International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 3 Issue 7, July - 2014

ANN based DTC for Induction Motor Drive

Swati Deshmukh
Department of Electrical Engineering,
Rungta College of Engineering and Technology, Bhilai (C,G.)

Neha Tiwari
Department of Electrical Engineering,
Rungta College of Engineering and Technology, Bhilai (C,G.)

***Abstract*—This paper describes a better way of controlling the propulsion system by designing Electrically driven model. In the Electric propulsion system, speed control of induction motor is controlled by direct torque control (DTC) method. DTC used for Induction Motor drive has quick torque response without complex orientation transformation and inner loop current control. This paper presents simple structured neural network for sector selection and stator voltage vector selection for induction motors using direct torque control (DTC) method. The Levenberg-Marquardt back-propagation technique has been used to train the neural network and the results are validated through simulation.**

Keywords - Artificial neural network (ANN), Direct torque control (DTC), Induction Motor, Reference frames, Sector selector.

1. INTRODUCTION

Field- oriented or vector control is given by BLASCHKE and HASSE which is a greatest improvement in the field of induction motor. Instead of dc motor it has been employed in various industrial applications for achieving a quick torque response. It is compulsory to calculate the orientation of the rotor flux vector in vector control technique. It is compulsory to calculate the orientation of the rotor flux vector in vector control technique. Rotor time constant of squirrel-cage induction machine is very large and on comparison with stator flux linkage rotor flux linkage changes slowly and the rotor flux almost unchanged during a short transient, this is its main disadvantage. Direct torque control (DTC) is been introduced to overcome this disadvantage of vector control method of induction motor torque control. DTC provides a good tracking for electromagnetic torque and stator flux. The main advantage is that induction motors do not require an electrical connection between stationary and rotating parts of the motor. Therefore, they do not need any mechanical commutator (brushes), leading to the fact that they are maintenance free motors. Induction motors also have low weight and inertia, high efficiency and a high overload capability. Therefore, they are cheaper and more robust, and less proves to any failure at high speeds.

2.MODELLING OF INDUCTION MACHINE

2.1 Axes Transformation: During start-up and other severe transient operations induction motor draws large currents, produces voltage dips, oscillatory torques and can even generate harmonics in the power systems. In order to investigate such problems, the d, q axis model has been designed. To convert three-phase voltages Vas, Vbs, Vcs to voltages $Vqs^{e,}$ Vds^{e} in the two phase synchronously rotating frame [1], they are first converted to two-phase stationary frame $Vqs^{s,}$ Vds^{s} using equation(2.1)and then from frame to the synchronously rotating [1] using equation(2.2).Fig. 1 symmetrical three-phase induction machine with stationary as-bs-cs axes at 2π/3-angle apart.

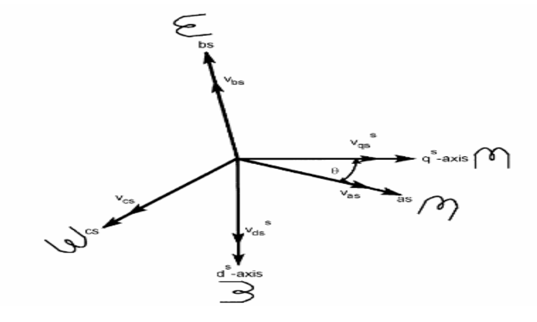

Fig. 1. Stationary frame a-b-c to d^s-q^s axes transformation

The voltages V_{ds}^{s} and V_{qs}^{s} can be resolved into as- bs -cs components and can be represented in the matrix form as [4].

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 120°) & \sin(\theta - 120°) & 1 \\ \cos(\theta + 120°) & \sin(\theta + 120°) & 1 \end{bmatrix} \begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{os}^{s} \end{bmatrix} \quad (2.1)$$

The corresponding inverse relation is

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} \cos\theta & \cos(\theta-120^\circ) & \cos(\theta+120^\circ) \\ \sin\theta & \sin(\theta-120^\circ) & \sin(\theta+120^\circ) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} V_c \\ V_l \\ V_c \end{bmatrix} \quad (2.2)$$

