Radak Blange[1]
Arvind Kumar Singh[1]

Fuzzy Based Direct Torque Control of Induction Motor for EV Application.

Journal of Electrical Systems

Abstract: Now an electric vehicle(EV) are being adopted a means of transportations. This EV is power by Battery system via electric motor for the purpose of propulsion. Among the electric motors induction motor is one of the widely used in electric vehicle system. Hence, speed and torque control of the induction motor is emerging topics which have been emphasized lots of attentions by researchers and scientist. Various methods of induction motor(IM) control which includes the state vector modulation(SVM) based direct-torque-control(DTC) and this DTC have been established the one of the best and efficient techniques of control IM drive-system. However, it is observed that conventional DTC use two controllers namely two level hysteresis and three level torque comparators for the generation of stator vector voltage which have lots of drawbacks. To overcome these drawbacks of DTC, adoption of fuzzy logic controller(FLC) replacing both the controllers have very bright future scope for smooth control torque of IM for EV application. In this work, FLC based DTC control of IM drive modelled in Matlab Simulink Environment is presented. At the same time, the performances analysis of electromagnetic torque behaviors of the of Conventional DTC and Fuzzy based DTC have been evaluated and compared. From the results of simulation, it is observed that FLC based DTC is much better that the Conventional DTC method as the former easily trackdowns the given reference torque and thereby efficiently improve toque-speed of IM drive. The behavior-response of Speed-torque of IM with FLC are much quicker cum faster and will greatly suitable for the torque changing application of EV drive in any form of road-conditions. In addition to this the proposed Fuzzy algorithms is very simple, robust and can be easily implemented on Microcontroller or in FPGA platform.

Keywords:-Fuzzy-Logic-Controller(FLC), Induction Motor(IM) Electric-Vehicle(EV),Direct Torque Control(DTC),Space-Vector-Modulation(SVM).

I. INTRODUCTION

Electric motors are broadly of two types-AC-Motor and DC-Motor.Due to the simple structure,cheaper,rugged,reliable and having higher efficiency,AC-motors are widely preferred over DC-Motors for the industrial drives.IM especially the squirrel cage-Induction motor(SCIM) is one of the most widely used AC motors in EVs. The SCIM were earlier used in constant speed drives applications, however with the development of advancement-technology in semiconductor world, it had been able to use for wide range of speed variable drives application[1]. The IM can be directly operated from the supply mains but for achieving variable speeds, frequency –converter has been connected between supply and the motors. [2].The estimation and control of IM drives coupled with emerging technology and power-electronic has become a vast subjects, in general induction motor is control by scalar control known as open control and by vector control known as closed loop control. Rotor magnetic flux(ϕ) and rotor torque(T_s) can be controlled by vector control method by estimating the speed and the voltage either by directly done through measurement or indirectly through calculations[3]. Vector control make AC drive an equivalent to DC drive for the independent control of flux(ϕ) and torque(T_s) but superior to Dc drive Dynamic-performance[4].One if the latest vector control for Induction motor drives is the direct torque control(DTC).In DTC drive of induction motor, feedback control of stator flux and torque are used which obtained from measured-valued of stator-voltage and stator-currents[5]. But DTC has some vital disadvantages of steady-state ripple both in flux and torque thereby affecting the estimation of speed. To overcome these drawbacks of DTC, fuzzy logic controller replacing both the hysteresis and torque comparator which are tremendously encouraging one.

In the present work, an attempt has been made for smooth control of induction motor drives by uses of fuzzy logic based IM drives by complete replacement of torque hysteresis system(THS) in Matlab Simulink Environment. For the details of study, the write up have been divided into VII-Sections.
Section-I deals introduction, Section-II describes concept of DTC, Section-III covers motor-modelling, Section-IV explains Hysteresis-Controllers as well as voltage switching-vector, Section-V explains the FLC, Simulation results in Section-VI AND Section-VII explain the Conclusion.

