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Adaptation of Fuzzy Logic in improving the performance of Direct Torque Control of Induction Motor

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Abstract - *Fuzzy Logic Controller (FLC) is a type of non-conventional control system, which is knowledge, based approach. Fuzzy logic is a rule-base decision making method, used to control a process that a human can control with expertise gained from experience. FLC step forward as an alternate for conventional control strategies in automatic control systems. Both linear and nonlinear operation can be obtained.*

In the paper work the fuzzy based speed controller and fuzzy based voltage vector detector are developed for Direct Torque Control (DTC) of the three phase induction motor using MATLAB/SIMULINK software. Fuzzy logic is used to overcome the conventional DTC drawbacks. The results of the conventional DTC and fuzzy logic based DTC are compared and inference such that fuzzy logic gives better performance is drawn.

***Key Words*: Fuzzy Logic Controller, PI Controller, DTC, Inverter, Induction motor.**

1. INTRODUCTION

Induction motors (IM) are famous for their robustness, cheapness, high speed operation and less maintenance requirements and they are the most common type of electromechanical drive in industrial, commercial and residential applications. To reach the best efficiency of induction motor drive, many new techniques of control have been developed in the last few years. Induction motor can be controlled by scalar and vector control schemes. Vector control aims to control the rotor flux and torque of the motor by estimating the speed and voltage. A simpler alternative to the vector control is the direct torque control (DTC) which is an advanced scalar control. While DTC and vector control have different concept of operation, they both provide an effective control of the flux and torque. Main features of DTC are decoupled control of torque and flux, absence of mechanical transducers and current regulator, coordinate transformation is not required, very simple control scheme, low computational time and reduced parameter sensitivity.

DTC is a closed loop approach in which motor speed is continuously checked and the appropriate voltage vector for the three phase inverter is chosen.

Space vector modulation technique is used to give gate pulses to inverter switches. MOSFET switches are used in the inverter due to its advantages over other power electronic switches. There are eight states of the inverter switches out of which two are zero states; the active six states are controlled with the six angular sectors. Thus, by having the proper voltage vector for that Particular speed the Inverter and intern the motor operation can be achieved efficiently in the closed loop.

The conventional DTC scheme is shown in Figure 1. It has the PI controller for the speed control and provides the reference torque as output. Further this torque and flux are compared with the estimated values and errors are given to hysteresis comparator to provide the required space voltage vector to the inverter operation.

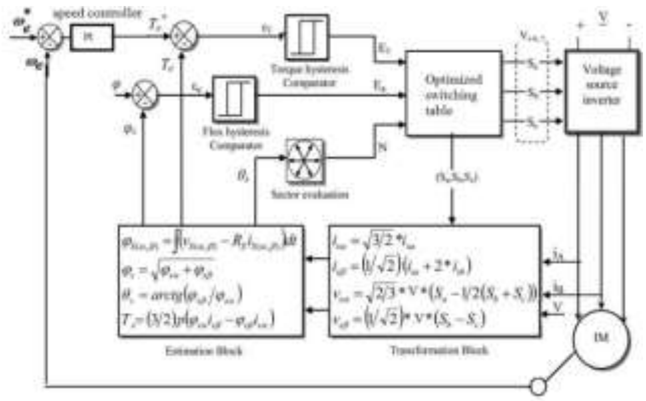

Figure -1: Conventional DTC

Hysteresis controller for the torque is of three levels and for the flux is of two levels, the level condition can be defined as follows:

H_{Te}= 1 for E_{Te}> + HB_{Te}

H_{Te}= -1 for E_{Te}<- HB_{Te}

H_{Te} = 0for-HB_{Te}< E_{Te}< +HB_{Te} and,

H_{ψ}= 1 forE_{ψ}> + EB_{ψ}

H_{ψ}= -1 forE_{ψ}> - EB_{ψ}

The hysteresis comparator values are made into a look-up table. Using the look up tables the particular voltage vector for the inverter is chosen. Because of the disadvantages of PI speed controller and hysteresis comparators DTC gives much ripple in stator current, flux and electromagnetic torque output. Hence in the project work dual fuzzy logic will be employed to reduce the ripples.