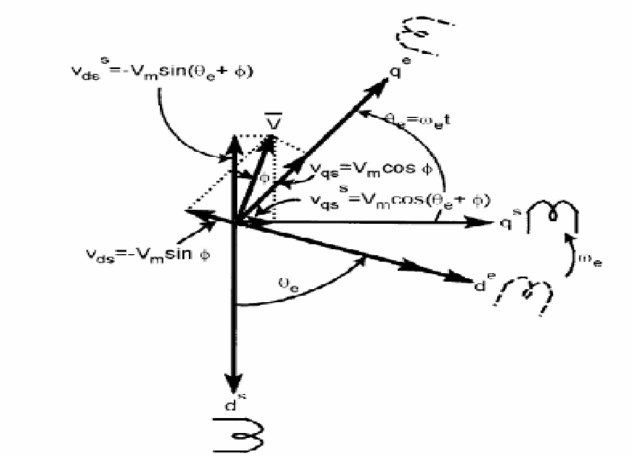

Fig. 2. Stationary frame d^s- q^s to synchronously rotating frame d^e- q^e transformation

Fig. 2 shows the synchronously rotating d^e- q^e, which rotate at synchronous speed ω_e with respect to the d^s-q^s axes and the angle $\theta_e = \omega_e t$. the two-phase d^s- q^s windings are transformed into the hypothetical windings mounted on the d^e-q^e axes[5].

2.2 Transient Modeling: Dynamic behavior of the machine may be analyzed using any one of following the reference frames:

- Stationary reference frame
- Rotor reference frame
- Synchronous reference frame

A. Stationary Reference Frame: The speed of the reference frames is that of the stator $\omega_e = 0$, the electrical transient model in terms of voltage and currents can be given in matrix form [3].

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & -\omega_r L_m & R_r + L_r p & -\omega_r L_r \\ \omega_r L_m & L_m p & \omega_r L_r & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Electromagnetic torque equations are given by:

Te =3/2* p/2* Lm* (iqs* idr- ids* iqr) (2.3)

B. Rotor Reference Frame: The speed of the rotor reference frames is $\omega_e = \omega_r$, where ω_r is the rotor frequency. The induction-motor model in rotor reference frames [1] is obtained by the following equations:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & -\omega_r L_m & R_r + L_r p & -\omega_r L_r \\ \omega_r L_m & L_m p & \omega_r L_r & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Electromagnetic torque equations are given by:

Te =3/2* p/2* Lm* (iqs^r *idr^r – ids^r *iqr^r) (2.4)

C. Synchronously Rotating Reference Frame Dynamic Model : The speed of the reference frame is $\omega_e = \omega_r$,motor model equations in synchronous reference frames [3] are given by:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} \begin{bmatrix} R_s + SL_s & \omega_e L_s & SL_m & \omega_e L_m \\ -\omega_e L_s & R_s + SL_s & -\omega_e L_m & SL_m \\ SL_m & (\omega_e - \omega_r) L_m & R_r + SL_r & (\omega_e - \omega_r) L_r \\ -(\omega_e - \omega_r) L_m & SL_m & -(\omega_e - \omega_r) L_r & R_r + SL_r \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Electromagnetic torque equations are given by

Te =3/2* p/2* Lm* (iqs^e * idr^e – ids^e * iqr^e) (2.5)

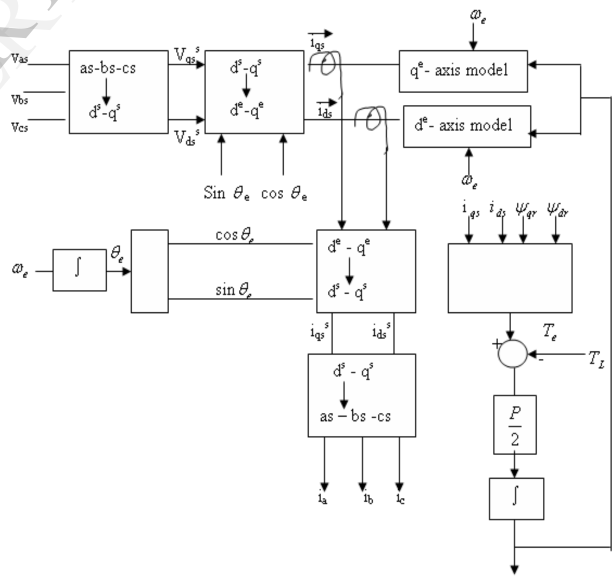

Fig. 3. Synchronously rotating frame machine model with input voltage and output current transformations.

3. STRATEGY FOR DIRECT TORQUE CONTROL

The basic concept of DTC is to control the stator flux and torque directly by using the effective voltage vector generated from voltage source 6-step inverter. In DTC algorithm, a direct hysteresis stator flux and electromagnetic torque control that trigger directly one voltage vector among the six effective voltage vectors (V1,V2, V3, V4, V5, V6), and two null voltage vectors (V0, V7),as shown in Fig. 4 in order to keep stator flux and torque within pre-specified error tolerance bands. The proper selection of the inverter switches forces the stator flux vector in the direction where the reference values of the motor torque and the stator flux are achieved as shown in Fig. 5. Motor model estimates the actual torque, stator flux, and stator flux vector position by means of measurements the motor phase currents and voltages. The optimum selection of the inverter switching modes, both errors of flux and torque shall be within the hysteresis bands [7].

