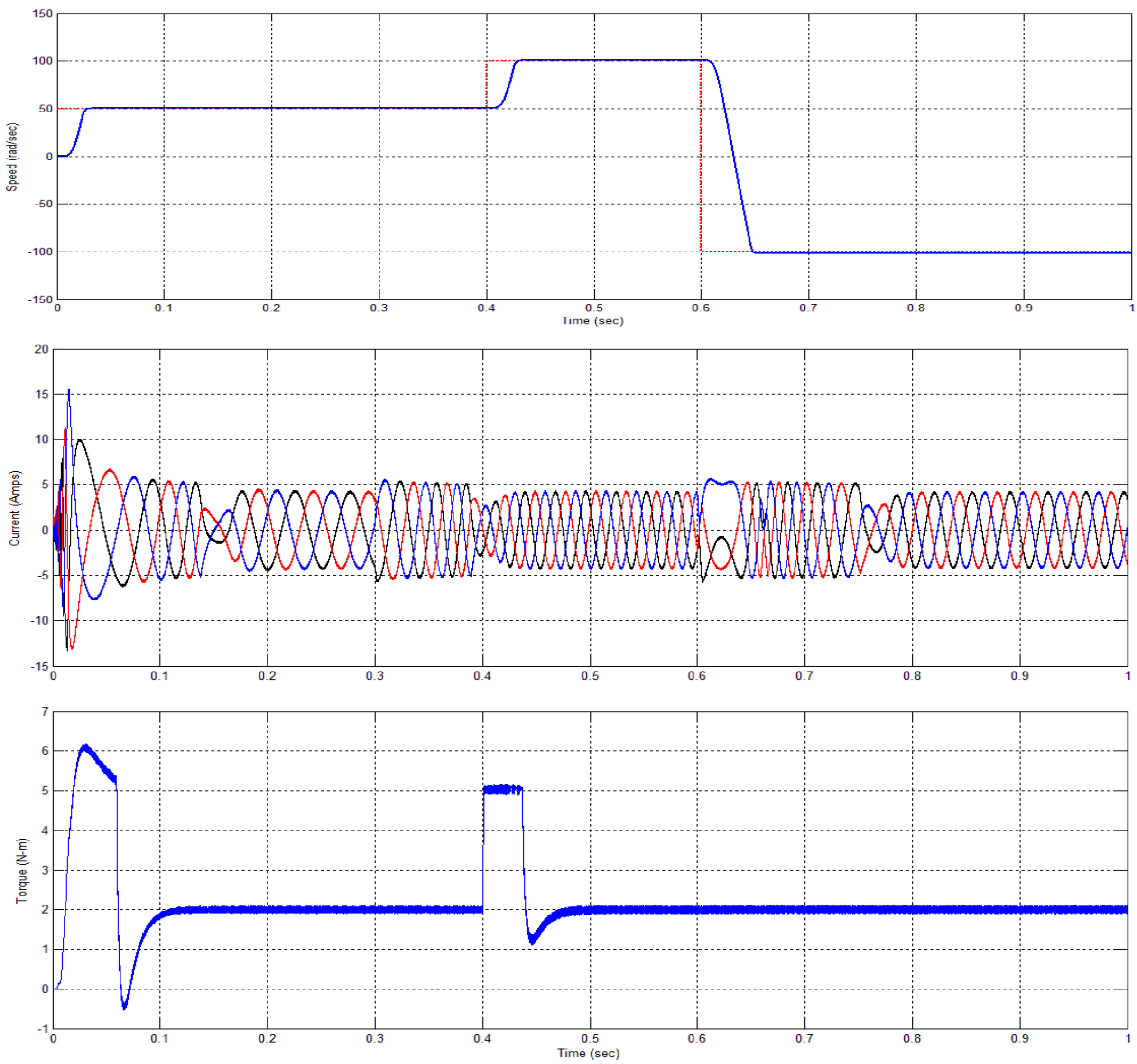


Figure 5.12 Dynamic performance of IVCIM under reverse braking condition

5.3 Hardware Results of Indirect Vector Control of Induction Motor Drive with PI controller

A complete hardware setup for the 3 HP, 230 V, 1440 rpm Induction motor operated with indirect vector control is implemented and its operation with PI is described to validate the results shown through simulation study. The experimental is already described in the previous chapter.