2. PI CONTROLLER

PI speed controller is used in the DTC. It takes the reference speed and the actual motor speed and the speed error so computed is processed with the K_p and K_i gain values to provide the reference torque as output. Figure 2 shows the PI controller design.

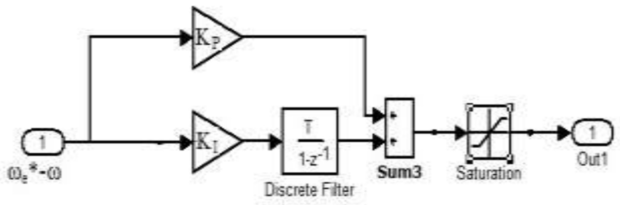

Figure -2: PI controller

Since there exists only one reference torque value for the speed error the exact operation needed by the inverter will not be obtained. This can be overcome by giving the ranges for reference torque value by using the fuzzy logic speed controller. Thus, for the speed error value the appropriate torque output, a linguistic value can get selected.

3. FUZZY LOGIC

Fuzzy logic controller consists of three parts: fuzzification of the input variables, application of the fuzzy operator (AND or OR) and defuzzification. Fuzzification is the processes of determining the input degree to which they belong to each of the appropriate fuzzy sets via membership functions. The procedure of converting fuzzy values into crisp values is known as defuzzification.

Many membership functions (MFs) shapes can be chosen based on the designer preference and experience. In the project triangular and the trapezoidal membership functions are used. Figure 3 shows the fuzzy controller design.

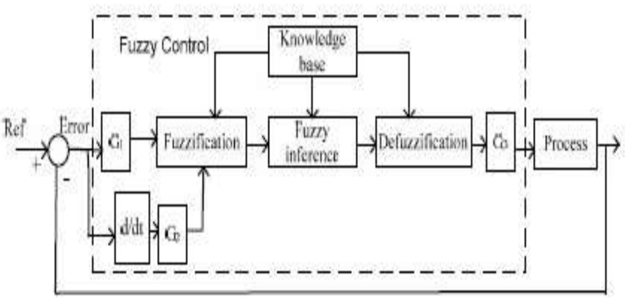

Figure -3: Fuzzy controller design

4. PROPOSED MODEL

The three phase inverter output is given to the three phase induction motor. The stator voltages and currents are taken and upon using relations listed as in figure.1 the torque, flux and flux angle are calculated. For the reference torque generation fuzzy speed controller is adapted in which for the particular speed error the particular reference torque value is taken. And further this reference torque and estimated torque are compared and the torque error is got. Similarly the reference flux and estimated flux are compared and error is taken. And upon giving torque error, flux error and flux angle to the fuzzy logic voltage vector detector, a particular voltage vector for the inverter is fed. Figure 4 shows the proposed model block diagram.

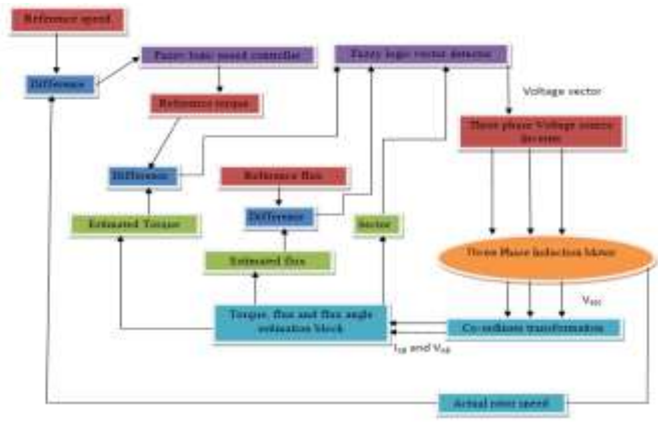

Figure -4: Block diagram of the proposed model

5. FUZZY SPEED CONTROLLER

The speed and the change in speed are taken and fuzzified using rules as shown in the Table 1. The output is reference torque which is obtained after defuzzification process. Mamdani method is used for the fuzzification and centre of area method is used for the defuzzification process. Figure 5 shows the triangular membership function design adopted in the project work.

