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DIRECT TORQUE CONTROL OF INDUCTION MOTOR USING SPACE VECTOR MODULATION

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ABSTRACT: The speed of induction motor is controlled by varying the stator flux through a PI flux controller. The tuning of PI controller is carried out by varying proportional gain and integral gain in a predetermined manner. The selected values of proportional gain have been taken to improve the speed response of the induction motor drive for given values of integral gain and integral time constant.

After reaching satisfactory value of proportional gain, the integral gain is varied to obtain an improved response keeping proportional gain and integral time constant unchanged. On observing the speed response of the drive suitable adjustments is again attempted in proportional gain to further improve the dynamic behavior of the drive.

I. OVERVIEW OF INDUCTION MOTOR

An induction motor or asynchronous motor is a type of alternating current motor where power is supplied to the rotor by means of electromagnetic induction. There are several ways to supply power to the rotor. In a DC motor, this power is supplied to the armature directly from a DC source while, in an induction motor, this power is induced in the rotating device. An induction motor is sometimes called a rotating transformer because the stator is essentially the primary side of the transformer and the rotor is the secondary side.

Unlike the normal transformer which changes the current by using time varying flux, induction motors use rotating magnetic fields to transform the voltage. The current in the primary side creates an electromagnetic field which interacts with the electromagnetic field of the secondary side to produce a resultant torque, thereby transforming the electrical energy into mechanical energy. The induction motors have many advantages over the rest of the types of motors. The main advantage is that induction motors does not require an electrical connection between the stationary and the rotating parts of the motor.

Therefore, they do not need any mechanical commutator (brushes), making these motors as maintenance free motors. Besides, induction motors also have low weight and inertia, high efficiency and a high overload capability. Therefore, they are cheaper and more robust, and less prone to any failure at high speeds. Furthermore, the motor can work in explosion prone environments because no sparking is feasible as per design.

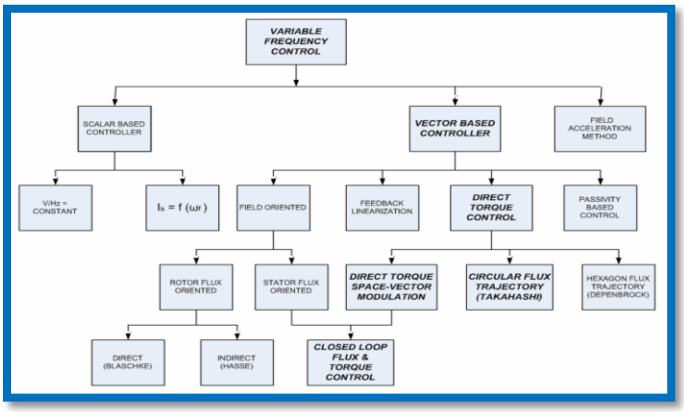

Fig. 1.1 Overview of induction motor control methods.

II. OBJECTIVE

- To develop a MATLAB code for direct torque control of induction motor using space vector modulation.
- To study the dynamic response of the model.
- To tune PI flux controller for speed regulation using the DTC scheme.

III. LITERATURE SURVEY

Takahasi and Noguchi (1985) introduced direct torque control as a new quick response and efficiency control strategy where in limit cycle control of both flux and torque, optimum inverter voltage selection with the help of a switching table and efficiency optimization in the steady state operation have been talked about [1]. T.G. Habetler, F. Profumo, M. Pastorelli, and L.M. Tolbert (1992) discussed the direct torque control of induction motor using space vector modulation. They describe a control scheme for direct torque and flux control of induction machines based on the stator flux field-orientation method. With the proposed predictive control scheme, an inverter duty cycle has directly calculated each fixed switching period based on the torque and flux errors, the transient reactance of the machine, and an estimated value of the voltage behind the transient reactance [2].Kazmierkowski and Kasprowicz (1995) explain the advantages of direct torque control over field oriented control and give design of flux and torque controllers. The paper also deals with the problem of the direct torque control drive, at start and zero speed operation, by introducing an additional carrier signal to the torque controller input [3].P. Vas (1998) discusses sensor less techniques associated with vector control and direct torque control concept in great detail using spacephasors to model and unify the treatment of the motors, proceeding with a control theory view of the overall drive systems and implementation of the physical realization of the drive system with the help of equations and block diagrams [4]. Lascuet Al (1998) deal with the torque, flux and current pulsations that occur during the steady state in direct torque control and their reflection on speed estimation, speed response and acoustical noise by introducing a direct torque and flux control method based on space vector modulation for induction motor sensor less drives [5]. Kang and Sul (1999) propose a direct torque control method to minimize torque ripple while maintaining constant switching frequency. In the proposed torque ripple control algorithm, the optimal switching instant is calculated at each switching cycle to satisfy ripple minimum condition based on instantaneous torque slope equations [6]. Boldea and Nasar (1999) present a comprehensive view of modern variable speed drives where in topology, performance, design element, simulation, test result and practical issues in industrial drives have been covered [7].