5.3.1 Performance of IVCIM using PI controller under condition of variable load

Initially the Induction motor is made to run at no load. The motor is set to a rated speed of 150 rad/sec. At t= 10 sec, the load was increased to 7 N-m. On applying the load, there was momentary dip in the motor speed but PI controller regulates the speed of the motor to 150 rad/sec within 2 seconds. The profile of the stator current (i_a), motor speed (ω_r) and electromagnetic torque (T_e) is shown in figure 5.13.

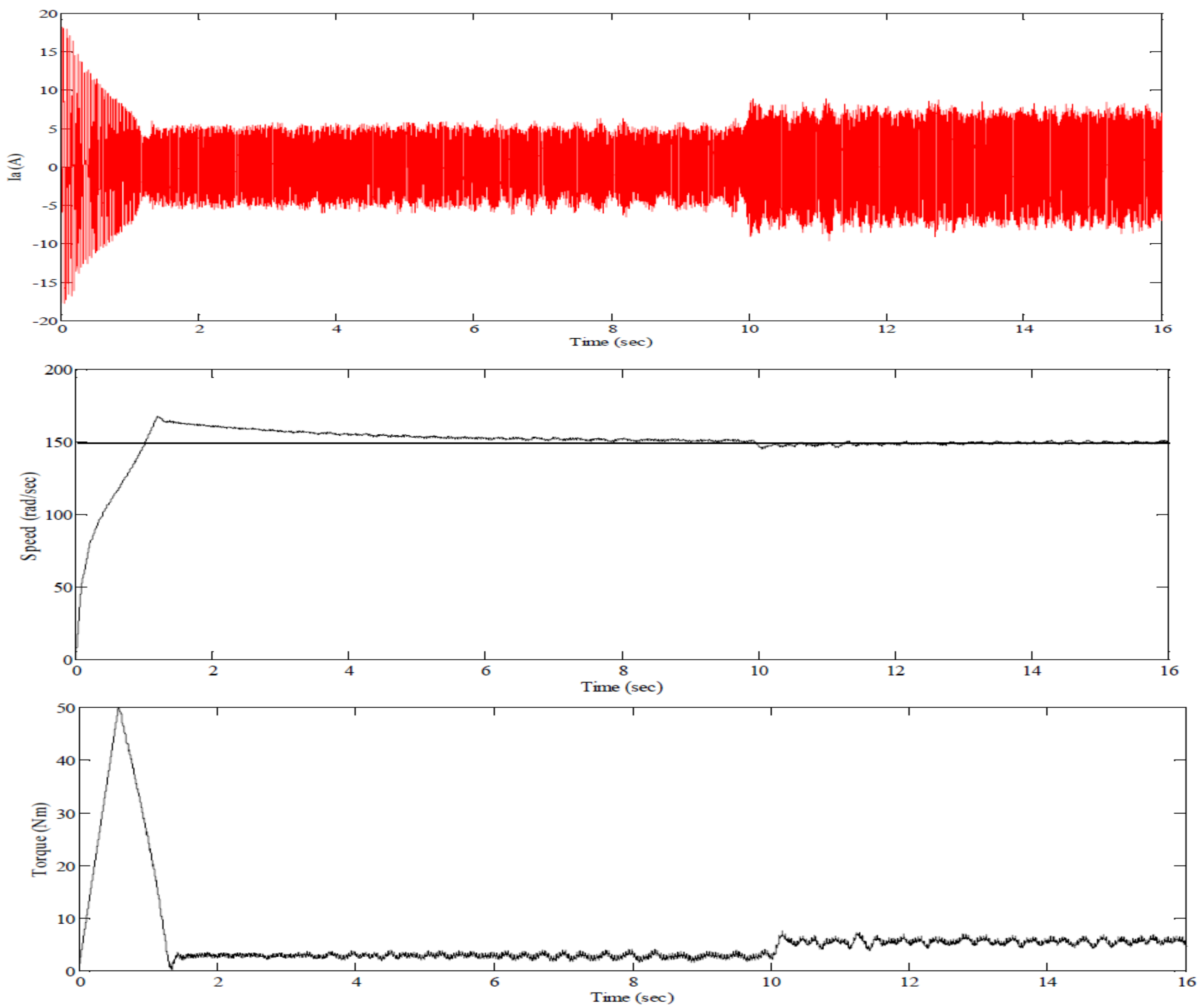


Figure 5.13 Dynamic performance of IVCIM under variable load condition

5.3.2 Performance of IVCIM using PI controller under condition reverse braking

Initially motor was made to run in forward motoring mode and then at t= 6.2 secs, drive was made to run under reverse braking condition with reference speed of 100 radian/ sec. And again at t=14 sec, motor was brought to forward motoring mode with reference speed of 100 radian/sec. The profile of the stator current (i_a), motor speed (ω_r) and electromagnetic torque (T_e) is shown in figure 6.14.

