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Implementation of Fuzzy Logic Tuned Direct Torque Control in Induction Motor for Torque Ripple Reduction

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Abstract: **This paper deals with a new method of reducing the torque ripple in a Direct Torque Control (DTC) scheme adapted to induction motor. The main aim of this paper is on the use of a new fuzzy logic (FL) control for the DTC scheme. The performance of DTC scheme with a PI controller is compared with that using Fuzzy logic control. The comparison shows that the use of DTC_FL reduced the torque and stator flux ripples. The strength of the proposed methods is confirmed by the simulative results.**

Keywords: **Direct Torque Control (DTC), Induction Motor, Intelligent Control, Fuzzy logic (FL).**

I. INTRODUCTION

Induction motors are having complex, highly nonlinear and time varying dynamics and inaccessibility of some states and output for measurements and hence can be considered as a problem. The torque and flux control techniques have partially solved induction motor control problems, because they are sensitive to drive parameter variations and performance may be reduced if conventional controllers are used. Intelligent controllers are considered as potential candidates for such an application. Adaptive intelligent techniques are applied to achieve high performance decoupled flux and torque control. The DTC method is characterized by its simple implementation and a fast dynamic response. However if the control is implemented on a digital system (which can be considered as a standard nowadays). The actual values of flux and torque could cross their boundaries too far. The main advantages of DTC are absence of coordinate transformation and current regulator; absence of separate voltage modulation block, Common disadvantages of conventional DTC are high torque ripple and slow transient response to the step changes in torque during start-up[1]-[4]. For that reason the application of Fuzzy logic attracts the attention of many scientists from all over the world [1].

II. STATOR FLUX AND TORQUE ESTIMATION

The components of the current ($Is\alpha$, $Is\beta$), and stator voltage ($Vs\alpha$, $Vs\beta$) are obtained by the application of the transformation given by (1) and (2) and this equation is taken from the reference [1]

$$\begin{cases} I_{s\alpha} = \sqrt{\dfrac{2}{3}} Isa \\ I_{s\beta} = \dfrac{1}{\sqrt{2}} (Isb - Isc) \end{cases} \quad (1)$$

$$\begin{cases} V_{s\alpha} = \sqrt{\dfrac{2}{3}} U_0 \left(C_1 - \dfrac{1}{2}(C_2 + C_3) \right) \\ V_{s\beta} = \dfrac{1}{\sqrt{2}} U_0 (C_2 - C_3) \end{cases} \quad (2)$$

The components of the stator flux (ϕsα, ϕsβ) given by (3)

$$\begin{cases} \overline{\varphi}_{S\alpha} = \int_0^t (\overline{V}_{S\alpha} - R_S \overline{I}_{S\alpha})dt \\ \overline{\varphi}_{S\beta} = \int_0^t (\overline{V}_{S\beta} - R_S \overline{I}_{S\beta})dt \end{cases} \quad (3)$$

The stator flux linkage phase is given by (4)

$$\varphi_S = \sqrt{\varphi_{S\alpha}^2 + \varphi_{S\beta}^2} \quad (4)$$

The electromagnetic couple be obtained starting from the estimated sizes of flux (ϕsα,ϕsβ and calculated sizes of the current, Isα Isβ)

$$\Gamma_{em} = p(\varphi_{s\alpha} I_{s\beta} - \varphi_{s\beta} I_{s\alpha}) \quad (5)$$

III. ABOUT DIRECT TORQUE CONTROL

There are two methods of controlling torque. First method is field oriented control and the second method is Direct torque control. In this project the approaching method is direct torque control. The comparison and also advantageous of Direct torque control is that DTC has better steady state and transient response and another important point is that it does not require current regulators for pulse generation.

Direct torque control is a method of control using variable frequency drive. It is used to control the torque and flux and is used to estimate the magnetic flux of the motor. The following are the important properties of direct torque control.

1) Torque and flux can be changed very fast by changing the reference,

3) The step has no overshoot

2) The current and voltage measuring devices have to be high quality ones without noise and low pass filtering.

IV. ABOUT DTC FED INDUCTION MOTOR

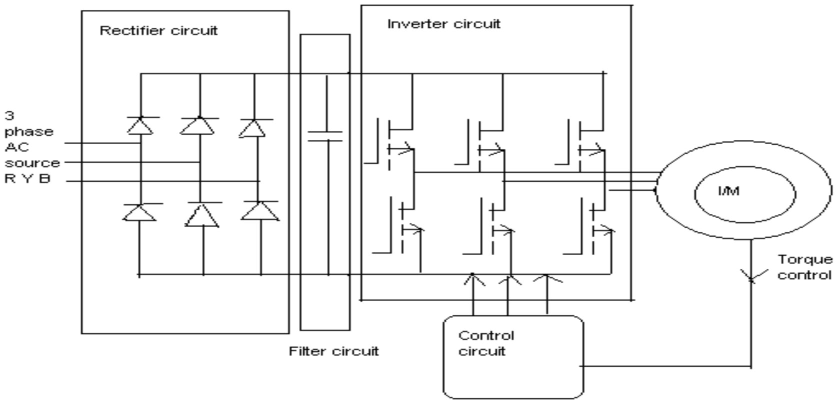


Fig.1. DTC Based Induction Motor

Fig.1 shows the DTC based induction motor. Initially three phase AC supply is given; rectifier circuit is used to convert AC in to DC source. After that Capacitor is used. Why the capacitor is used here is to filter out the unwanted ripples. Here high value of Capacitor is used for this purpose to reduce ripples and to get appropriate pure DC supply is produced. After that the inverter circuit is connected to convert DC into AC and then this AC supply is given to the Induction motor. After this the required torque is to be estimated by using the direct torque control method.

