IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 4, Issue 5, May 2016

Simulation & Modelling of Direct Torque Control of Induction Motor Using Fuzzy Logic Controller

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Abstract: This paper mainly focused on Fuzzy Logic Controller used to improve the performance of Direct Torque Control (DTC) of induction motor. At the time of switching DTC drive gives the high torque ripple. In DTC induction motor drive there are torque and flux ripples because of incorrect voltage vector selection by VSI states is unable to generate the exact voltage value required to make zero both the torque electromagnetic error and the stator flux error. To overcome this problem a Fuzzy Logic Controller is proposed. The fuzzy logic controller is used to reducing the torque and flux ripples and it improve performance DTC especially at low speed.

Keywords: direct torque control, induction motor, fuzzy logic, torque ripple minimization, fuzzy logic controller.

I. INTRODUCTION

The Induction Motor (IM) drives controlled with the vector control method has mostly accepted in the industry[1]. However, this control technique requires complex coordinate transformation, inner current control loop and accurate system parameters. On the other hand, the Direct Torque Control (DTC) method provides robust and fast torque response without such coordinate transformation, PWM pulse generation and current regulators[2]. Moreover, DTC minimizes the use of motor parameters technique suffers from a major disadvantage of steady state ripple in torque and flux, because none of the inverter-switching vector is able to generate the exact stator voltage at proper instants as well as in space. These torque and flux ripples affect the accuracy of speed estimation; result in high acoustic noise and harmonic losses[3]. There are many methods to reduce this torque and flux ripple: (a) the alternative inverter topologies, multilevel inverters and matrix converters which increase the number of switches, and thus cost and complexity; (b) the higher switching frequencies reduce the harmonic content of stator current and thus torque and flux ripple[4]. However, such higher switching frequencies lead to increased switching losses and stress on semiconductor switches of the inverter (c) yet, another method of reducing torque and flux ripples is fuzzy logic controller gives constant switching frequency. Moreover this method requires complex control schemes than classical DTC and is machine parameter dependent.

DTC drive over the last decade becomes one possible alternative to the well-known Vector Control of Induction Machines. Its main characteristic is the good performance, obtaining results as good as the classical vector control but with several advantages based on its simpler structure and control diagram. DTC (Direct Torque Control) is characterized, as deduced from the name, by directly controlled torque and flux and indirectly controlled stator current and voltage. The DTC has some advantages in comparison with the conventional vector-controlled drives, like:Direct torque control and direct stator flux control, Indirect control of stator currents and voltages, Approximately sinusoidal stator fluxes and stator currents, High dynamic performance even at locked rotor, Absences of co-ordinates transform, Absences of mechanical transducers, Current regulators, PWM pulse generation, PI control of flux and torque and co-ordinate transformation are not required, Very simple control scheme and low computation time, Reduced parameters sensitivity, Very good dynamic properties[5-6].Conventional DTC has also some disadvantages :Possible problems during starting and low speed operation, High requirements upon flux and torque estimation, Variable switching frequency. These are disadvantages that we want to remove by using fuzzy logic.

II. DTC SCHEMATIC

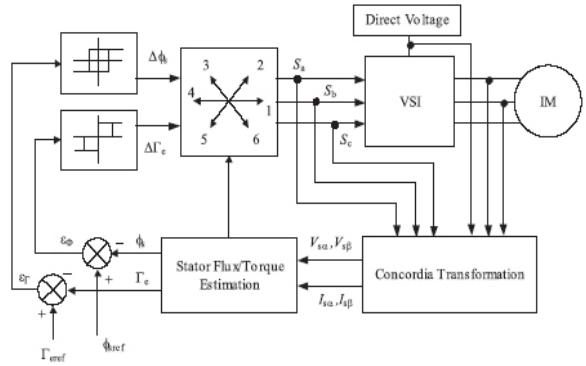

Fig.1. Block diagram of DTC scheme

DTC scheme is given in Fig. 1, the ϵ_Φ and ϵ_τ signals are delivered to two hysteresis comparators. The corresponding digitized output variables: change of magnetic fluxΔ_{Φ}, of mechanical torque $\Delta_{\tau e}$and the stator flux position sector S_N created a digital word, which selects the appropriate voltage vector from the switching table. The selection table generates pulsesS_a, S_b, S_c, to control the power switches in the inverter. Three-level torque and two level flux hysteresis controllers are used according to the outputs of the torque controller and the sector information S_{Φ} of Φ_s, , appropriate voltage vectors for both the inverters are selected from a switching table as it is shown in table 1

