Design of Hybrid Controller for Direct Torque Control of Induction Motor Drive

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Abstract – *This paper presents direct torque control of three phase Induction Motor (IM) and superior hybrid controller for the control of speed of IM. The performance of hybrid controller is simulated over the conventional controller. To remove the disadvantage of PI controller hybridization of PI and Fuzzy Logic Controller (FLC) has been done. The hybrid controller performs well again in terms of settling time, undershoot, overshoot and rise time problems. For the control of the system DTC operating principle is used. The projected method is applied to a three phase IM, and then the measurement results are analyzed.*

***Key Words*:Induction Motor (IM), Direct Torque Control (DTC), PI controller, Fuzzy Logic Controller (FLC), Hybrid Controller**

1.INTRODUCTION

For speed control reason electric drives are used. The types of electric drives are AC and DC drives. Because of high efficiency, better performance, robustness and less maintenance AC drives especially Induction Motor Drives (IMD) are most commonly used in industrial applications instead of DC drives. The IMD control method is further classified as scalar and vector control method. Operating in steady state, the angular speed of current, voltage and flux linkage in the space vectors are controlled by scalar control. Hence during transient state the scalar control doesn't operate in space vector position. The instantaneous position of current, flux linkage and voltage of space vector along with the angular speed and magnitude are controlled with the vector control.[2]-[3] The vector control allows controlling of induction motor like a separately excited dc motor.

For the control of different plants, PI controllers are used in various industries to have reasonable performance. But it is not desirable for certain applications like ac drive control. Therefore it is needed to replace these conventional controllers with advanced controllers. The perfect control is not achieved by the PI controller. The speed of induction motor can't be kept at desired set speed continuously when there is a disturbance and change in set speed. Hence hybrid controller is used for the better control of induction motor instead of conventional PI controller.

The Fuzzy Logic Controller (FLC) is an advanced control technique which doesn't require any complex mathematical algorithms. FLC is based on the linguistic rules consists of IF_THEN type rules. A hybridization of controller is done, by keeping the advantages present in both PI and FLC, and treated as a single controller [12]-[13].

This paper gives the mathematical modeling of Induction Motor, introduction of DTC and its principle, discussion about PI, FLC and hybrid controller. Finally we discuss about the simulation results obtained.

2. MATHEMATICAL MODELLING OF INDUCTION MOTOR

The induction motor has stator and rotor voltage which are given as

$$V_s = \frac{d\psi_s}{dt} + R_s i_s$$

$$0 = \frac{d\psi_r}{dt} - j\omega.\psi_r + R_r i_r$$

Rotor windings are short circuited hence rotor voltage has zero magnitude. Modeling of induction motor by its voltage equations in stator co-ordinates is given. The following equations give stator flux linkage, stator voltage, rotor flux linkage, stator current and rotor current respectively.

$$\psi_s = \begin{bmatrix} \psi_{ds} \\ \psi_{qs} \end{bmatrix}$$

$$V_s = \begin{bmatrix} V_d \\ V_q \end{bmatrix}$$

$$\psi_r = \begin{bmatrix} \psi_{dr} \\ \psi_{qr} \end{bmatrix}$$

$$i_s = \begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix}$$

$$i_r = \begin{bmatrix} i_{dr} \\ i_{qr} \end{bmatrix}$$

Where,

R_s –Resistance of Stator
R_r – Resistance of Rotor
ω_r – Rotor in elect.rad/sec
The following equations give stator flux linkage and rotor flux linkage in the form of stator and rotor currents.

$$\psi_s = L_s i_s + L_m i_r$$
$$\psi_r = L_r i_r + L_m i_s$$

Where,
L_r –Self inductance of Rotor
L_s – Self inductance of Stator
L_m – Mutual inductance
In d-q axis reference frame the induction motor has equations which are formulated as

$$V_{ds} = r_s i_{ds} + p\psi_{ds}$$
$$V_{qs} = r_s i_{qs} + p\psi_{qs}$$
$$V'_{dr} = r'_r i'_{dr} + p\psi'_{dr} + \omega_r \psi'_{qr}$$
$$V'_{qr} = r'_r i'_{qr} + p\psi'_{qr} - \omega_r \psi'_{dr}$$

Zero sequence components are neglected as they are not responsible for the production of torque. Following equations give the various flux linkages

$$\psi_{ds} = L_s i_{ds} + L_m i'_{dr}$$
$$\psi_{qs} = L_s i_{qs} + L_m i'_{qr}$$
$$\psi'_{dr} = L'_r i'_{dr} + L_m i_{ds}$$
$$\psi'_{qr} = L'_r i'_{qr} + L_m i_{qs}$$