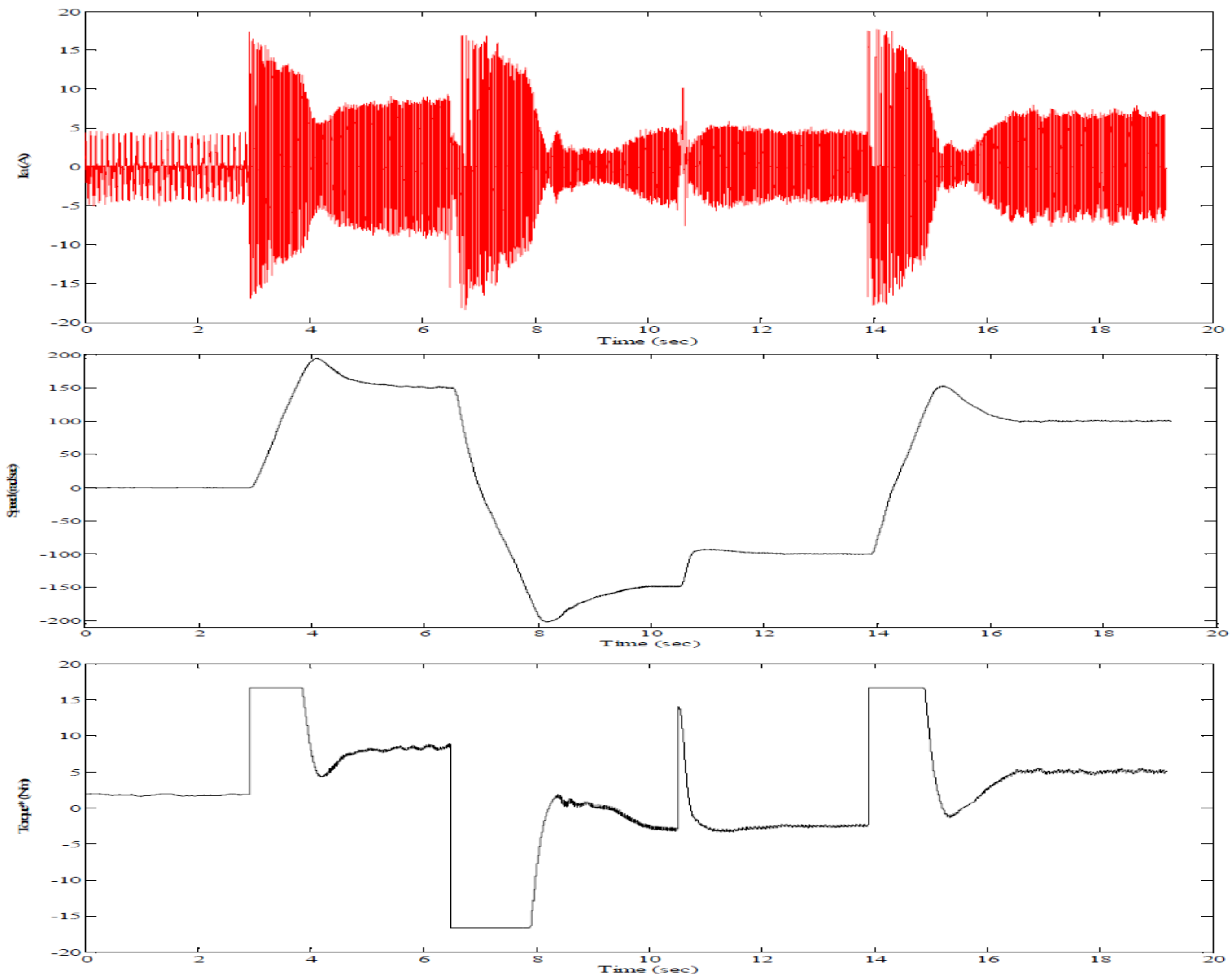


Figure 5.14 Dynamic performance of IVCIM under reverse braking condition

5.4 COMPARISON OF PERFORMANCE OF VARIOUS CONTROL SCHEMES OF IVCIM

Figure 5.15 shows the comparison of performance of the two controllers when they attain desired speed. Comparison shows the performance of Fuzzy logic controller is better than the PI controller in terms of