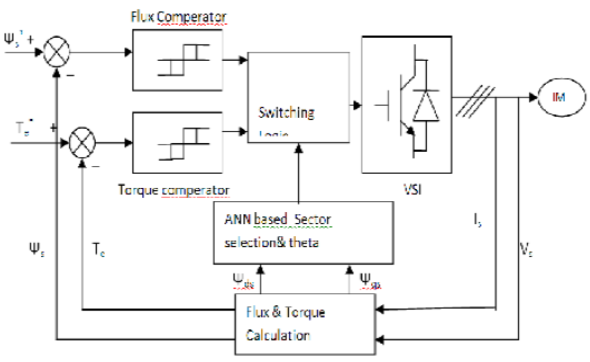

Fig. 4 . ANN based DTC Scheme

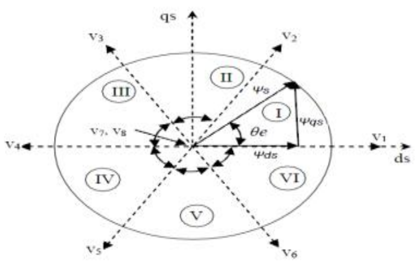

Fig.5. Inverter output voltage vectors and stator flux sectors

The switching logic given below in the Table .1 developed from the output signals of hysteresis comparators represents the increment (decrement) of the flux (torque)

TABLE-1
SWITCHING LOGIC

CONDITION FOR FLUX	S_ψ	Flux Errors
$\lvert\psi_s\rvert \leq \lvert\psi_s^*\rvert - \lvert\Delta\psi_s\rvert$	1	Positive error
$\lvert\psi_s\rvert \geq \lvert\psi_s^*\rvert + \lvert\Delta\psi_s\rvert$	-1	Negative error
CONDITION FOR TORQUE	S_{Te}	Torque error
$\lvert Te\rvert \leq \lvert Te^*\rvert - \lvert\Delta Te\rvert$	1	Positive error
$\lvert Te\rvert = \lvert Te^*\rvert$	0	Error within acceptable limits

4. ARTIFICIAL NEURAL NETWORK BASED VOLTAGE VECTOR SELECTION

NN is a machine like human brain with basic properties of learning capability and generalization. In this paper a feed forward neural network is to select the voltage vector is used to determine the sector number. There are six sectors, each sector of 60 degree each [9,11]. There are two input and one output feed forward network with three layers. Back Propagation is a systematic method for training multilayer artificial networks. It is a multilayer forward network using extend gradient-descent based delta-learning rule, commonly known as back propagation rule. The aim of this network is to train the net to achieve a balance between the ability to respond correctly to the input patterns that are used for training and the ability to provide good responses

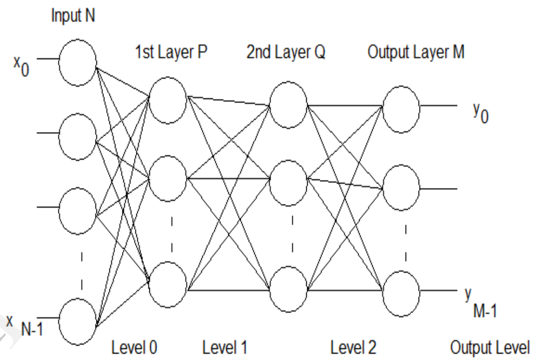

Fig. 6. Example of layer network for Back propagation algorithm

5. SIMULATION RESULT

5.1 Modelling of Induction Machine

The simulation results are obtained for induction motor and its parameters as given in appendix. The machine model is implemented for speed control using DTC scheme.