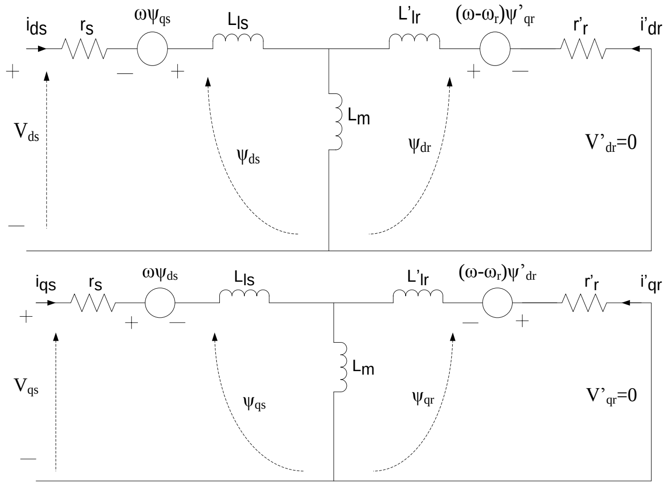

Fig.1 d-q Equivalent Circuit of Induction Motor.

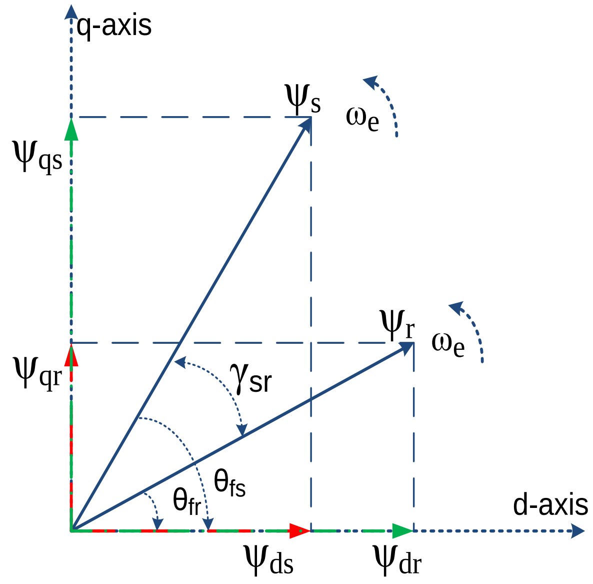

Fig.2 Vector Diagram for Induction Motor.

The electromagnetic torque in three phase induction motor is specified as

$$T_e = \frac{3}{2}\frac{P}{2}\left(\psi_{ds}.i_{qs} - \psi_{qs}.i_{ds}\right)$$
$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{\sigma L_s L_r}\left(\psi_{qs}.\psi_{dr} - \psi_{ds}.\psi_{qr}\right)$$
$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{\sigma L_s L_r}|\psi_s||\psi_r|\sin\gamma_{sr}$$

Where,
σ – Leakage factor
γ_{sr} –similar to torque which is angle between stator and rotor flux.
The torque can be controlled by changing the angle γsr. To deliver rated power and to avoid the saturation of motor the value of flux is kept constant. Hence for the control of torque γ_{sr} is controlled.

3. DIRECT TORQUE CONTROL

Simple control structure, robustness, fast dynamic response etc. are the advantages of DTC. The control of electromagnetic torque and stator flux linkage has been done in DTC by choosing the optimum inverter voltage vector. The switching look-up table contributes for low harmonic losses, fast torque response, and low inverter switching frequency. The following figure shows the DTC scheme.

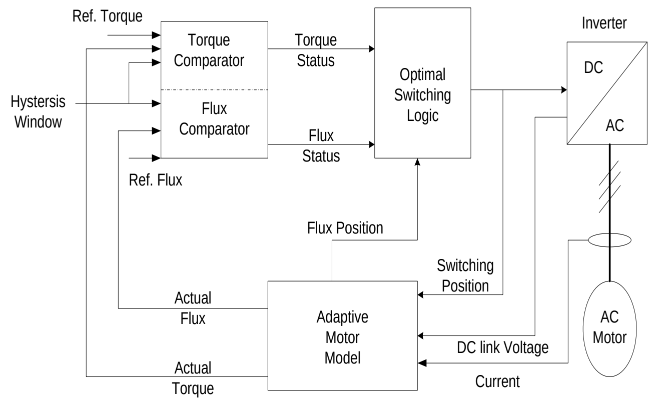

Fig.3 Basic DTC Scheme

It has most advantageous switching logic, torque comparator and flux comparator. The adaptive motor model evaluates actual torque, stator flux and actual speed. The error values are evaluated by the comparison of actual values with the reference values of stator flux and torque. The two level hysteresis block is fed with stator flux error and that of three level hysteresis block with torque error. The outputs of these blocks are given to the optimal switching logic block and then switching logic is provided to the inverter.