settling time and regaining the desired speed after application of sudden load.

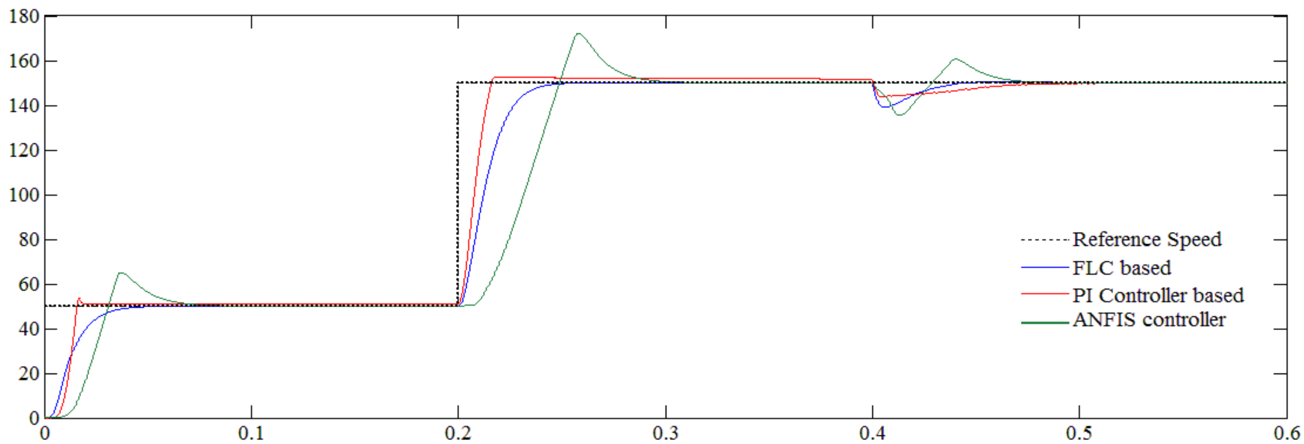


Figure 5.15 Comparison of speed variation in PI, Fuzzy and ANFIS controllers

Drive was operated at rated speed (150 rad/sec) and load of 4 N-m was applied at t=0.4 seconds, the performance index of drive under above operating conditions is summarized in table 2.