IV. INDUCTION MOTOR CONTROL SCHEMES

The simple induction motor fulfills admirably the requirements of substantially constant speed drive. However, two factors have led to a re-examination of many of these applications: concern about process quality and productivity in manufacturing and about the cost of electric energy. An ability to adjust the speed of the industrial drive addresses both these concerns. The synchronous speed of an induction motor can be changed by changing the number of poles or by varying the line frequencies. The operating slip can change by varying the line voltage or by varying the rotor slip energy recovery.

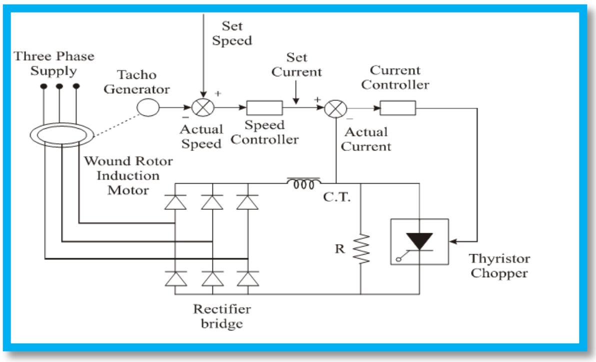

Fig. 4.1 Rotor resistance control.

4.1 ROTOR ENERGY RECOVERY

In rotor resistance control, if the slip power lost in the resistance could be returned to the AC source.The overall efficiency of the drive system would be very much increased. Here the diode bridge rectifies the rotor power. A smoothing coil is used to smooth the rectified current out. The output of rectifier is then connected to the DC terminals of inverter, which inverts this DC power to AC power and feeds it back of the AC source. The schemes pertaining to the rotor side control can be used only for wound rotor induction motors. Also, the rotor resistance control scheme suffers from the drawback of being less efficient and the slip energy recovery drive always has a lower power factor.

4.2 VARIABLE FREQUENCY CONTROL

With the advent of high-speed power electronics, inverters have become very successful in producing variable frequency voltage and currents and reduce total harmonics distortion. The variation of supply frequency can successfully control the speed of three-phase induction motor.

4.3 DIRECT TORQUE CONTROL

Direct torque control (DTC) is one of the most excellent control strategies of torque control in induction machine. It is considered as an alternative to the field oriented control (FOC) or vector control technique. These two control strategies are different on the operation principle but their objectives are the same. They aim to control effectively the torque and flux. Torque control of an induction machine based on DTC strategy has been developed and a comprehensive study is present in this research. Induction machine have provided the most common form of electromechanical drive for industrial, commercial and domestic applications that can operate at essentially constant speed. Induction machines have simpler and more rugged structure, higher maintainability and economy than DC motors. They are also robust and immune to heavy loading. Basically, there are two types of instantaneous electromagnetic torque-controlled AC drive used for high performance applications which are:

- Vector Control (VC): Based on stator current control in the field rotating reference frame.
- Direct Torque control (DTC): based on stator flux control in the stator fixed reference frame using direct control of the inverter switching.

V. SIMULATIONS AND RESULTS

In this chapter simulation have been carried out for the implementation of direct torque control scheme. The MATLAB code has been written for implementation of DTC for the induction motor model taken from [9]. The mathematical model consists of differential equations in terms of machine and motor parameters. The main parts of the direct torque control of induction motor are induction motor, voltage source inverter (VSI) and the functional blocks like adaptive motor model, hysteresis controller and optimum pulse selector.