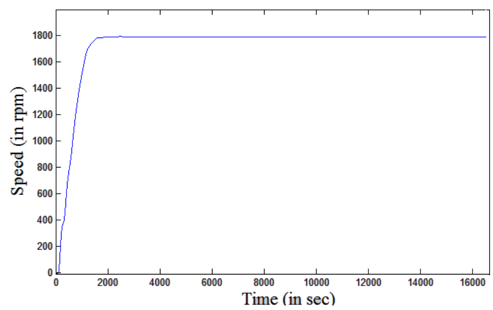

Fig. 7. Speed of Induction Motor

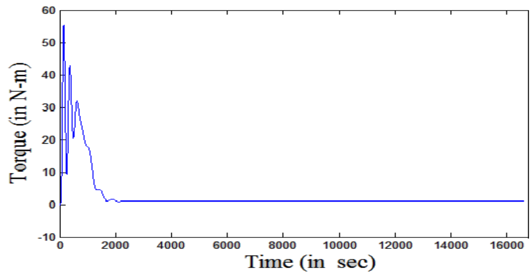

Fig. 8. Electromagnetic Torque of induction motor

5.2 *Simulation Results of DTC scheme*

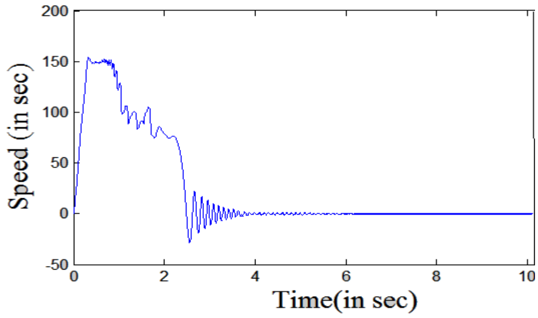

Fig. 9. Speed Response of DTC scheme

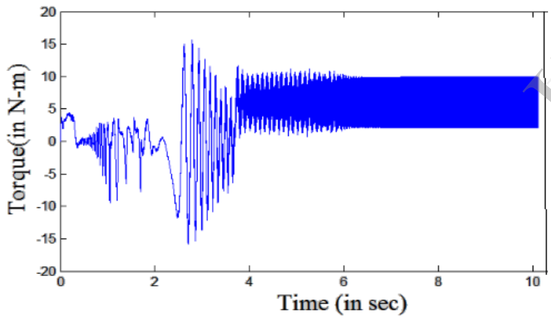

Fig. 10. Electromagnetic Torque Response of DTC scheme

5.3 Simulation Results of ANN Based DTC Scheme

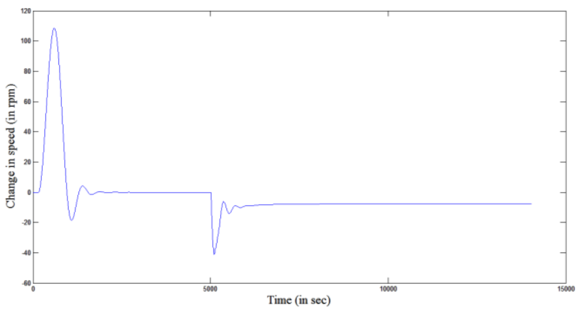

Fig.11 Speed response of ANN based DTC scheme

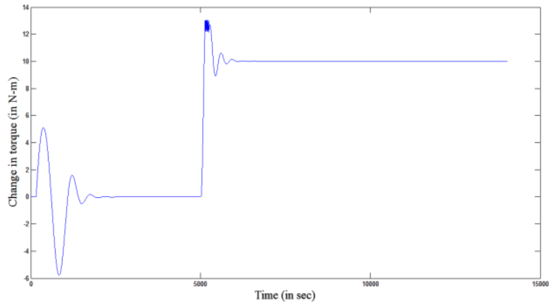

Fig.12 Torque response of ANN based DTC scheme

The speed and torque response of induction motor by DTC technique and ANN based DTC technique is shown in fig. (9) and (10) , (11) and (12) respectively. It can be seen that the ripple in torque with ANN based DTC technique is less as compared to DTC technique which supports accuracy in the ANN based estimator.

6. CONCLUSION

In this paper a mathematical model is developed for induction motor and conducted in Matlab/Simulink. The direct torque technique has several disadvantages like torque and flux control difficulties at very low speed, more ripples in current and torque, behaviour of variable switching frequency, high level of noise at low speed and lack of direct current control. To overcome these disadvantages, another torque controller must be implemented. Therefore ANN control is used in place of conventional DTC control. In this project, for proper selection of sector, a smart technique ANN is used, which makes better the work of induction motor in way of speed and torque. The speed reference is rapidly achieved by induction motor without overshoot and with small steady state error as simulation results also support this and also the load disturbances is rejected very fast. When Conventional DTC is compared, the ANN based DTC gives improved torque response in terms of decreased torque ripple. Mat-Lab/Simulink are used to carry out the result. Reduction of torque ripples in transient and steady state is the main improvement.