4. PRINCIPLE OF DTC

Stator currents are transformed into d-q reference for the control of Induction Motor torque which involve determination of both torque and flux errors. These errors help switching look up table to select proper voltage vector required to drive IM. Stator voltage vector estimates the flux by neglecting stator resistance it is formulated as

$$\bar{\Psi}_s = \int_0^{\Delta t} (\bar{V}_s - \bar{i}_s R_s) = \bar{V}_s \Delta t$$

For the achievement of preferred stator current the output voltage is regulated with controller.

5. PI CONTROLLER

The block diagram of PI controller is given as

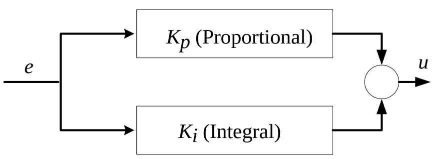

Fig.4 Block diagram of PI controller

Kp – Proportional Gain Constant
Ki –Integral Gain Constant
e - errors
u - output

The limiter is used next to the PI controller to stabilize the system and to limit the value of gain when it exceeds certain value. Speed errors are maintained by the limiter within saturation limits even though the PI controller gain is high. The reference speed is then achieved by the motor rapidly.

6.FUZZY CONTROLLER

While operating on no load PI speed controller has zero steady -state error and is simple in operation. But the main drawback of this PI controller is the occurrence of overshoot at the time of starting and load removal also undershoots while application of load. For the removal of these drawbacks Fuzzy controller is used along with PI controller. The membership functions, fuzzy rules and their distribution determine the performance of the Fuzzy controller.

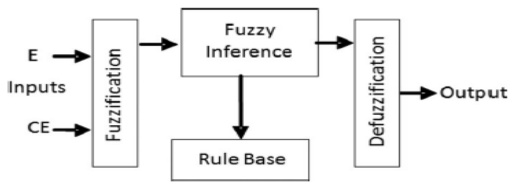

Fig. 5 Block diagram of FLC

7. HYBRID CONTROLLER

The benefits of both the PI and FLC are used in hybrid controller. The negligible overshoot and undershoot are the main advantages of FLC and zero steady state error is that of PI controller.

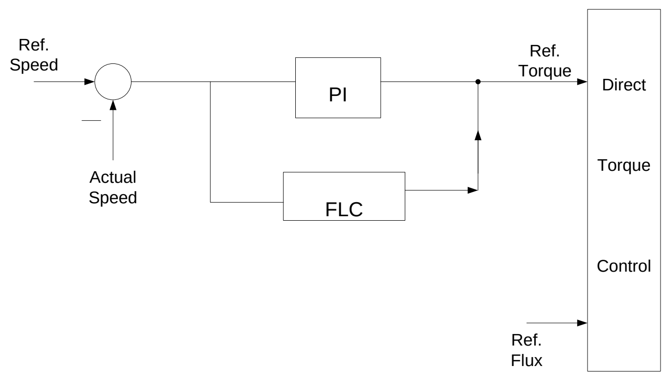

Fig. 6 Block diagram of Hybrid Controller

The linguistic rule base for the FLC is as follows

Table I

N / N*	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

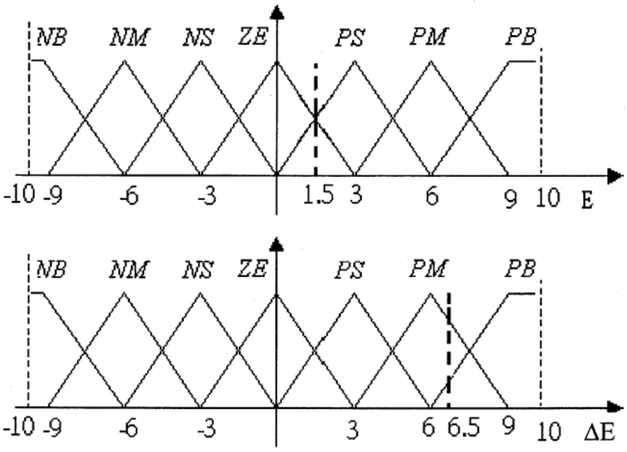

Fig .7. Membership Function And Input Variables

8.MATLAB/SIMULINK MODEL

DTC block is the main element of the simulink has flux and torque hysteresis block, toque and flux calculator block, switching control block and switching table block. For the estimation of the motor flux d-q components and electromagnetic torque, the torque and flux calculator blocks are used. The flux and torque hysteresis block has and three-level hysteresis comparator for the toque control and two-level hysteresis comparator for flux control. For the proper selection of voltage vector the switching table has look-up tables in it working according to the output of the flux and torque hysteresis comparison. Switching control block is used to limit the inverter commutation frequency.