II. DIRECT TORQUE CONTROL OF IM.

Feedback control of stator-flux and torque are used in DTC method. These two quantities are obtained from the measured value of stator-voltage(SV) and stator-current(SC)[5]
The details of Block-diagram of conventional DTC drive is provided in Fig.1 stator reference-model of induction motor have been used in the method as we avoid long and tedious operation of trigonometric operations for the Coordinate Transformation of Synchronous Reference Frame(SRR) which one of the advantages of DTC technique [6]. To control

[1*],[2]Dept. of Electrical Engineering, NERIST-Nirjuli-791109, Arunachal Pradesh.Email-id: radakblange@gmail.com

the stator-flux(SF) and torque of induction motor, Hysteresis Band(HB) are used. When the SF moves out of HB, then the Inverter-Switching-Stator(ISS) are altered so that SF adopts on optimal path in line with desired valued [4].Using the error signal of estimated value of torque(T_s) and flux(ϕ), direct control of inverter states is possible so that error is reduced with the tolerance band limits[2].No voltage is required to be applied on the motor when the error signal is well within the acceptable range. In absence of various Controllers and Transformations, the delaying in signal processing is immensely reduced besides provisions of Instantaneous Voltage Vector Direct torque control Method.
However, Direct torque Control method have some disadvantages, out which Steady-State Ripple(SSR) in both the torque(T_s) and flux(ϕ) which directly affects accuracy in estimation of speed[7].

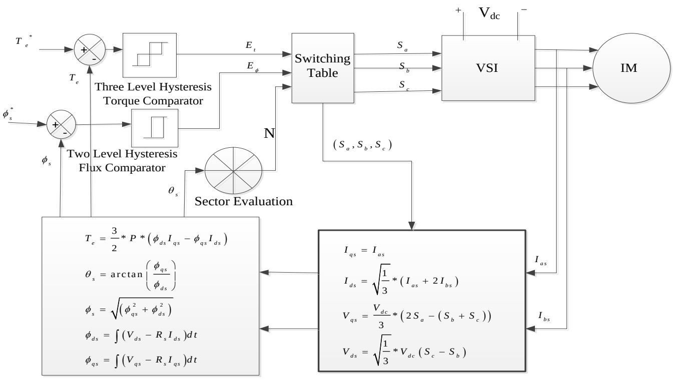

Fig 1. Block Diagram of DTC based IM Drives.

III. INDUCTION MOTOR MODEL.

IM have been modelled by the following set of equations given below, All Quantities are referred as either with respect to Stator or Rotor. The Three Switching Voltage Vectors(TSVV) for Voltage Source Inverter(VSI) have been considered as S_a, S_b, S_c using which the Direct(d) and Quadrature(q) components of the stator voltages are achieved as follows:

$$V_{ds} = \left(\sqrt{\frac{1}{3}}\right) * V_{dc}\left(S_c - S_b\right) \qquad (1.1)$$

$$V_{qs} = \left(\frac{V_{dc}}{3}\right) * \left(2S_a - \left(S_b + S_c\right)\right) \qquad (1.2)$$

Where V_{dc} is Input DC Voltage. The corresponding component of d and q of flux ϕ_s w.r.t to Stator are given as under:

$$\phi_{ds} = \int \left(V_{ds} - R_s I_s\right) dt \qquad (1.3)$$

$$\phi_{qs} = \int \left(V_{qs} - R_s I_s\right) dt \qquad (1.4)$$

The Stator Flux(ϕ_s) and Electromagnetic Torque(T_e) of Motor as well as the shifted Angle of (θ_s) are given by the following eqns.

$$\phi_s = \sqrt{\left(\phi_{qs}^2 + \phi_{ds}^2\right)} \qquad (1.5)$$

$$T_e = \left(\frac{3}{2}\right) * P * \left(\phi_{ds} I_{qs} - \phi_{qs} I_{ds}\right) \qquad (1.6)$$

$$\theta_s = arctg\left(\frac{\phi_{qs}}{\phi_{ds}}\right) \qquad (1.7)$$

Where P is the Number of Stator Poles, I_{ds} and I_{qs} are the d and q Components of Stator Current