V. ABOUT FUZZY LOGIC BASED INDUCTION MOTOR

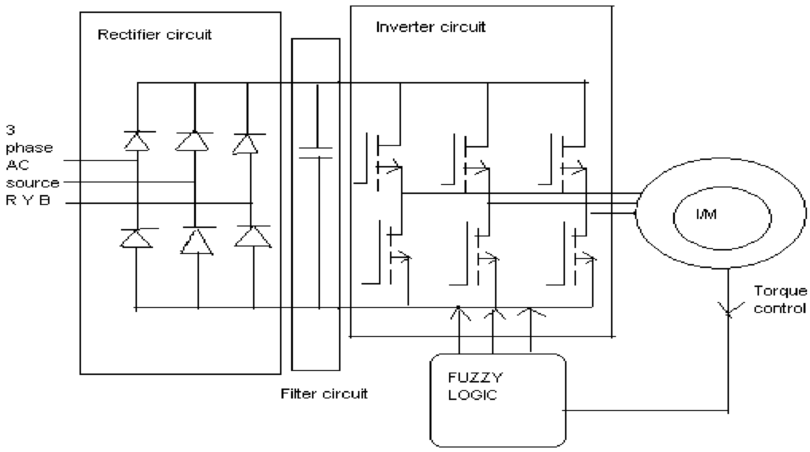


Fig.2. Fuzzy Logic Based Induction Motor

Fig.2 shows the fuzzy logic based induction motor. Instead of using control circuit, here fuzzy logic control is used to control the motor. In fuzzy system first we tune the motor with PI control in closed loop form after that using fuzzy logic and given to the program of IF ELSE statement required pulse is given to the motor, and required torque and flux is to be estimated.

VI. ABOUT FUZZY LOGIC

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalued logic. However in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets. A theory which relates to classes of objects with unsharped boundaries in which a membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of FL. Even in its more narrow definition; fuzzy logic differs both in concept and substance from traditional multivalued logical system. Hence fuzzy logic is a form of multi valued logic derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. Just as in fuzzy set theory the set membership values can range (inclusively) between 0 and 1. In fuzzy logic the degree of truth of a statement can range between 0 and 1 and is not constrained to the two truth values true, false as in classic predicate logic.

6.1. General Observations about Fuzzy Logic

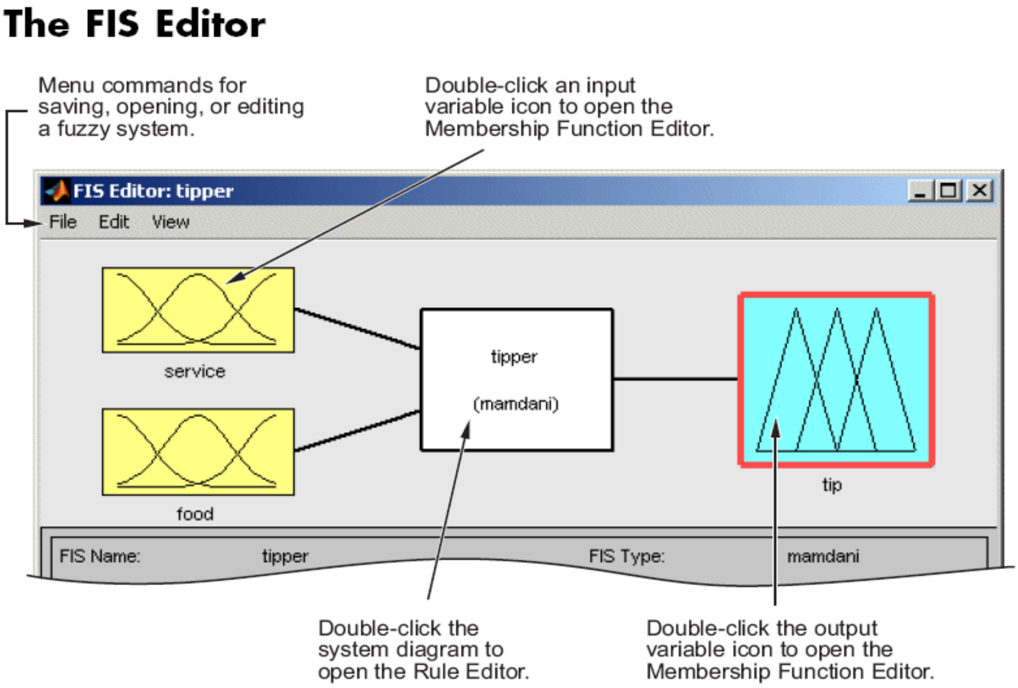
- Fuzzy logic is conceptually easy to understand. The mathematical concepts behind fuzzy reasoning are very simple. Fuzzy logic is a more intuitive approach without the far-reaching complexity.
- Fuzzy logic is flexible. With any given system, it is easy to layer on more functionality without starting again from scratch.
- Fuzzy logic is tolerant of imprecise data. Everything is imprecise if you look closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.
- Fuzzy logic can model nonlinear functions of arbitrary complexity. You can create a fuzzy system to match any set of input-output data. This process is made particularly easy by adaptive techniques like Adaptive Neuro-Fuzzy Inference Systems (ANFIS), which are available in Fuzzy

6.2. Summary of Membership Functions

- Fuzzy sets describe vague concepts (e.g., fast runner, hot weather and weekend days).
- A fuzzy set admits the possibility of partial membership in it. (e.g., Friday is sort of a weekend day, the weather is rather hot).