5.1 SIMUALTION FOR DIRECT TORQUE CONTROL SCHEME

For the scheme R_r, L_s, L_r, L_m, J, P, T_{load} used for initialization, are as given in the Appendix A. This method uses feedback control of torque and stator flux, which are computed from the measured stator voltage and currents. The scheme uses stator flux-linkages control. The scheme depends on stator resistance and on no other parameter. For its flux and torque control, this control scheme requires the position of the flux phasor. The torque, flux and speed errors are calculated first which leads to the optimum pulse selection for VSI switching, the three phase voltage values, obtained at the output of the VSI, are used for the calculation of I_{ds}, I_{qs}, λ_{ds}, λ_{qs} after abc to dq0 transformation. Then calculation of electromagnetic torque, actual speed, stator, flux, estimated torque and estimated speed follows on the basis of which the torque, flux and speed errors are generated. It is proposed to evolve a suitable speed controller for a typical induction motor in the present investigations.

5.2 VALIDATION OF DYNAMIC MODELING RESULT

A typical motor system available in reference [9] has been considered for validation and further investigations. The details of the system are given in Appendix A. The following curves indicate the motor response obtained with the help of MATLAB code developed. The output of Execution as below.

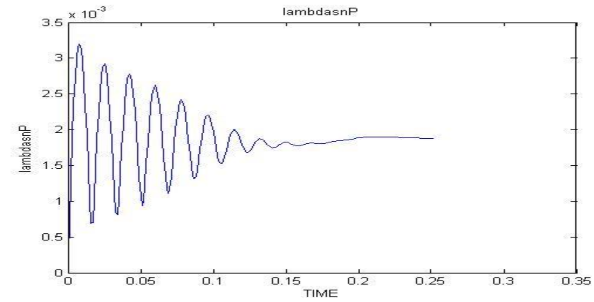

Fig. 5.1 Plot between stator flux linkages and time.

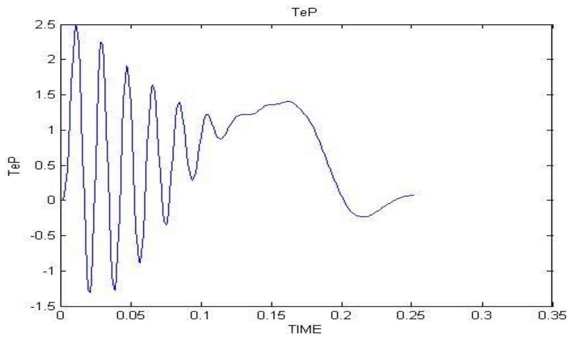

Fig. 5.2 Plot between normalised torque and time

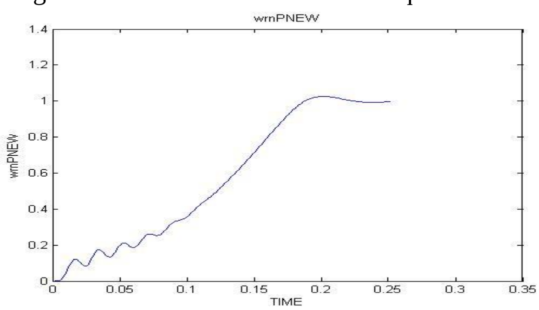

Fig. 5.3 Plot between speed and time.

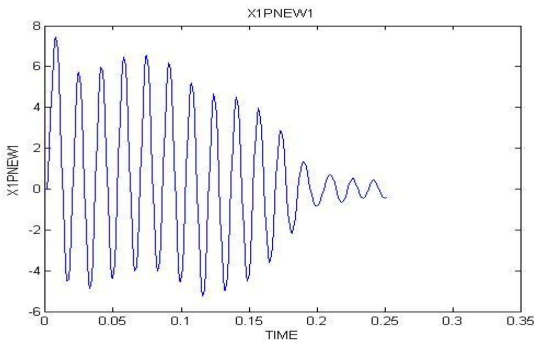

Fig. 5.4 Plot between q-axis stator current and time.