IV. HYSTERESIS- BAND CONTROLLER AND VECTOR OF SWITICHING VOLTAGE

The estimated Torque and Stator Flux are compared with the Reference value of Torque and Reference Flux respectively. From the fig.1, it is observed that T_e^* and T_e are the two input to Three Level Hysteresis Comparator and similarly ϕ_s^* and ϕ_s are the input to the Two Level Hysteresis Comparator and Torque error $E_t = T_e^* - T_e$, flux error $E_\phi = \phi_s^* - \phi_s$ AND the sector Evaluation N are the three input the Switching Table.

On the basis of desired output from Torque Hysteresis(TH) and Flux Hysteresis(FH), the Switching States(SS) for the Hex-Bridge Inverters is desirably generated. Depending upon the increment or decrement of Torque and Flux at a given value of Flux-Sector the required and the corresponding Voltage Vector(VV) are generated and the incremental or detrimental of Torque and Flux determines VV for which their relation is provided Table-I[6]

Table I: Switching-Voltage-Vector for VSI.

E_Φ	E_T	N=1	N=2	N=3	N=4	N=5	N=6
1	1	V6	V1	V2	V3	V4	V5
1	0	V7	V0	V7	V0	V7	V0
1	-1	V2	V3	V4	V5	V6	V1
0	1	V5	V6	V1	V2	V3	V4
0	0	V0	V7	V0	V7	V0	V7
0	-1	V3	V4	V5	V6	V1	V2

V. FUZZY LOGIC CONTROLLER BASED DTC

In the recent years, FLC based controller have been active research area for effective for Controlling IM drives[8-10].The Space-Vector Modulation(SVM) based direct torque control adopt two proportional Integral controller for the generation of required reference stator-vector but direct torque control technique have major drawbacks. To overcome the drawbacks of DTC-SVM, FLC based DTC by substituting the PI-controllers which attains and achieve a de-coupling torque, stator-flux control with very low ripple showing very good performance attaining quick and faster response[9-10].The block diagram of proposed Fuzzy based DTC of Induction Motor drive is provided in Fig.2.and the block-diagram of FLC is provided in Fig.3

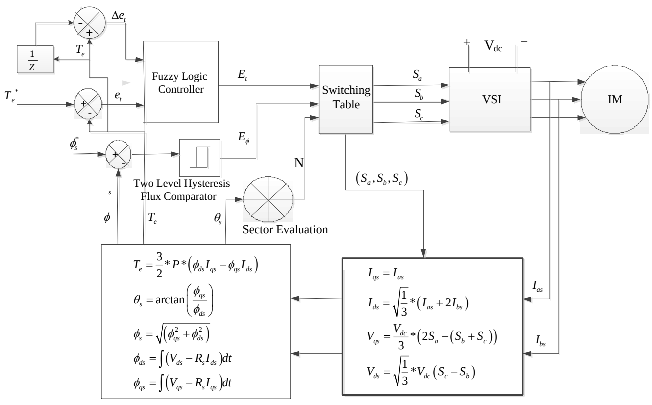

Fig 2. Block Diagram of DTC with Proposed FLC based IM Drives

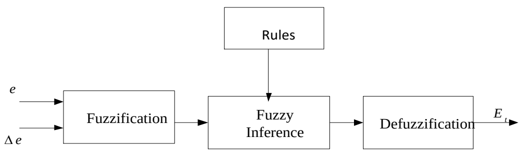

Fig 3. Block Diagram of Fuzzy logic Controller

The FLC block as shown in Fig.3 has two inputs and one output. The two input variables are error(e)=$T_{ref} - T_{actual}$ and change in Error(Δe) =$T_{present} - T_{previous}$ and Output Variables(OPV) is E_t. The Input Variables(IPV) “change in error” and the output-torque have been converted in per unitary.The Fuzzy Membership Functions (MF) of IPV and OPV are in Fig.4, Fig.5 and Fig.6 respectively. Negative- High(NH),Negative-Medium(NM),Negative-Low(NL),Very-Negative Low(VNL),Zero(Z),Positive- High(PH), Positive- Medium(PM),Positive- Low(PL),Very Positive- Low(VPL).