TABLE I. CLASSICAL DTC SWITCHING TABLE

Table Head	Classical DTC switching table							
	Flux	Torque	Sector Sφ					
1	Δφ	Δτ	Sφ 1	Sφ 2	Sφ 3	Sφ 4	Sφ 5	Sφ 6
2	1	1	V2	V3	V4	V5	V6	V1
3	1	0	V7	V0	V7	V0	V7	V0
4	1	-1	V6	V1	V2	V3	V4	V5
5	-1	1	V3	V4	V5	V6	V1	V2
6	-1	0	V0	V7	V0	V7	V0	V7
7	-1	-1	V5	V6	V1	V2	V3	V4

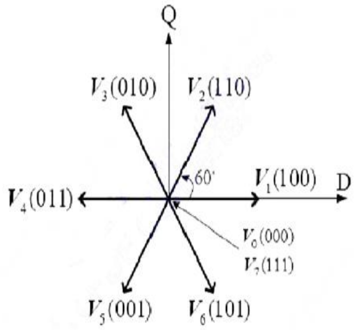

Fig.2. Eight possible voltage space

Fig.2 shows the voltage vectors which are usually employed in DTC scheme when the stator flux vector is lying sector I is shown in fig 3. The selection of a voltage vector at each cycle period is made in order to maintain the torque and the stator flux within the limits of two hysteresis bands. This simple approach allows a quick torque response to be achieved, but the steady state performance is characterized by undesirable ripple in current, flux and torque. This behaviour is mainly due to the absence of information about torque and rotor speed values in the voltage selection algorithm.

III. VECTOR TRANSFORMATIONS

A. Concordia transformation for voltages

By using this transformation, two voltages V_{sd} and V_{sq} are obtained. The measured voltage U0 is necessary and the switching table also S_a, S_b, S_c.

$$V_{sd} = \sqrt{\frac{2}{3}} U_0 \left(S_a - \frac{1}{2}(S_b + S_c) \right)$$

$$V_{sq} = \frac{1}{\sqrt{2}} U_0 (S_b - S_c)$$

B. Concordia transformation for currents

This transformation is used to obtain currents I_{sd} andI_{sq}, after measures ofI_{sa}, I_{sb} and I_{sc} of the stator.

$$I_{sd} = \sqrt{\frac{3}{2}} I_{sa}$$

$$I_{sq} = \frac{1}{\sqrt{2}} (I_{sb} - I_{sc})$$

C. Flux and torque estimations

DTC command is based on estimation in flux and in torque. In order to realize these estimators, we used results of Concordia transformations.

Because stator voltage is define by:

$$Vs = Rs * Is + (d\varphi s/dt)$$

We have $\varphi_s = \int Vs - Rs * Is$

That's why, we have two equations:

$$\Phi_{sd} = \int_0^t (V_{sd} - R_s I_{sd})\, dt$$

$$\Phi_{sq} = \int_0^t (V_{sq} - R_s I_{sq})\, dt$$

We can now estimate torque,

$$\tau_e = p[\Phi_{sd} I_{sq} - \Phi_{sq} I_{sd}]$$

IV. DTC CONTROLLER

The way to impose the required stator flux is by means of choosing the most suitable Voltage Source Inverter state. If the ohmic drops are neglected for simplicity, then the stator voltage impresses directly the stator flux in accordance with the following equation:

$$\frac{d}{dt}\bar{\psi}_s = \bar{u}_s$$

Or

$$\overline{\Delta\psi}_s = \bar{u}_s \Delta t$$

Decoupled control of the stator flux modulus and torque is achieved by acting on the radial and tangential components respectively of the stator flux-linkage space vector in its locus. These two components are directly proportional (R_s=0) to the components of the same voltage space vector in the same directions.