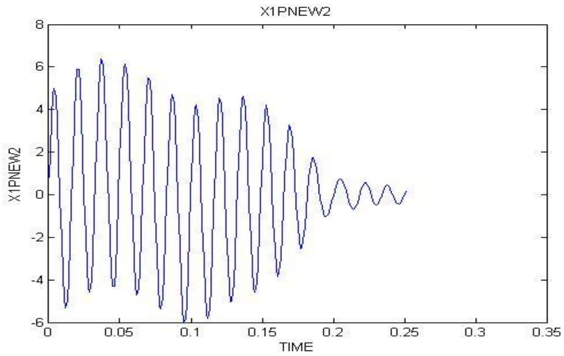

Fig. 5.5 Plot between d-axis stator current and time.

The response curves indicated above exactly match with those given in the reference [9].Results of PI Controller Tuning The DTC scheme is implemented on the dynamic model of the induction motor for its speed control using PI controller. Accordingly, the speed control is affected by regulating the stator flux through this PI controller. In the present investigations, the desired speed is set at 0.9 per unit. The initial value of the stator flux is set at 0.8 per unit. By varying the proportional gain, integral gain and integral time constant attempt is made to obtain the best response of the motor. The various response curves for the tuning of the PI controller are given below for different combinations of proportional gain, integral gain and integral time constant. The various combinations of proportional gain, integral gain and integral time constant for which the response curves have been obtained are given in Tables 5.1, 5.2 and 5.3.

Table 5.1 Variation of K_pL for given values of K_iL and T.

S. No.	K_pL (proportional gain)	K_iL (integral gain)	T (integral time constant), second
1.	0.010	0	0.01
2.	0.011	0	0.01
3.	0.012	0	0.01
4.	0.013	0	0.01
5.	0.014	0	0.01
6.	0.015	0	0.01
7.	0.016	0	0.01
8.	0.017	0	0.01

As given in the Table 5.1 K_pL is varied from .010 to .017 and $K_iL$and T are kept constant at 0 and 0.01 respectively. The various response curves of the induction motor drive system for the combinations K_pL=0.01, K_iL=0, T=0.01 and K_pL=0.017, K_iL=0, T=0.01 are shown below

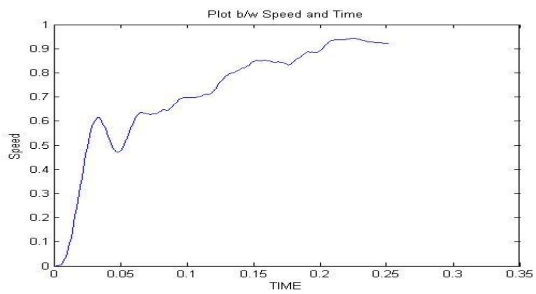

Fig. 5.6(a) Plot between Speed and time when K_pL=0.01, K_iL=0, T=0.01.

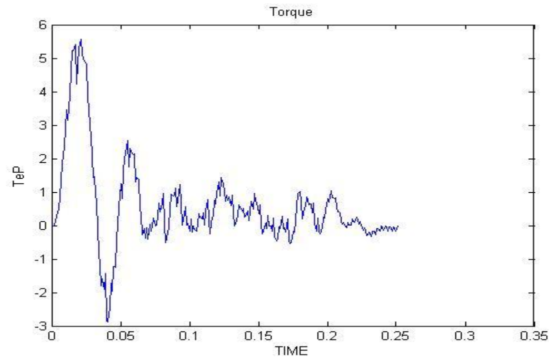

Fig. 5.6(b) Plot between Torque and time when K_pL=0.01, K_iL=0, T=0.01.

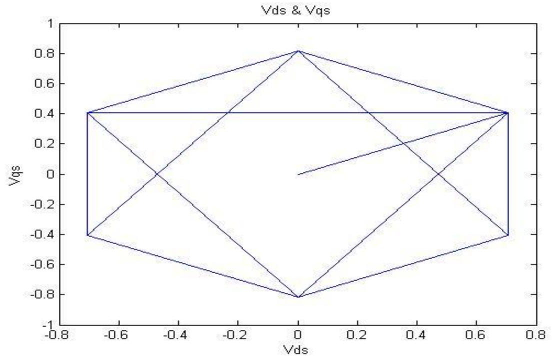

Fig. 5.6(c) Plot between d and q axis stator voltages when K_pL=0.01, K_iL=0, T=0.01.