NOMENCLATURE

d^s-q^s = Stationary reference frame d and q axis
d^e-q^e = Synchronously rotating reference frame d and q axis
V_{ds}, V_{qs} = Stator d and q axis winding voltage, [Volt]
V_{dr}- V_{qs} = Rotor d and q axis winding voltage,[Volt]
I_{ds}, I_{qs} = Stator d and q axis winding voltage,[Volt]
I_{dr} . I_{qr} = Rotor d and q axis winding voltage,[Volt]
ψ_s = Stator flux linkage in [Wb]
ψ_{ds}, ψ_{qs} = Stator d and q axis winding flux linkage[Wb]
ψ_{dr}, ψ_{qr} = Rotor d and q winding flux linkage, [Wb]
Lm = Magnetizing inductance, [H]

Ls,Lr = Stator and rotor per phase winding inductance [H]
Rs, Rr = Stator and rotor per phase winding resistance, [Ω]
T_e = Electro-magnetic torque, [N-m]
J = Inertia of Motor
T_L = Load Torque
p = No. of poles

APPENDIX

The parameters of the three-phase Induction Motor, employed for simulation purpose, in SI units are Stator Resistance=Rs = 1.95[Ω], Rotor Resistance = Rr = 1.66[Ω], X_{ls} = 0.754 Ω, X_{lr} = 0.754 Ω, X_m = 26.13 Ω , ,No. of poles = p = 4, Moment of Inertia of test machine set up = J = 0.013 kg/m^2

REFERENCES

[1] Bose B.K. "Modern Power Electronics and AC Drives", Pearson Education, 4th Edition, 2004.
[2] R.Krishnan. "Electric Motor Drives, Modeling, Analysis, and Control", Pearson Education, First Indian Reprint, 2003.
[3] Shakuntla Boora , S.K. Agarwal , K.S. Sandhu " Dynamic D-Q axis modeling of three phase asynchronous machine using Matlab,'' *International Journal of Advanced Research in Electrical,Electronics and Insrtumentation Engineering,* vol. 2, pp. 3942-3951 , 2013.
[4] Adel Aktaibi & Daw Ghanim , M.A.Rahman, St. John's , " Dynamic Simulation of a Three Phase Induction Motor Using Matlab Simulink."
[5] Takahashi and T. Noguchi, "A New quick-response and high-efficiency control strategy of induction motor," *IEEE Trans. Ind.* septmember., vol. 22, no. 5, pp. 820–827, 1986.
[5] I. Takahashi and Y. Ohmori, "High-performance direct torque control of induction motor," *IEEE Trans. Ind*. Appl., vol. 25, no. 2, pp. 257–264, 1989.
[6] Hoang Le- Huy , "Comparison of Field – Oriented Control and Direct Torque Control for Induction Motor Drives," *IEEE Trans.* pp. 1245-1252 , 1999.
[7] P.Marino , M.D'Incecco, N.Visciano, "A Comparison of Direct Torque Control Methodologies for Induction Motor," *IEEE Porto Power Tech Conference,* pp. 7803-7139,2001.
[8] Domenico Casadei , Francesco Profumo, Giovanni Serra , Angelo Tani , "FOC and DTC : Two Viable Schemes for Induction Motors Torque Control," *IEEE Transaction on Power Electronics* , vol. 17 , no. 5, September 2002.
[9] S. N. Sivanandam, S. Sumathi , S. N. Deepa, "Introduction to Neural Networks Using Natlab 6.0," Tata McGeaw-Hill , 2006.
[10] S. Haykin , "Neural Networks – A Comprehensive Foundation," Prentice Hall , 1999.
[11] Martin T. Hagan , Mohammad B. Menhaj , "Training Feedforward Networks with the Marquardt Algorithm," *IEEE Transactions On Neural Networks*, Vol. 5 , No. 6 , pp. 989-993 , November 1994.
[12] Tsong – Terng Sheu , Tien – Chi Chen , "Self – Tuning Control of Induction Motor Drive Using Neural Network Identifier ," *IEEE Transaction on Energy Conversion* , vl. 14 , no. 4 , pp. 881-886 , December 1999.

AUTHOR BIOGRAPHIES

Swati deshmukh has received her Bachelor of Electrical Engineering From Bhilai Institute of Technology Durg , India in 2010. She pursuing her Master in Engineering (Power Electronics) from Rungta College of Engineering and Technology, Bhilai. Currenty she is lecturer in the department of Electrical Engineering Mansa Polytechnic College Bhilai, India. Her current Research include AC drives, neural network based controller design.

Neha Tiwari did her BE in Electrical and Electronics from SSCET, Bhilai (CG) and M Tech in Electrical Instrumentation from IIT Kharagpur (WB). She is an Assistant Professor in Electrical Engineering Department at RCET,Bhilai (CG). Her main field of interest is – MEMS devices and Packaging, Instrumentation, Power Electronics.