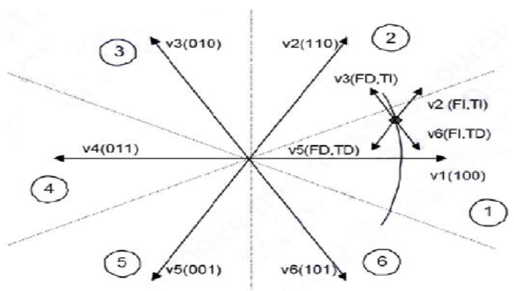

Fig.3. Stator flux vector locus

DOI 10.17148/IJIREEICE.2016.4515

The hysteresis band has to be set large enough to limit the inverter switching frequency below a certain level that is usually determined by thermal restriction of power devices. Since the hysteresis bands are set to cope with the worst case, the system performance is inevitably degraded in a certain operating range, especially in a low speed region. In torque hysteresis controller, an elapsing time to move from lower to upper limit, and vice versa can be changed according to operating condition.

V. FUZZY LOGIC CONTROLLER

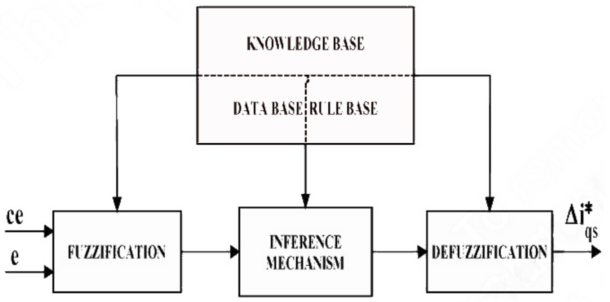

Fig.4. Block diagram for fuzzy logic controller

The fuzzy logic controller includes four major blocks: knowledge base, fuzzification, inference mechanism, and defuzzification. The knowledge base is composed of a data base and a rule base. The data base consists of input and output membership functions. The rule base is made up of a set of linguistic rules relating the fuzzy input variables to the desired fuzzy control actions. Fuzzification converts crisp input signals, the error e and error rate Δe, into fuzzified signals[7-8]. The inference mechanism uses the collection of linguistic rules to convert the input conditions into a fuzzified output. Finally, the defuzzification converts the fizzy outputs into crisp controlling signals, which in our system is the frequency change (Δf) for driving the induction motor. Inputs and output membership functions .

In such a Fuzzy Logic system, there are three inputs, stator flux position, electromagnetic torque error and the motor working point i.e. speed and torque. The output is the duty ratio. The fuzzy system comprises four groups of rules.

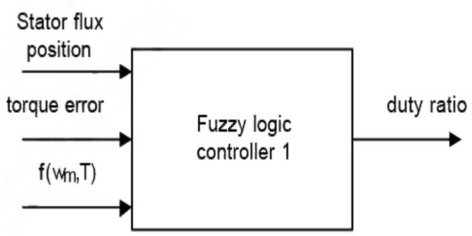

Fig.5.fuzzy Logic duty ratio estimator

Two of them are used when the stator flux is smaller than its reference value (Flux increase) and the other two in the opposite case (Flux decrease). The working point is firstly divided into two different cases. These two cases are speed wpc higher than torque Tpc (both in percent) and the opposite case. In any case just one fuzzy system is used per iteration, and it depends on the working point.

VI. SIMULATION

A) Motor characteristics: The rating of induction motor is 5Hp, 415V, 50Hz, 1430 rpm star connected induction motor.

For all simulation, the motor characteristics will be

Stator Resistance	(ohm)	1.405
Rotor Resistance	(ohm)	1.395
Stator Self Inductance	(H)	0.005839
Rotor Self Inductance	(H)	0.005839
Mutual Inductance	(H)	0.2037
No. of poles		4
Moment of Inertia	(kg.m^2)	0.03
Load torque (Nm)		15
Sampling time	(Ts)	1 sec