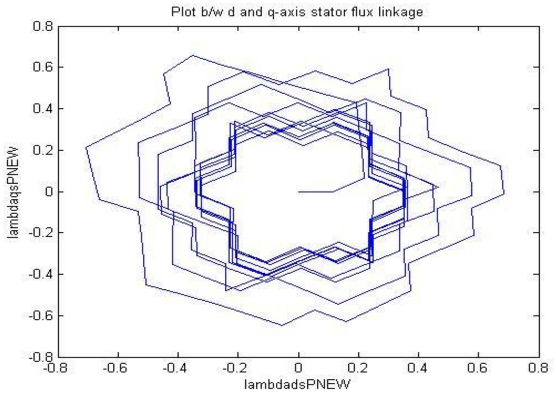

Fig. 5.6(d) Plot between d and q stator flux when K_pL=0.01, K_iL=0, T=0.01.

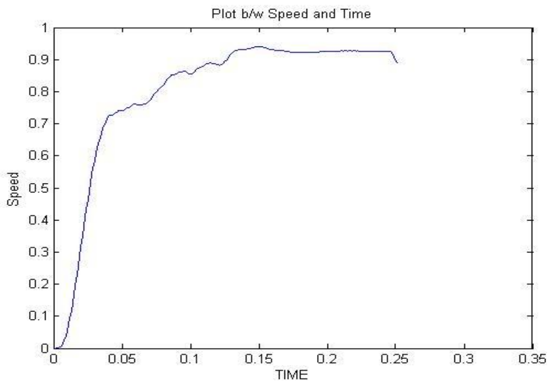

Fig. 5.7(a) Plot between Speed and time when K_pL=0.017, K_iL=0, T=0.01.

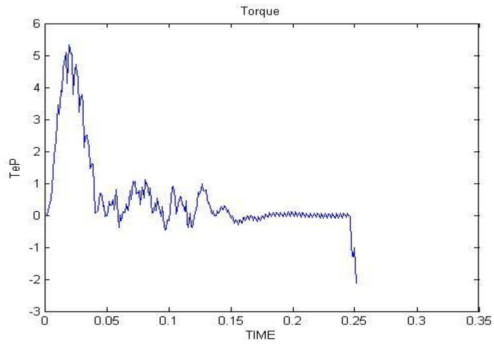

Fig. 5.7(b) Plot between Torque and time when K_pL=0.017, K_iL=0, T=0.01.

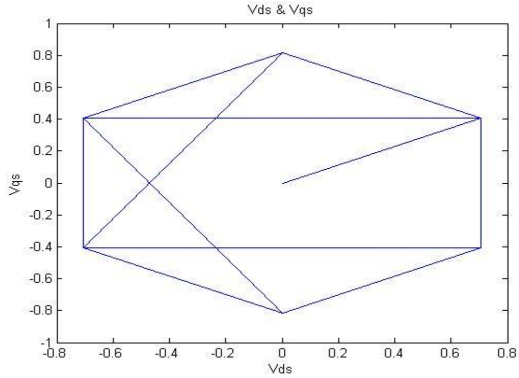

Fig. 5.7(c) Plot between d and q axis stator voltages when K_pL=0.017, K_iL=0, T=0.01.

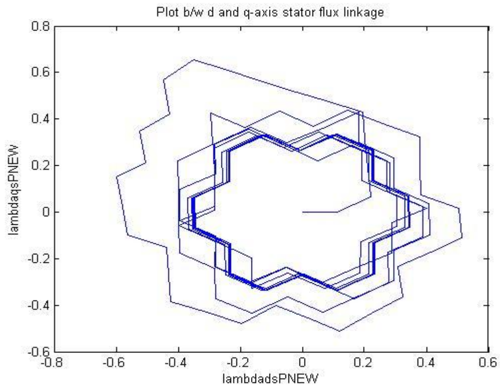

Fig. 5.7(d) Plot between d and q stator flux when K_pL=0.017, K_iL=0, T=0.01

Table 5.2 Variation of K_iL for given values of K_pL and T.