- The degree an object belongs to a fuzzy set is denoted by a membership value between 0 and 1. (e.g., Friday is a weekend day to the degree 0.8).
- A membership function associated with a given fuzzy set maps an input value to its appropriate membership value.

6.3. Fuzzy Logic Tool Set



VII. DTC BASED FUZZY LOGIC:

The fuzzy controller is designed to have three fuzzy state Variables and one control variable for achieving direct torque Control of the induction machine[8][9], there are three variable input fuzzy logic controllers, the stator flux error, electromagnetic torque error, and angle of flux stator respectively the output it is the voltage space vector.

7.1 Flux Linkage Errors

The errors of flux linkage is related value of stator's flux ϕ_s* and real value of stator's ϕ_s*, they are subject to equation (6)

$$\Delta\varphi = \varphi_s^* - \varphi_s \qquad (6)$$

We use the three following linguistic terms: negative value, zero value and positive value denoted respectively N, Z and P. Three fuzzy sets are then defined by the delta and trapezoidal membership functions as given by Fig.3, [9][10].

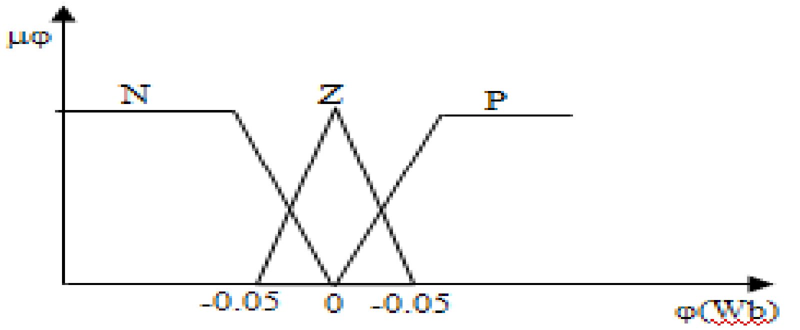


Fig.3 Membership functions for flux error

7.2 Electromagnetic Torque Errors

Error of torque E_{te} is related to desired torque value T^* e and real torque value Te, they are subject to equation (7)

$$\Delta\Gamma = T^*_e - T_e \quad (7)$$

rules may be described by language variable, i, e. Positive Large (LP), Positive Small (PS), Negative Small (NS), and Negative Large (NL), their membership function's distribution is shown as Fig.4, [9],[10] [14],

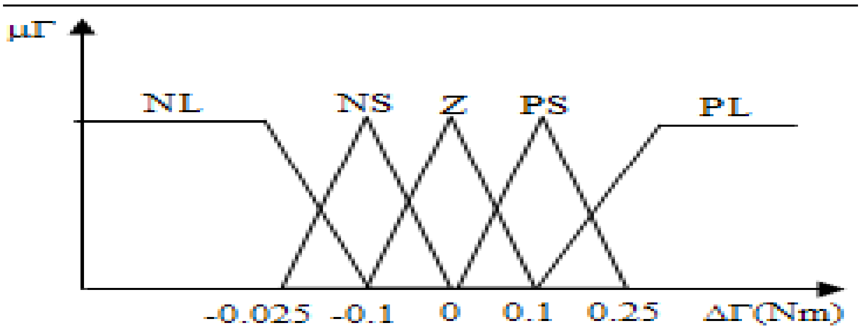


Fig. 4 Membership functions for flux error

7.*3 Angle of Flux Linkage Θ_s*

The angle of flux linkage θsis an angle between stator's flux ϕs and a reference axis is defined by equation (8)

$$\theta s = ar \tan \frac{\varphi_{\beta s}}{\varphi_{\alpha s}} \quad (8)$$

Fuzzy variable may be described by 12 language value (θ1→θ12),it's the membership function's distribution is shown Fig.5 and taken from the reference[9].