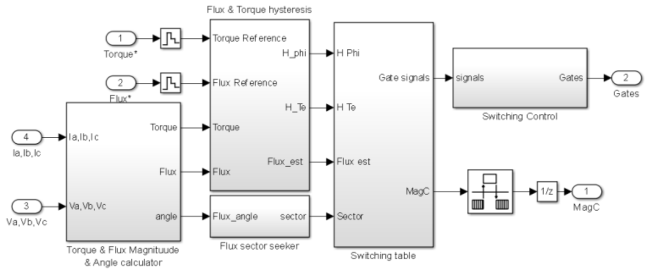

Fig.8 Simulink Model for DTC

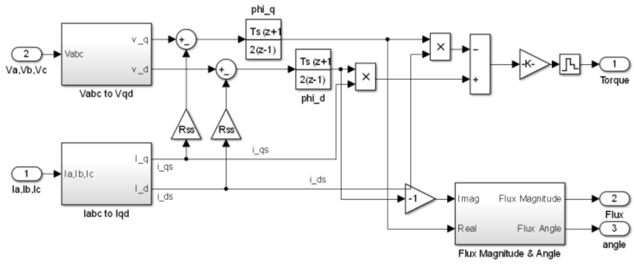

Fig.9 Torque, Flux Magnitude and Angle Calculator.

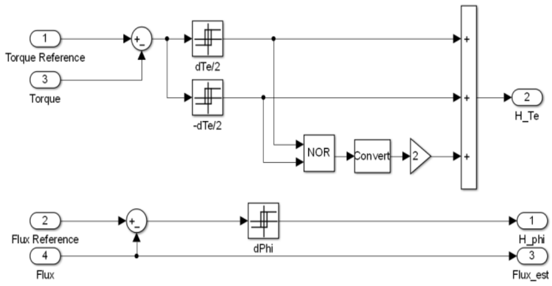

Fig.10 Flux and Torque Hysteresis.

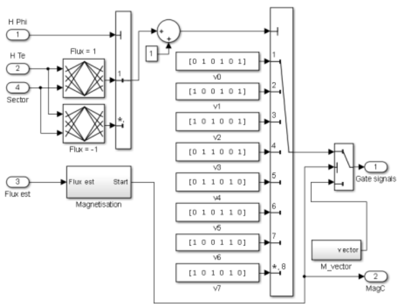

Fig.11 Simulink Model for Switching Table

9.SIMULATION RESULTS

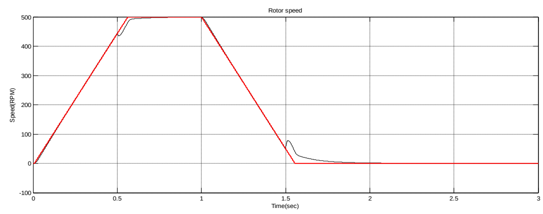

Fig.12 Rotor

speed

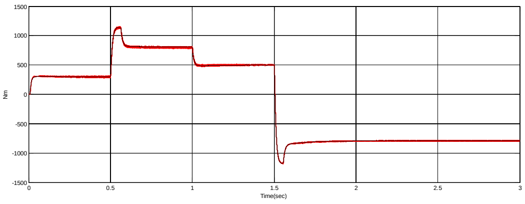

Fig.13 Electromagnetic Torque

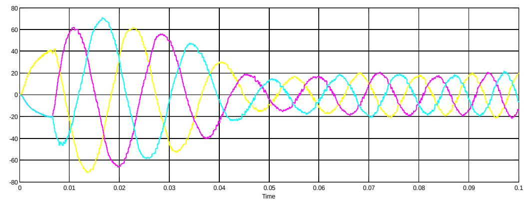

Fig.11 Stator Currents Ia,Ib,Ic.

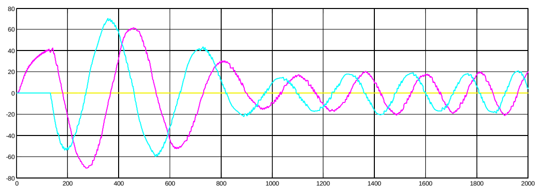

Fig.12 Stator Currents Id and Iq.