Table -1: Rule table for speed controller

$E\omega_r$ \ $\Delta E\omega_r$	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	ZE
NS	NB	NB	NS	ZE	PS
ZE	NB	NS	ZE	PS	PB
PS	NS	ZE	PS	PB	PB
PB	ZE	PS	PB	PB	PB

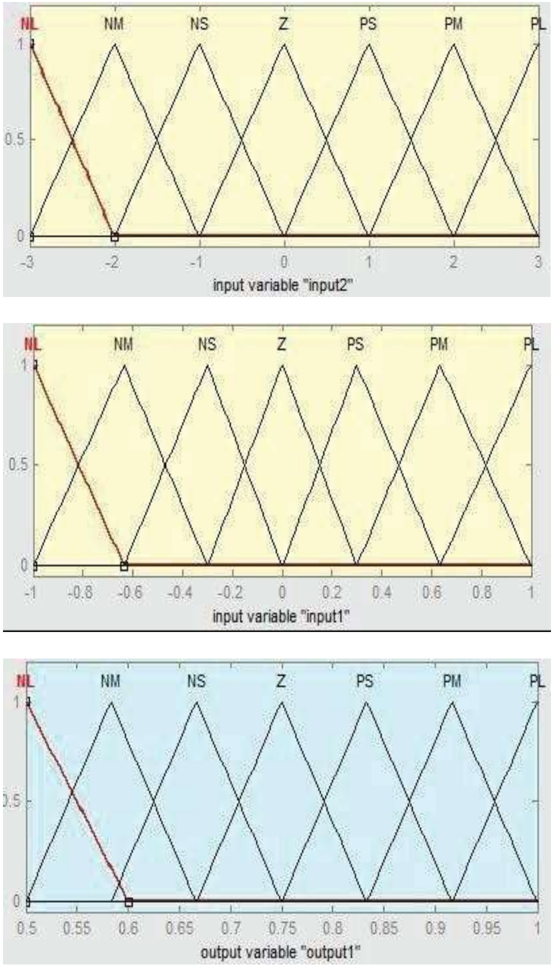

Figure -5: Membership function designs involved on fuzzy logic speed controller

6. FUZZY VOLTAGE VECTOR DETECTOR

The reference torque from the fuzzy logic speed controller is compared with the estimated torque using relation and the error is got. Similarly the flux error is got by comparing reference and estimated value. The flux angle, torque error and flux error are the three inputs given to fuzzy voltage detector. The output will be the voltage vector for the inverter. The rules for these controllers are created by using the Table 2 as shown below. And the membership function designs are shown in Figure 6. Here Triangular and trapezoidal membership functions are used.

Table -2: Rule tables for voltage vector detector

ΔC_e \ $\Delta\varphi_s$	P	ZE	N
PL	V1	V2	V2
PS	V2	V2	V3
ZE	V1	V0	V4
NS	V6	V5	V4
NL	V6	V5	V5

(a) Angle: θ1 and θ7

ΔC_e \ $\Delta\varphi_s$	P	ZE	N
PL	V2	V3	V3
PS	V3	V3	V4
ZE	V2	V0	V5
NS	V1	V6	V5
NL	V1	V6	V6

(b) Angle: θ2

ΔC_e \ $\Delta\varphi_s$	P	ZE	N
PL	V3	V4	V4
PS	V4	V4	V5
ZE	V3	V0	V6
NS	V2	V1	V6
NL	V2	V1	V1

(c) Angle: θ3

ΔC_e \ $\Delta\varphi_s$	P	ZE	N
PL	V4	V5	V5
PS	V5	V5	V6
ZE	V4	V0	V1
NS	V3	V2	V1
NL	V3	V2	V2

(d) Angle: θ4

ΔC_e \ $\Delta\varphi_s$	P	ZE	N
PL	V5	V6	V6
PS	V6	V6	V1
ZE	V5	V0	V2
NS	V4	V3	V2
NL	V4	V3	V3