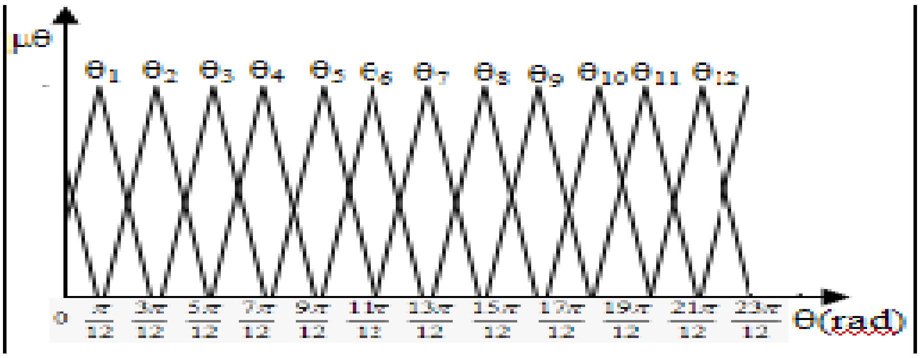


Fig. 5 Membership functions for flux error

7.4 Voltage Vectors U_i

For the voltage vectors Ui(i=0-6), the membership distribution function of Ui is given by Fig.6 taken from the reference [9]

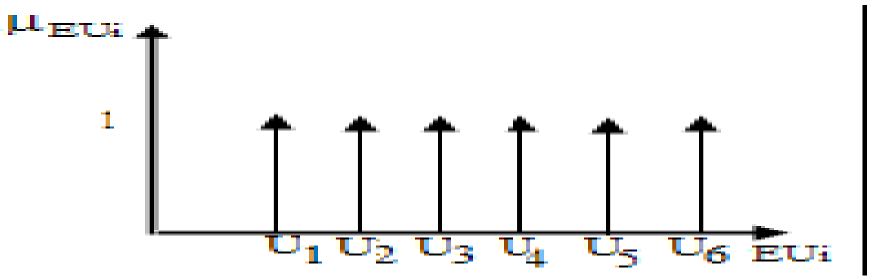


Fig. 6 Membership functions for flux error

VIII. COMPARATIVE STUDY BETWEEN DTC AND FUZZY

8.1 Involvement of DTC

Initially DTC control circuit is used to estimate the torque as output. In DTC control circuit the control variables used here is torque, flux and abc transformation of voltage and current. From Ref Torque and ref flux the variables will connect to flux and torque hysteresis circuit. From here the estimated torque and flux will be done by using hysteresis. And from the abc transformation the voltage and current reference is connected to Torque and flux calculator. From this the torque and flux will be calculated and given again to flux and torque hysteresis and also to flux sector. From this all the estimated and calculated torque and flux is given to switching table. From the switching table the torque and flux is given, and then the appropriate sectors are to be chosen to get the proper DTC output. The switching table is to be connected to calculate the torque and flux. In switching table V1, V2….. V7 shown as respective voltage vectors. Here the feedback flux and torque are calculated from the machine terminal voltages and currents. There are six sectors V1 to V7 (each Π/3 angle wide).

TABLE I: Switching table of DTC

Flux	Torque	Sectors V0	V1	V2	V3	V4	V5	V6	V7
F=1	T=1	0	1	1	0	0	0	1	1
	T=0	1	0	0	1	1	1	0	0
	T=1	0	0	1	1	1	0	0	1
F=-1	T=1	1	1	0	0	0	1	1	0
	T=0	0	0	0	0	1	1	1	1
	T=-1	1	1	1	1	0	0	0	0

8.2 Involvement of Fuzzy In Paper

The main aim of the paper is to reduce the torque ripple. Initially by using DTC control, the output of the torque and stator current are taken by using simulative results. After analyzing the torque output there are some distortions, noise and disturbances are occur. So in order to reduce the torque output further, the use of intelligent technique is to be done. The technique used here is Fuzzy. Fuzzy Logic technique is used to reduce the torque ripple further. In MATLAB Fuzzy Logic toolbox set is available. In that the fuzzy rules have to be framed. In toolbox the FIS editor is present. In FIS editor mamdani block is present. In mamdani the rules are to be framed. And correspondingly the rule viewer is to be shown as a graph according to the rule. The fuzzy rules are to be discussed below.

8.3 Fuzzy Rules

1. If (reference is 0) then (Frequency is 0) (1)
2. If (reference is 0) then (Frequency is 0) (1)
3. If (reference is 50) then (Frequency is 16.67) (1)
4. If (reference is 100) then (Frequency is 33.33) (1)
5. If (reference is 150) then (Frequency is 50) (1)
6. If (reference is 200) then (Frequency is 33.37) (1)
7. If (reference is 250) then (Frequency is 83.33) (1)
8. If (reference is 300) then (Frequency is 100) (1)
9. If (reference is 0) and (Error is z) then (Frequency is 0) (1)
10. If (reference is 0) and (Error is z) then (Frequency is 0) (1)
11. If (reference is 0) and (Error is z) then (Frequency is 0) (1)
12. If (reference is 0) and (Error is z) then (Frequency is 0) (1)
13. If (reference is 0) and (Error is z) then (Frequency is 0) (1)

The above fuzzy rules are nothing but the fuzzy rule matrix. The fuzzy rule matrix as explained below. The reference shown in rule matrix is input or error 'e'. Here reference is input or error 'e' and frequency is change in output 'cu'. And finally the error is change in error 'ce'. In first rule shows that If (e is Z) then (cu is Z). In next rule also If (e is Z) then (cu is Z). In third rule If (e is PS) then (cu is PVS). In fourth rule If (e is PS) then (cu is PS). In fifth rule If (e is PM) then (cu is PM). In sixth rule IF (e is PB) then (cu is PS). In seventh rule If (e is PB) then (cu is PB). In eight rule if (e is PB) then (cu is PVB). In ninth rule If (e is Z) and (ce is Z) then (cu is Z). In tenth rule If (e is Z) and (ce is Z) then (cu is Z). In eleventh rule If (e is Z) and (ce is Z) then (cu is Z). In twelfth rule If (e is Z) and (ce is Z) then (cu is Z). And the final thirteenth rule is If (e is Z) and (ce is Z) then (cu is Z). This is about the explanation of Fuzzy rule matrix. The below Fig.7 is a fuzzy rule viewer. By viewing this also can explain the rules as said above.