Control scheme / Parameter	PI	Fuzzy logic controller	ANFIS
Rise time (t_r)	0.0269 sec	0.0323 sec	0.322 sec
Peak time (t_p)	0.034 sec	0.0421 sec	0.381 sec
Steady state error	0.25 rad/sec	0.015 rad/sec	0.011 rad/sec
Maximum overshoot	1.7 %	0.14 %	30 %

Table 2: Comparison of various control schemes

5.5 CONCLUSION

The results of simulation in MATLAB were presented in this chapter and also performance of the drive was analysed. Also the results obtained from hardware setup for PI controller were presented and analysed for the performance estimation. From the comparison made in section 5.4 of the chapter, it is evident that performance of drive controlled with Fuzzy Logic controller is superior to that of PI and ANFIS controller in terms of maximum overshot. If we compare in terms of steady state error, then ANFIS controller is found to be superior of other two controllers. In terms of speed of response, PI control scheme is superior. The intelligent controllers are gaining the popularity these days because of this enhanced performance of the drive. The performance of the drive for forward and reverse braking was also analysed and it was observed that performance of Fuzzy logic controller was superior.

CHAPTER 6
CONCLUSION AND FUTURE SCOPE

6.1 MAIN CONCLUSION

In this project, an extensive review of PI, FLC and ANFIS controllers and feedback signal estimation techniques for squirrel cage-type induction motor drives is carried out. This class of drives is widely gaining popularity in various industrial applications, and the technology is continuously expanding. An intimate understanding of machine performance, under different operating conditions, is necessary to design modern high-performance drives. Often, for a particular application, where more than one type of machines is being used, this analysis is necessary.

Vector control was discussed extensively because of its importance in high-performance drive applications. The vector control implementation with corresponding feedback signal estimation is complex. The Fuzzy Logic Controller was reviewed in this thesis. The results are obtained in both MATLAB/Simulink and in real time through hardware implementation.

The performance of the drive was analysed using above three control schemes and few conclusions were drawn. The performance of PI controller is superior to other two control schemes in terms of rise time. During the operation of the drive in reverse braking condition, performance of Fuzzy logic controller was found to be superior. In is found that sudden change of load caused ripples in the developed electromagnetic torque which are minimised efficiently by ANFIS controller.

The characteristics of the drives are obtained and verified for the forward and reverse motoring mode and as well for plugging mode. The results from both simulation in MATLAB/Simulink and hardware confirm the conclusion.

6.2 FUTURE SCOPE OF PRESENT WORK

A number of control techniques are available that can be implemented to improve the performance of the AC drives. The conventional PID technique implementation in real time requires tuning of three parameters which is not simple and easy to achieve in real time. The implementation of the PI controller is relatively simple but the performance of the drive deteriorates due to variations in motor parameters. The PI and FLC can be implemented in hybrid mode to obtain a better performance.

The Neural Network techniques are being studied presently. The recent trend of the utilization of ANFIS, which is a hybrid of Fuzzy and Neural Network control algorithms, has also shown, wide potential for application in high performance IM drives. Besides this, in the present analysis, the hysteresis current control technique has been used for control of VSI, however, the SVPWM technique reduces the computational time of the processors. A synchronous current control voltage PWM can also be used. Speed Sensor less vector control is an emerging technology. A number of speed estimation techniques are being reviewed. However, very low-speed operation including start-up at zero frequency remains a challenge. Besides Sensor less Vector Control Scheme, there is also Direct Torque Control Scheme.

Its response has been found to be more superior to FOC scheme. Torque and flux are changed very fast by changing the references. High efficiency and low losses - switching losses are minimized because the transistors are switched only when it is needed to keep torque and flux within their hysteresis bands.

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