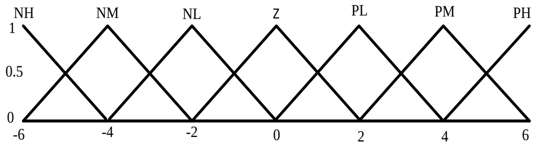

Fig 4. MF of input variables "error"

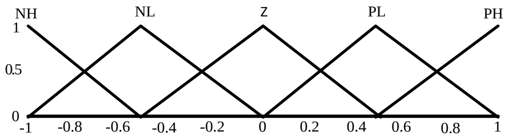

Fig 5. MF of input variables " Change in error"

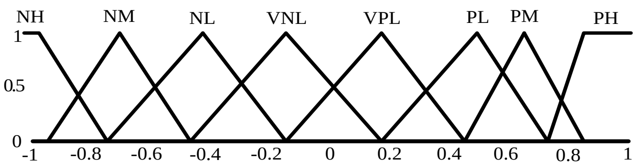

Fig 6. MF of Output variables " Torque"

The rules of fuzzy logic controller have been provided in Table-II. The set of fuzzy rules is based on Mamdani- Methods and the to obtained the output torque, centre of gravity method have been used for the defuzzifications of fuzzy rules.

TABLE.II Fuzzy Control Rules

Δe \ e	NH	NM	VNL	Z	PL	PM	PH
NH	NL	NL	VNL	VPL	PM	PH	PH
NL	NL	NL	VNL	VPL	PL	PM	PH
Z	NL	VNL	VNL	VPL	VPL	VNL	VPL
PL	NM	NM	NL	VNL	VPL	PL	PM
PH	NH	NM	NM	VNL	VPL	PL	PL

VI. SIMULATION RESULTS

The simulation of the proposed method have been carried out in Matlab Simulink platform. For the purposed of simulation, the parameters of the induction motor taken have been provided in Table-III and motor chosen was squirrel cage type induction motor and 3.725 N-m was the reference torque at supply AC voltage of 415/220V,50Hz.

Table III-Parameters of IM.

Parameters	Values
Voltage	415/220V
Pole Pair	1
R_s	4.61Ω
R_r	7.548Ω
L_s	0.022H
L_r	0.022H
M_{sr}	o.447H
J	0.01484kg/m^2

The results from the simulations are provided in Fig.7, Fig.8. and Fig.8 respectively

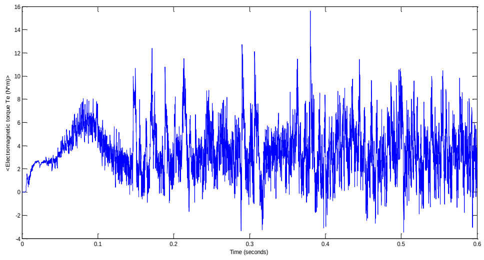

Fig 7. Output Torques of IM with Flux hysteresis and torque hysteresis

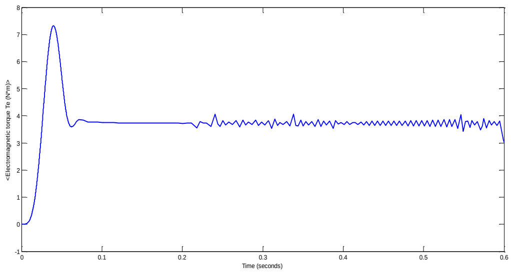

Fig.8 Output Torque of IM with Flux Hysteresis and torque hysteresis replaced by fuzzy logic controller

The results of output torque from simulations of Conventional-DTC and with Flux Hysteresis remain intake and replacing hysteresis comparator by fuzzy logic controller have been analyised and compared and are provided in Fig.9. From the results it is observed that FLC algorithm based DTC provides much faster response, quicker tracking of reference torque.