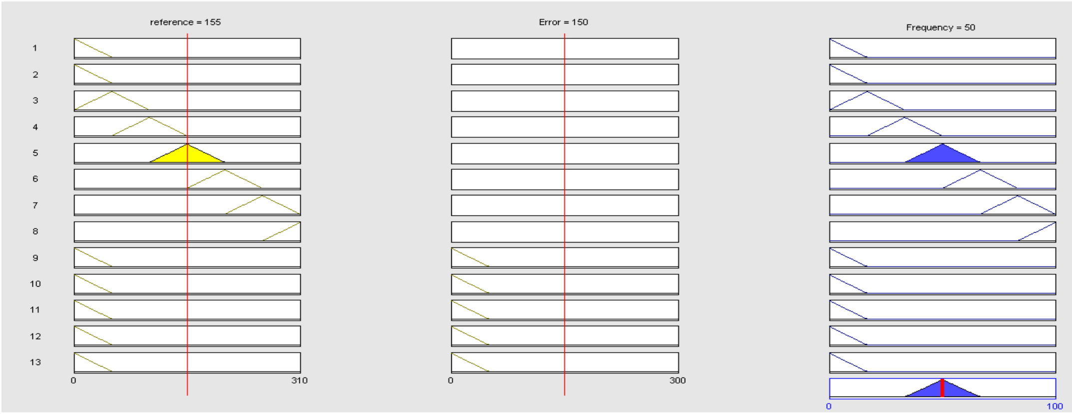


Fig.7 Fuzzy Rule Viewer

IX. RESULTS AND DISCUSSION

Results obtained from DTC using Fuzzy logic as applied to induction motor Torque, speed and flux reference values are to be estimated respectively. A comparison is done here with the results which also aim at torque and flux ripple minimization. The results of comparison are that it is reduced from the previous case. It is realized that the ripple minimization is more effective by using Fuzzy logic.

Using MATLAB simulation the output of DTC control and Fuzzy Logic control are taken. And the outputs are shown in the next chapter. Let us discuss the simulation outputs one by one.

9.1 Electromagnetic Torque- Without Fuzzy

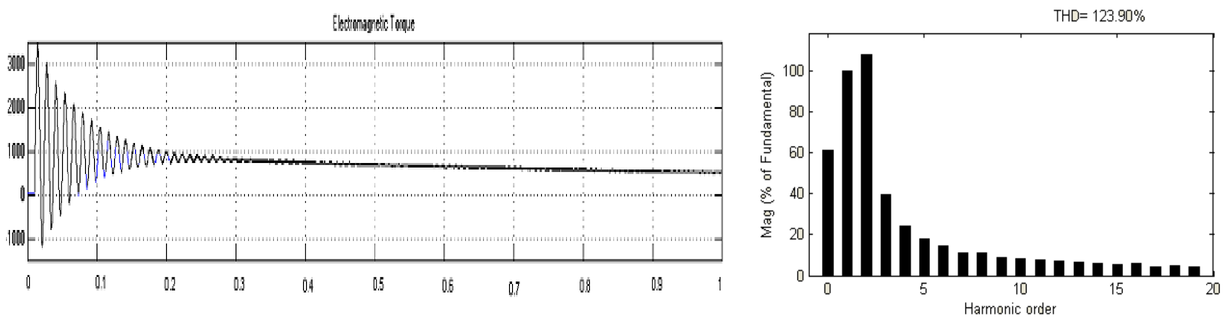


Fig. 8 Electromagnetic Torque without fuzzy and its Harmonic Order

First simulation output is Fig.8 is Electromagnetic torque without fuzzy. i.e., by using DTC, electromagnetic torque shows that initially it is rising up to 3000 and above and there is a lot of distortions and noise is present. For that reason the starting stage has many disturbances and after some time, i.e., around at the time of 0.3s of time it was settling down to 800 and after it is showing as constant torque as output. Here the applied load torque is 972. Hence approximately at 800 it is showing as constant output. The harmonic order of electromagnetic torque without fuzzy is 123.90%.