S. No.	K_pL (proportional gain)	K_iL (integral gain)	T (integral time constant), second
1.	0.017	0.01	0.01
2.	0.017	0.02	0.01
3.	0.017	0.03	0.01
4.	0.017	0.04	0.01
5.	0.017	0.05	0.01
6.	0.017	0.06	0.01

As given in the Table 5.2 we tune the K_iL by keeping the K_pL and T constant at 0.017 and 0.01 respectively. The various response curves of the induction motor drive system for the combination K_pL=0.017, K_iL=0.06, T=0.01 are shown below

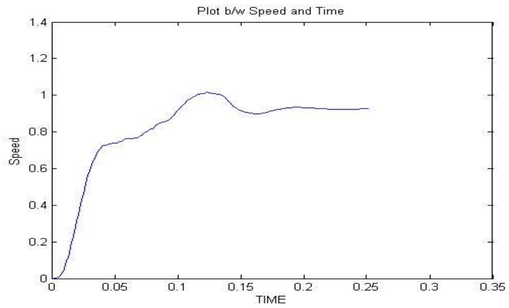

Fig. 5.8(a) Plot between Speed and time when K_pL=0.017, K_iL=0.06, T=0.01

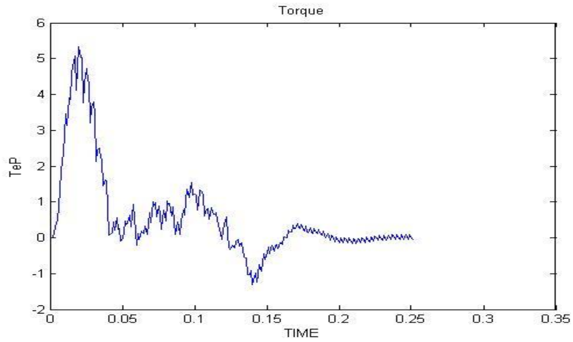

Fig. 5.8(b) Plot between Torque and time when K_pL=0.017, K_iL=0.06, T=0.01

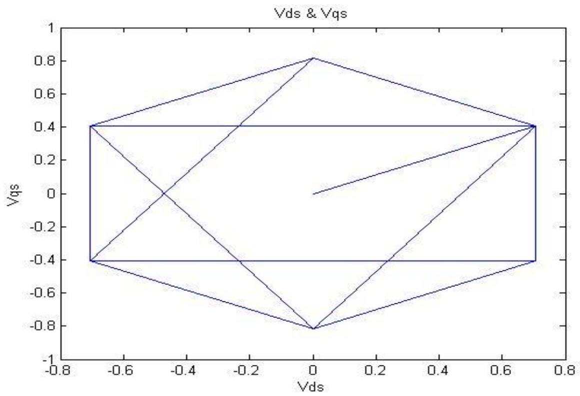

Fig. 5.8(c) Plot between d and q axis stator voltages when K_pL=0.017, K_iL=0.06, T=0.01

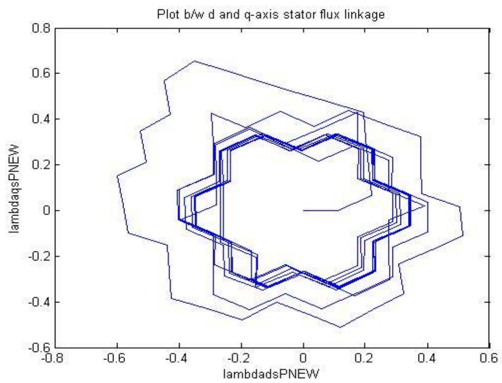

Fig. 5.8(d) Plot between d and q stator flux when K_pL=0.017, K_iL=0.06, T=0.01.

Table 5.3 Variation of K_pL for given values of K_iL and T.