(e) Angle: θ5

ΔC_e \ $\Delta\varphi_s$	P	ZE	N
PL	V6	V1	V1
PS	V1	V1	V2
ZE	V6	V0	V3
NS	V5	V4	V3
NL	V5	V4	V4

(f) Angle: θ6

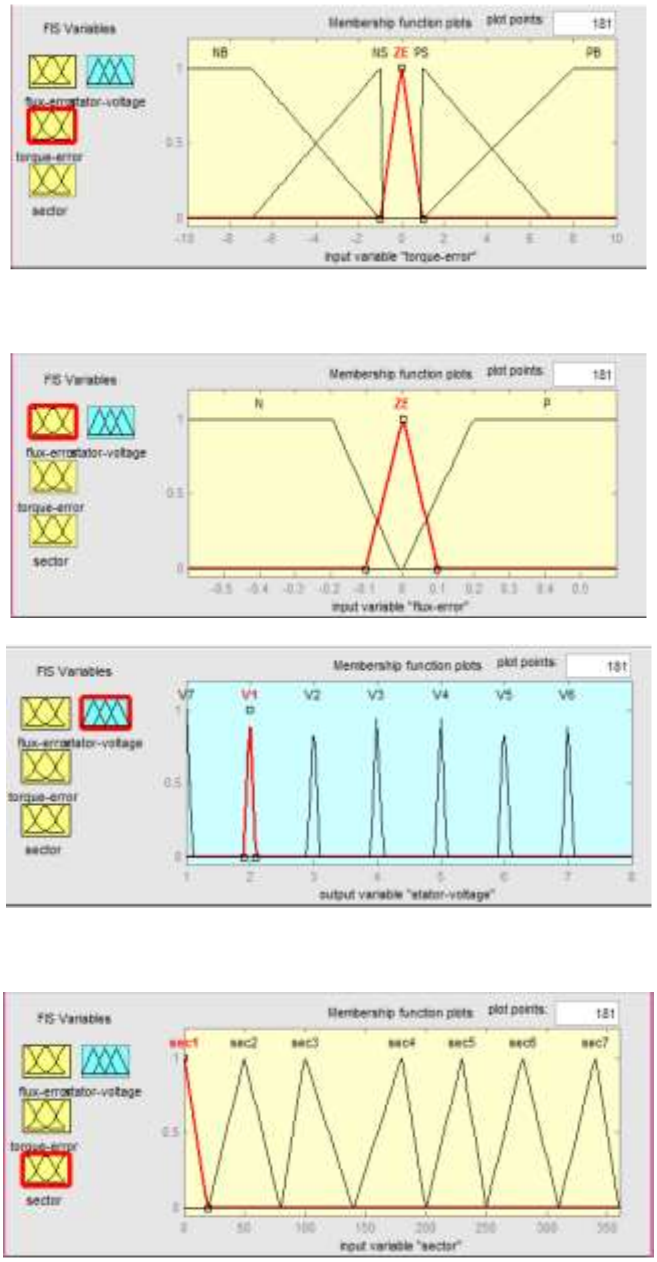

Figure -6: Membership function designs involved in fuzzy logic vector detector

7. RESULTS

The two models for the DTC are built in MATLAB/SIMULINK software and the result analysis is carried out. The efficiency of the proposed fuzzy logic speed controller and fuzzy logic voltage detector is found to be better than the PI speed controller and hysteresis comparators respectively. Since the fuzzy logic gives us many range for the reference torque values, the decision making property of the fuzzy logic speed controller will select the proper torque value for the particular speed error and upon performing rules on the torque , flux errors and flux angle, the fuzzy logic vector detector will select the perfect vector for inverter operation. For constant load torque applications the ripples of the Conventional DTC and fuzzy logic DTC are compared and found that fuzzy logic DTC gives less ripple in stator current, stator flux and output torque. The ripples are reduced to 8-9% in fuzzy DTC as that of the conventional DTC.

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