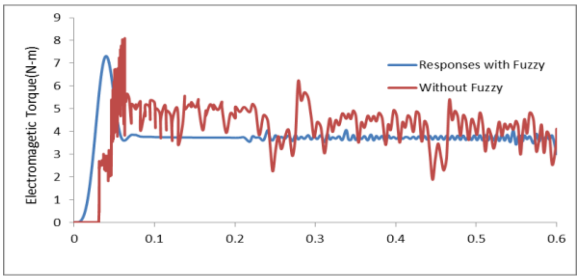

Fig.9 Comparison of output torques of conventional DTC of IM with Fuzzy controller

VI CONCLUSION

In the present work, fuzzy based DTC control of Induction motor have designed and presented. The Conventional-DTC keeping two level Flux Hysteresis remain intaked and replacing the three level Torque hysteresis comparator by fuzzy logic controller have been modelled and simlauted the same in Matlab Simulink Environment. The output torque of conventional DTC with all two level flux hysteresis and three level torque hysteresis from simulation results have been analyses and the results of output torque from simulations of Conventional-DTC and with Flux Hysteresis remain intake and replacing hysteresis comparator by fuzzy logic controller have been analyzed and compared. From the results it is observed that FLC algorithm-based DTC is much better in terms of faster response, quicker tracking of given reference torque that the Conventional DTC drives and ultimately provides better performance and improves efficiency which may be quit useful for fasting changing torque in EV applications.

REFERENCES

[1] M. Kazmierkowski, G. Buja, Review of direct torque control methods for voltage source inverter-fed induction motors, in IEEE conf.on Industrial Electronics Society , 2003,Vol. 1, pp. 981–991.

[2] I.. Takahashi, T. Noguchi, A new quick-response and high-efficiency control strategy of an induction motor,Industry Applications, IEEE Transactions on IA-22 (5) (1986) 820–827.

[3] F..Blaschke, The principle of field orientation as applied to the new transvector closed loop system for rotating field machines, Siemens Review Vol.39, no.3 (May 1972) 217–220.

[4] M. Depenbrock, Direct self-control (dsc) of inverter-fed induction machine, Power Electronics, IEEE Transactions on 3 (4) (1988) 420–429.

[5] T.Ohtani, Torque control using the flux derived from magnetic energy in induction motors driven by static converter, in: Conf. Record of International Power Electronics Conference, March 1983, pp.696–707.
[6] R..Krishnan, Electric Motor Drives: Modeling,Analysis,and control, PHI Learning, 2010.
[7] U. Senthil, B. G. Fernandes, Hybrid space vector pulse width modulation based direct torque controlled induction motor drive, in: Power Electronics Specialist Conference, 2003. PESC '03. 2003 IEEE 34th Annual, Vol. 3, 2003, pp. 1112–1117 vol.3.
[8] Turki Y.Abdalla et al" Direct Torque Control System for a three phase Induction Motor with Fuzzy Logic Based Speed Controller" 1st International Conference on energy,Power and Control(EPC-IQ)'2010.
[9] Jose L. Azcue P et al."The DTC-SVM scheme with Takagi-Sugeno fuzzy controller for three phase IM" on 8th international conference of fuzzy systems and knowledge Disvovery(FSKD) 2011
[10] Joes L. Azcue et al" SFO-DTC Scheme with Fuzzy Controller for Asynchronous machine" on 4th international Conference on power,Energy and electric drives ,2013