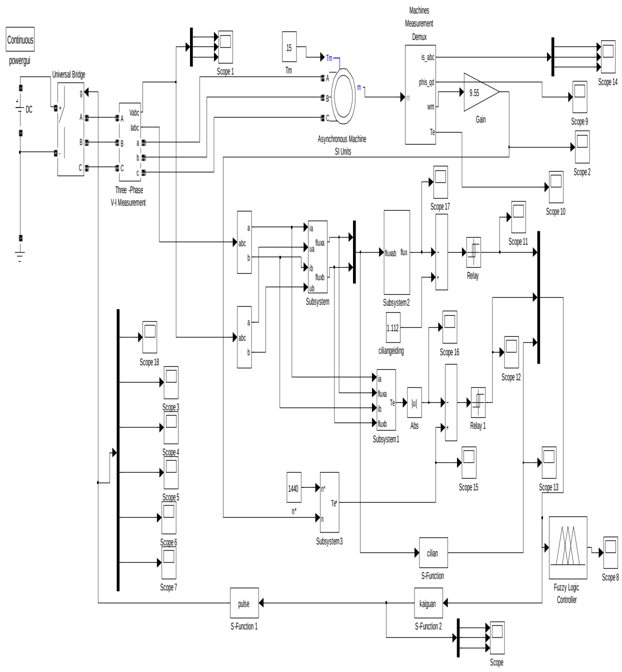

Fig. 6 .Direct Torque Control of Induction Motor with Fuzzy Logic Controller Schematic Using Simulink/Matlab.

B) SIMULATED RESULTS FOR DTC MODEL

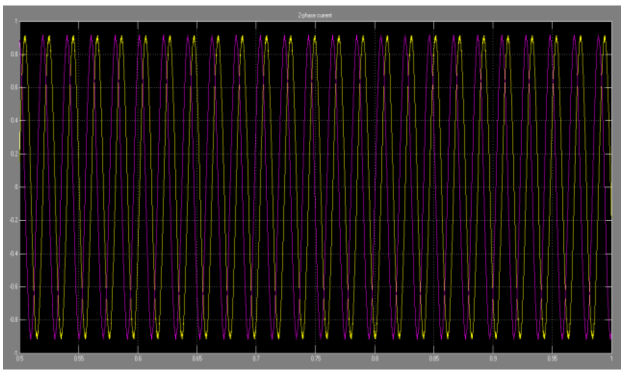

FIg.7. 2-phase current in DTC with FLC model

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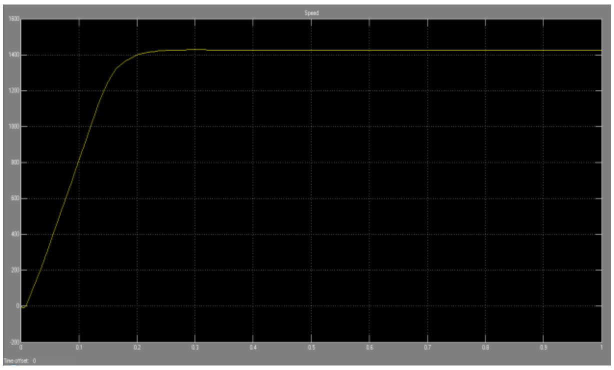
Fig.8. speed in DTC with FLC model