10. RESULTS

The results show the graph of rotor speed, electromagnetic torque and stator currents. Initially the speed is set at 500 rpm at time t=0 sec. We can observe that the speed is increasing in ramp fashion from initial position. After some time the speed sets at 500 rpm. After the application of load torque the speed of motor still ramps to its final value for short time. The speed is set zero at t= 1 sec. Though the value of torque varies the speed remain constant.

11. CONCLUSIONS

This paper proposes effective control technique in terms of hybrid controller for Direct Torque Control of Induction Motor Drive. The steady state errors, undershoot, overshoot and rise time this kind of problems are reduced with the help of hybrid controller. It gives better results than conventional type controllers. The drawbacks of the conventional controllers are removed by hybrid controller. The hybridization of PI and FLC has been done and presented as a single controller.

REFERENCES

[1] E P.M.Menghal and Dr.A.Jaya laxmi, “Dynamic Modeling, Simulation & Analysis of Induction Motor Drives,” International Conference on Science,Engineering and Management, Chennai, Ind., Nov. 2014.

[2] K.Suman,K.Sunita and M.Sasikala, “Direct Torque Controlled Induction Motor Drive With Space Vector Modulation Fed With Three Level Inverter,” International Conference on Power Electronics, Drives and Energy Systems , Bengaluru, Ind., Dec. 2012.

[3] Guiseppe Buja,Domenicco Casadei and Giovanni Serra, “Direct Torque Control of Induction Motor Drives,” Proceedings of the IEEE International Symposium on Industrial Electronics, Guimaraes, Jul. 1997.

[4] Dr.M.V.Aware, Dr.S.G.Tarnekar and Jagdish.G Chaudhari, “Improved Direct Torque Control Induction Motor Drive,” TENCON 2006 IEEE Region 10 conference, Hong Kong, Nov.2006.

[5] P.Tiitinen, P.Pohkalainen, and J.Lalu, “The next generation motor control method : Direct Torque Control (DTC)”, EPE Journal, Vo1.5, No.1, March 1995, pp.14-18.

[6] D.Casadei, G.Grandi, GSerra, and A.Tani, “Switching strategies in direct torque control of induction machmes”,Cod. Proc. of ICEM94, pp. 204-209.

[7] Domenico Casadei, B., Profumo, F., Serra, G., Tani, A.: ‘FOC and DTC: two viable schemes for induction motors torque control’, IEEE Trans. Power Electron., 2002, 17, (5), pp. 779-787.

[8] P. Titinen, M. Surandra, ”The next generation motor control method, DTC direct torque control,” Power Electronics, Drives and Energy System for Industrial Growth, 1996, Pro. of the 1996 International Conf. Vol. 1, pp. 37-43, 1996.

[9] B.K.Bose, Power electronics and variable frequency drives, IEEE Press, New York, 1996.

[10] Y. S. Lai, “Modeling and vector control of induction machines—A new unified approach,” Proc. IEEE PES Winter Meeting, pp. 47–52, 1999.

[11] Y. S. Lai, J. H. Chen, and C. H. Liu, “A universal vector controller for induction motor drives fed by voltage-controlled voltage source inverter,” Proc. IEEE PES Summer Meeting, pp. 2493–2498, 2000.

[12] Yen-Shin Lai, Juo-Chiun Lin, “New hybrid fuzzy controller for direct torque control induction motor drives”, Power Electronics, IEEE Transactions on , Volume: 18 , Issue: 5 ,Pages:1211–1219,Sept. 2003

[13] S. Mir, M. E. Elbuluk, and D. S. Zinger, “PI and fuzzy estimators for tuning the stator resistance in direct torque control of induction machines,” Proc. IEEE PESC, pp. 744–751, 1994.

[14] Y. Su, X. Wang, C. Ding, and Y. Sun, “Fuzzy control method with forward feedback integration for table furnace,” in Proc. SICE 38th Annu. Conf., 1999, pp. 1193–1197.

[15] Y. S. Lai and Y. T. Chang, “Design and implementation of vector-controlled induction motor drives using random switching technique with constant sampling frequency,” IEEE Trans. Power Electron., vol. 16, pp. 400–409, May 2001.

[16] Y. S. Lai and J. H. Chen, “A new approach to direct torque control of induction motor drives for constant inverter switching frequency and torque ripple reduction,” IEEE Trans. Energy Conv., vol. 16, pp. 220–227, Sept. 2001.

[17] M. Depenbrock, “Direct-self control of inverter-fed induction machine,” IEEE Trans. Power Electron., vol. 3, pp. 420–429, July 1988.