9.2 Electromagnetic Torque- With Fuzzy

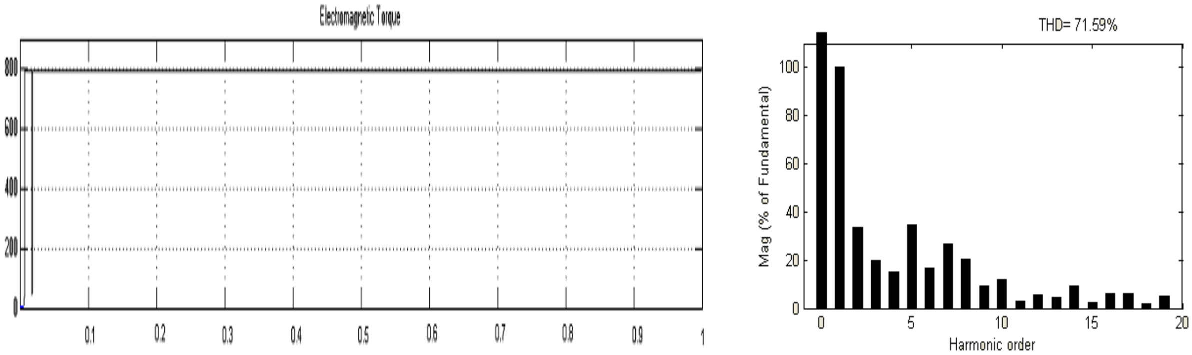


Fig. 9 Electromagnetic Torque with fuzzy and its Harmonic Order

Next, Fig.9 is electromagnetic torque with fuzzy. By using fuzzy the output as shown clearly. At starting time of around 0.01s time there is some noise is present. After that, it's settling time is 0.02s. After this the output is showing as constant torque around at 800. Hence by using fuzzy, settling time is very fast and there is less noise and fewer disturbances also. By earlier time itself it is showing as a constant torque. The harmonic order of electromagnetic torque with fuzzy is 71.59%. When compare to without fuzzy, with fuzzy has less percentage of harmonic order. This comparison shows that by using fuzzy the torque output is improved very much and the results are proved by using simulation.

9.3 Rotor Speed- Without Fuzzy

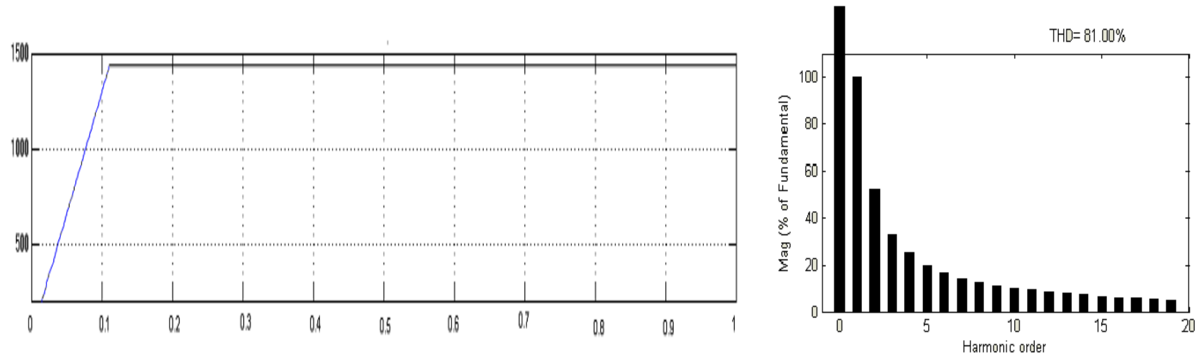


Fig. 10 Rotor Speed Without Fuzzy and its Harmonic Order

Next Fig.10 is rotor speed without fuzzy. In this rotor speed, the speed is around approximately 1470rpm. And the settling time of rotor speed is around 0.11s time. The harmonic order of without fuzzy in rotor speed is 81.00%.

9.4 Rotor Speed- With Fuzzy

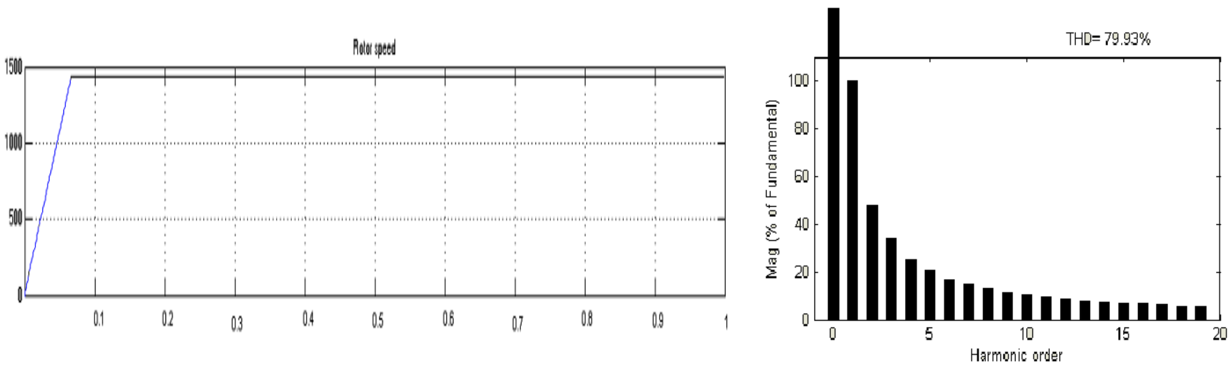


Fig.11 Rotor Current with Fuzzy and its Harmonic Order

Fig.11 is rotor speed with fuzzy. In this the speed is approximately 1470 rpm. And the settling time is approximately 0.06s in time. The harmonic order of Rotor speed with fuzzy is 79.93%. Hence when compare to without fuzzy, with fuzzy has settling very fast. This shows that, by using fuzzy the settling time is very fast and hence it is proved by using simulation.