S. No.	K_pL (proportional gain)	K_iL (integral gain)	T (integral time constant), second
1.	0.018	0.06	0.01
2.	0.019	0.06	0.01
3.	0.020	0.06	0.01

As given in the Table 5.3 after tuning the K_iL we again tune the K_pL for better responses. After tuning the PI controller gains the various response curves of the induction motor drive system for the combinations K_pL=0.020, K_iL=0.06, T=0.01 are shown below

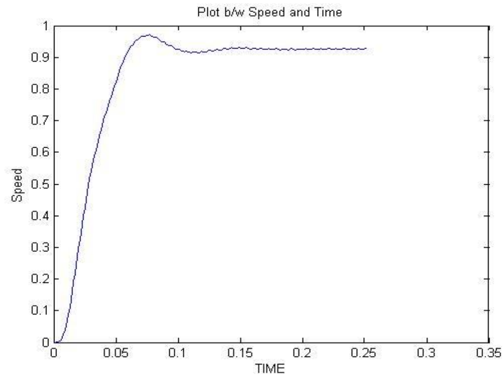

Fig. 5.9(a) Plot between Speed and time when K_pL=0.020, K_iL=0.06, T=0.01.

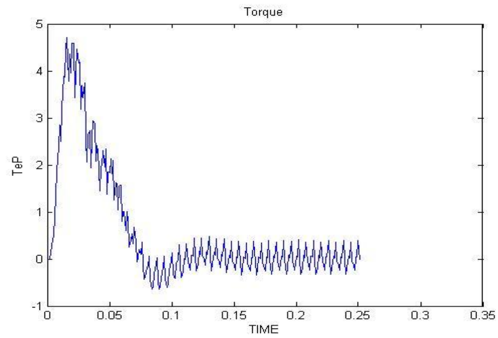

Fig. 5.9(b) Plot between Torque and time when K_pL=0.020, K_iL=0.06, T=0.01.

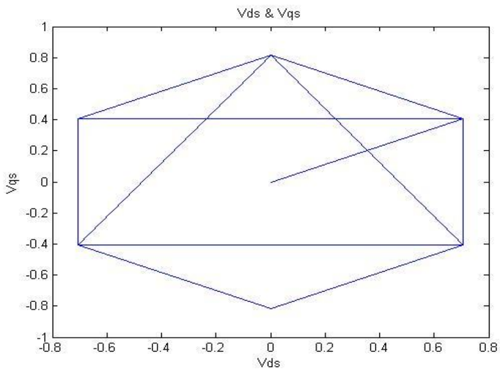

Fig. 5.9(c) Plot between d and q axis stator voltages when K_pL=0.020, K_iL=0.06, T=0.01.

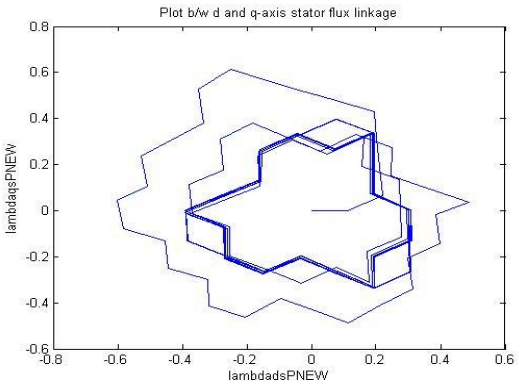

Fig. 5.9(d) Plot between d and q stator flux when $K_pL=0.020$, $K_iL=0.06$, T=0.01.

The response curves indicate that the gain setting corresponding to combination $K_pL=0.020$, $K_iL=0.06$, T=0.01is best for speed control of induction motor drive considered for investigation.