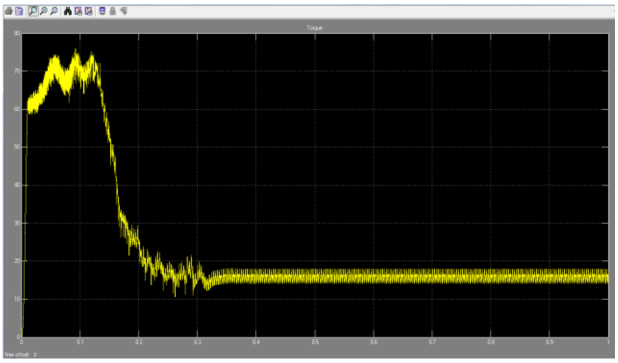
Fig.9. Torque in DTC with FLC model

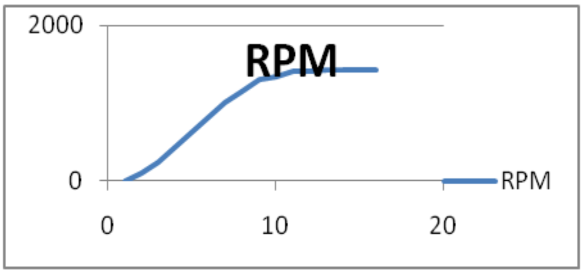

Fig.10.a.speed in dtc model

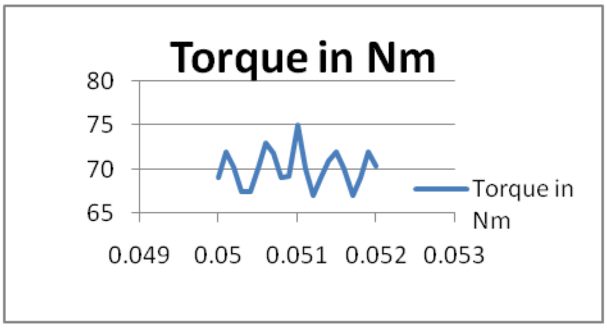

Fig.10.b.torque in dtc model

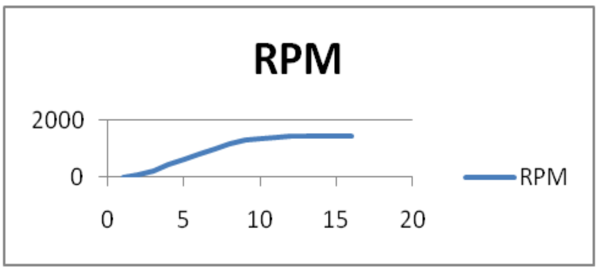

Fig.10.c.speed for DTC with Fuzzy Logic Controller

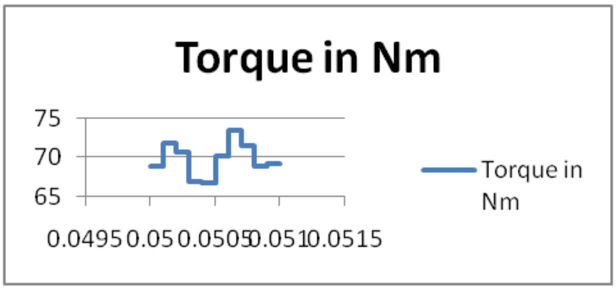

Fig.10.d.torque for DTC with Fuzzy Logic Controller

Fig.10.Study Cases- a,b) for DTC model c,d) For DTC with Fuzzy Logic Controller

The simulations of the DTC induction motor drive were carried out using the Matlab/Simulink simulation package. We get speed fuzzy DTC control of the induction machine fig show the Vab, Iab, Speed, Torque characteristics with Conventional DTC and Fuzzy DTC. From figure torque ripple is significantly reduced when fuzzy controller is in use. The fuzzy controller provides the desired amplitude according to the torque ripple level and operating condition, as it is shown in paper. It is seen that the steady state performance of the DTC-with fuzzy controller is much better than of the DTC-without fuzzy controller. For dynamic performance, the modified DTC is almost as good as the conventional DTC.

VII. CONCLUSION

For any IM drives, Direct torque control is one of the best controllers proposed so far. It allows decoupled control of motor stator flux and electromagnetic torque. From the analysis it is proved that, this strategy of IM control is simpler to implement than other vector control methods as it does not require pulse width modulator and co-ordinate transformations. But it introduces undesired torque and current ripple. DTC scheme uses stationary d-q reference frame with d-axis aligned with the stator axis. Stator voltage space vector defined in this reference frame control the torque and flux. The main inferences from this work are:

1. In transient state, by selecting the fastest accelerating voltage vector which produces maximum slip frequency, highest torque response can be obtained.

2. In steady state, the torque can be maintained constant with small switching frequency by the torque hysteresis comparator by selecting the accelerating vector and the zero voltage vector alternately.

3. In order to get the optimum efficiency in steady state and the highest torque response in transient state at the same time, the flux level can be automatically adjusted.

4. If the switching frequency is extremely low, the control circuit makes some drift which can be compensated easily to minimize the machine parameter variation.

The estimation accuracy of stator flux is very much essential which mostly depends on stator resistance because an error in stator flux estimation will affect the behaviour of both torque and flux control loops. The torque and current ripple can be minimized by fuzzy logic controller technique.

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