9.5 Stator Current – Without and With Fuzzy

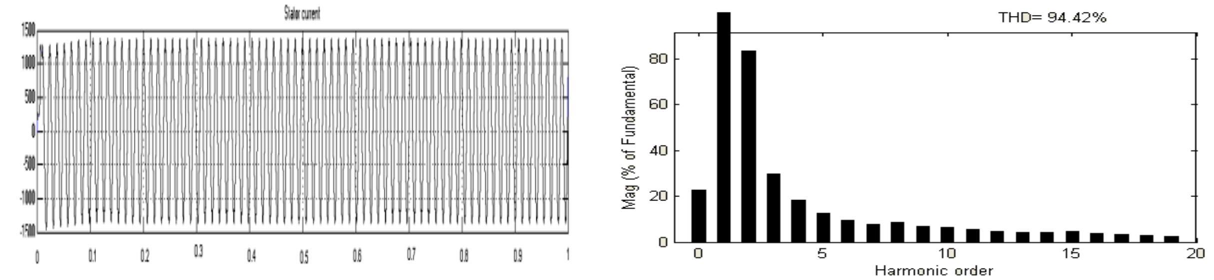


Fig. 12 Stator current without fuzzy and its Harmonic Order

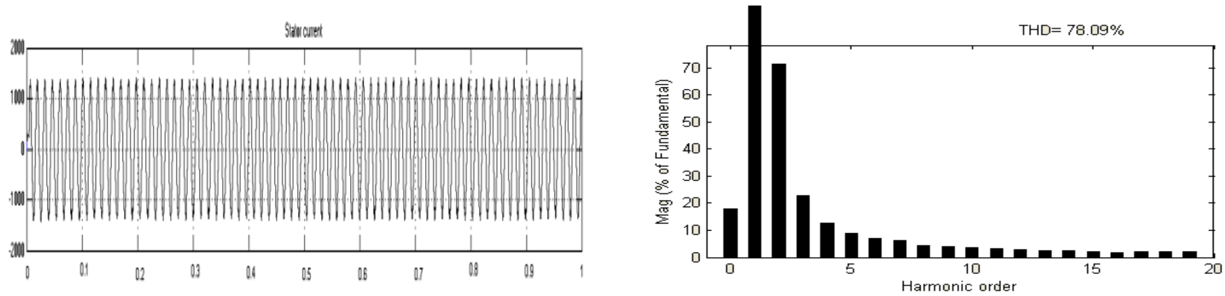


Fig. 13 Stator Current with Fuzzy and its Harmonic Order

Fig.12 is stator current without fuzzy. Its harmonic order is 94.42%. Next is Fig.13 is stator current with fuzzy. Its harmonic order is 78.09%. Hence it is proved that by using fuzzy the harmonic order is reduced by using simulation.

9.6 Dc Bus Voltage – Without and With Fuzzy

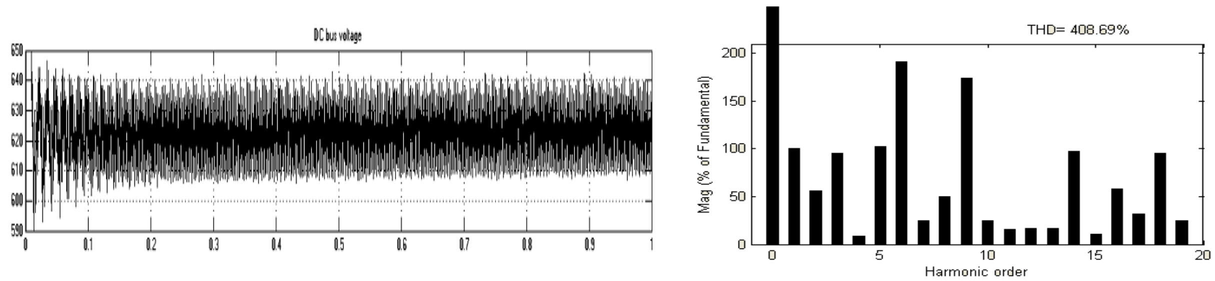


Fig.14 DC Bus Voltage without Fuzzy and its Harmonic Order

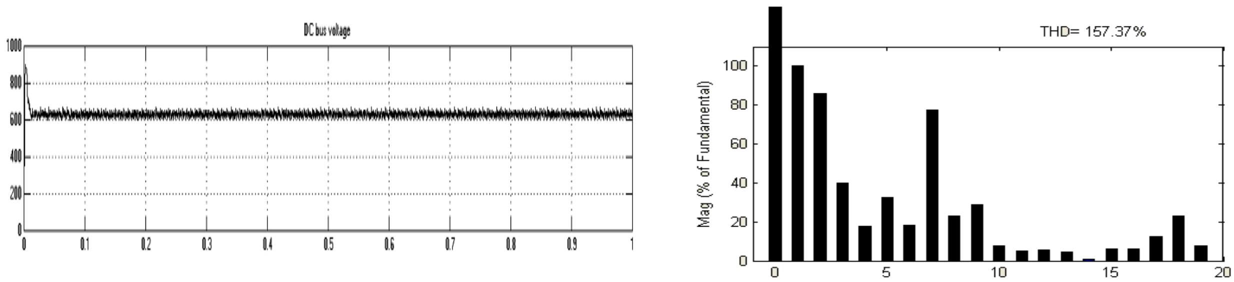


Fig.15 DC Bus Voltage without Fuzzy and its Harmonic Order

Next is Fig.14. It is DC Bus voltage without fuzzy. By using DTC the Dc bus voltage is having many noise and disturbances. The distortions are showing very clearly. The harmonic order of DC Bus Voltage without fuzzy is 408.69%. By using DTC it attains very abnormal condition. Then the next Fig.15 is Dc Bus Voltage with fuzzy. In this the noise is reduced and the settling time is around 0.01s time. After settling time it attains a Constant DC Bus Voltage. The Harmonic order of DC Bus Voltage using Fuzzy is 157.37%. Hence it is proved that by using Fuzzy the improved output is clearly present and it is proved by using simulation output.