VI. CONCLUSIONS AND FUTURE SCOPE

Direct Torque Control is supposed to be one of the best control strategies for any induction motor drive. Its principles and basic concepts have been thoroughly explained and illustrated. It is also emphasized in the thesis that the method of direct torque control also allows the decoupled control of motor torque and motor stator flux. It may be added that the DTC strategy is simpler to implement than the flux vector control method because it does not require voltage modulators, and co-ordinate transformations. In this scheme the speed is regulated based on the stator flux control in the stator reference frame using direct control of inverter switching. For developing a schematic model of the DTC scheme a mathematical description, the relevant dynamic characteristics of the components, characterized by differential equations in terms of machine and performance parameters, representing the governing relations between the various constituents of the system. A suitable algorithm is used to develop the MATLAB code to determine the dynamic response of induction motor drive using DTC scheme for speed control. The results of validation are encouraging and the response curves of the induction motor drive exactly match. The MATLAB code is adapted for carrying out research investigations to evolve a suitable PI flux controller for speed regulation of the induction motor drive considered for investigations. In other words, the speed of induction motor is controlled by varying the stator flux through a PI flux controller. The resources developed in the course of present investigation could be easily used for further research work is to evolve PI torque controller, PID speed controller, PID torque controller, coordinated speed-torque controller etc.

REFERENCE

[1] Takahashi and T. Noguchi, “A New Quick Response and High Efficiency Control Strategy of an Induction Motor”. Conf. Rec. IEEE-IAS Annual Meeting, Oct. 1985, pp. 496-502.

[2] T.G. Habetler, F. Profumo, M. Pastorelli, and L.M. Tolbert, “Direct Torque Control of Induction Machines using Space Vector Modulation.” IEEE Trans. Industry Applications. Vol. 28, No. 5, Sept/Oct 1992, pp. 1045-1054.

[3] M.P. Kazmierkowski and A.B. Kaprowicz, “Improved Direct Torque and Vector Control of PWM Inverter Fed Induction Motor Drives”, IEEE Trans. on Industrial Electronic, Vol. 42, No. 4, 1955, pp. 344-349.

[4] P. Vas, “Sensorless Vector and Direct Torque Control”, Oxford Univ. Press, Oxford, U.K., 1st edition, 1998.

[5] C. Lascu, I. Boldea and F. Blbjerg, “A Modified Direct Torque Control for Induction Motor Sensorless Drive”, IEEE Trans. On Industrial Application, Jan/Feb. 1998, Vol. 36, no.1, pp. 122-130.

[6] Jun-Koo Kng and Sun-Ki Sul, “New Direct Torque Control of Induction Motor for Minimum Torque Ripple and Constant Switching Frequency”, IEEE Trans. on Industry Application, Vol. 35, no.5, Sept./Oct. 1999, pp. 1076-1082.

[7] Boldea and S.A. Nasar, “Electric Drives”, CRC press, New York, 1st edition, 1999.

[8] K. L. Shi, T. F. Chan, Y. K. Wong and S. L. H, “Modelling and Simulation of the Three-Phase Induction Motor using Simulink”, Int. J. Elect. Engg. Edue, Printed in Great Britain, 1999, Vol. 36, pp. 163-172.

[9] R. Krishnan, “Electric Motor Drives- Modeling, analysis and control.” 2001 by Prentice-Hall.

[10] Purcell and P.P. Acarnley, “Enhanced Inverter Switching for Fast Response Direct Torque control”, IEEE Trans. on power electronics, May 2001, Vol. 16, no.3, pp. 382-389.

[11] D. Telford, M.W. Dunnigan and B.W. Williams, “A New Torque-Ripple Reduction Strategy for Direct Torque Control”, IEEE Trans. on Industrial Electronics, August 2001, Vol. 48 no.4, pp. 867-870.

[12] Jun-Koo Kang and Sung-kiSul, “Analysis and Prediction of Inverter Switching Frequency in the Direct Torque Control of Induction Machine based on Hysteresis Bands and Machine Parameters”, IEEE Trans. On Industrial Electronics, June 2001, Vol. 48, no. 3, pp. 545-553.

[13] J.C. Trounce, S.D. Round, R.M. Duke, “Comparison by Simulation of Three-level Induction Motor Torque Control Scheme for Electric Vehicle Applications”, Proc. of international Power Engineering Conference, Singapur, May 2001, vol. 1, pp. 294-299.

[14] D. Cacadei, F. Profumo, G. Serra & A. Tani, “FOC & DTC: Two Viable Schemes for Induction Motors Torque Control”, IEEE Trans. on Power Electronics, Sept. 2002, Vol. 17, no.5, pp. 779-787.