TABLE II: TABULATION OF COMPARISON RESULTS

OUTPUTS	SETTLING TIME	THD (%)
WITHOUT FUZZY (TORQUE)	0.3	123.90
WITH FUZZY (TORQUE)	0.02	71.59
WITHOUT FUZZY (SPEED)	0.11	81.00
WITH FUZZY (SPEED)	0.06	79.83
WITHOUT FUZZY (STATOR CURRENT)	ATTAINS SINUSOIDAL CONDITION	94.42
WITH FUZZY (STATOR CURRENT)	ATTAINS SINUSOIDAL CONDITION	78.09
WITHOUT FUZZY (DC BUS VOLTAGE)	DISTORTIONS, REACHING ABNORMAL CONDITION	408.69
WITH FUZZY (DC BUS VOLTAGE)	0.01	157.37

X. CONCLUSION

In this paper a Fuzzy logic based induction machine is proposed. An improved torque and flux response is achieved with the help of FL_DTC than the conventional DTC. The performance is tested by simulations and a comparison is made with the existing system. The results show that there is a reduction of torque and flux ripple when Fuzzy logic is used.

REFERENCES

[1] Takahashi, T. Noguchi, ″A new quickresponse and high-efficiency control strategy of induction motor″, IEEE Trans. On IA, Vol.22, N°.5, Sept/Oct 1986, PP.820-827.

[2] M. Depenbrock, ″Direct self – control (DSC) of inverter – fed induction machine″, IEEE Trans. Power Electronics, Vol.3, No.4, Oct 1988, PP.420-829.

[3] D. Casadei, F. Profumo, G.Serra and A.Tani, ″FOC and DTC: Tox Viable Schemes for induction Motors Torque Control″, IEEE Trans. Power Electronics. On PE, Vol.17, N°.5, Sept2002,

[4] D. Casadei and G.Serra, ″Implementation of direct Torque control Algorithm for Induction Motors Based On Discrete Space Vector Modulation″, IEEE Trans. Power Electronics. Vol.15, N°.4, JULY2002,

[5] A.A.Pujol, ″Improvement in direct torque control of induction Motors″, Thèse de doctorat de L'UPC, Novembre2000

[6] R.Toufouti ,H.Benalla, and S.Meziane ″Three-Level Inverter With Direct Torque Control For Induction Motor″, World Conference on Energy for Sustainable Development: Technology Advances and Environmental Issues, Pyramisa Hotel Cairo - Egypt, 6 - 9 December 2004.

[7] JIA-QIANG YANG, JIN HUANG ″ A New Full-Speed Range Direct Torque Control Strategy for Induction Machine″, Proceedings of the Third International Conference on Machine Learning and Cybernetics, Guangzhou, 26-29 August 2004.

[8] R.Toufouti S.Meziane ,H. Benalla, "Direct Torque Control for Induction Motor Using Fuzzy Logic" ICGST Trans. on ACSE, Vol.6, Issue 2, pp. 17-24, June, 2006.

[9] Jia-Qiang Yang, Jin Huang, ″Direct Torque Control System for Induction Motors With Fuzzy Speed Pi Regulator″ Proceedings of the Fourth International Conference on Machine Learning and Cybernetics,Guangzhou, 18-21 August 2005.

[10] Hui-Hui Xia0, Shan Li, Pei-Lin Wan, Ming- Fu Zhao, ″Study on Fuzzy Direct Torque Control System″, Proceedings of the Fourth International Conference on Machine Learning and Cybernetics, Beijing, 4-5 August 2002.

[11] Bimal K.Bose, Modern Power Electronics and AC Drives (third Indian reprint), Pearson education, 2003.

[12] Timothy J.Ross, Fuzzy Logic with engineering Applications (Second Edition),Wiley India Edition.

[13] Gopal K. Dubey, Fundamentals of Electrical Drives (Second Edition), Narosa publishing house.

[14] R.Krishnan, Electric motor Drives (second Indian reprint), Prentice hall of India, 2003.

[15] Power Electronics, Dr.P.S.Bimbhra, Khanna publishers.

[16] KMITL Sci. Tech. J. Vol. 5 No. 3 Jul.-Dec. 2005 HIGH – PERFORMANCE ADAPTIVE INTELLIGENT DIRECT TORQUE CONTROL SCHEMES FORINDUCTION MOTOR DRIVES M. Vasudevan and R. Arumugam Department of Electrical and Electronics Engineering, Anna University, Chennai, Tamilnadu, India

[17] DP. Kothari – IJ Nagrath, Electric machines – Tata Mc graw-Hill publishing-Third Edition, second Reprint 2005.