FLC based Direct Torque Control of Induction Motor Using Single Current Sensor

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Abstract- **Direct Torque Control (DTC) is a well known control technique for high performance drives in a wide variety of industrial application. This paper presents a Direct Torque Control of Induction Motor (IM) using Fuzzy Logic Controller (FLC). The Fuzzy Logic Controller is proposed to adjust the bandwidth of torque hysteresis controller in order to reduce the torque and flux ripples. The main aim is to develop a low-cost, less-ripple, high performance IM drive. The proposed algorithm is obtained from only one shunt resistor to reconstruct the phase current. Reconstructed current used to estimate the motor flux and electromagnetic torque. Space Vector Modulation (SVM) technique is used for voltage vector selection. FLC is used to reduce the computation burden and produce the satisfactory result. FLC is designed to select the optimum bandwidth of the torque hysteresis controller inorder to reduce the torque and flux ripples.**

Index Terms- **Direct Torque Control (DTC), Induction Motor (IM), Fuzzy Logic Controller (FLC), Single Current Sensor, Torque and Flux Hysteresis Controller.**

I. INTRODUCTION

THE Induction Motor (IM) was widely used in industries and many other fields due to their advantageous merits of cost, reliability, robustness and performance [1] [2]. However, the control system of IM is complex and expensive. In the year of 80's, new IM Direct Torque Control (DTC) was developed by Takahasi and Noguchi. DTC of an induction motor plays a major role in industrial applications mainly due to its simple structure.

All well known the advantage of DTC when compared to Field Oriented control (FOC). DTC scheme does not require any feedback current control, vector transformation, current regulators and Pulse Width Modulation (PWM) [3] [4]. The major problem of DTC based motor drive is steady state ripples in the torque and flux of the motor. The ripples in flux and torque will affect the accuracy and performance of the motor. It also produces higher acoustical noise and harmonic losses.

Normally, there are two methods to reduce the torque and flux ripples for the DTC drives. The first method is multilevel inverter, the cost and complexity of the controller is increased. The second method is SVM, switching frequency changes continuously.

Another one of the important criteria is cost. In general, current sensors such as Hall-effect sensor and current transducers are used in many applications. They need two outputs of the inverter inorder to provide current feedback signals. This kind of sensors performs well, but it also has some disadvantages in terms of cost. In order to reduce the number of sensors, phase current reconstruction is applicable. The DTC requires the stator current from the dc-link voltage, which is used with the switching state of the inverter for estimating the values of stator flux and electromagnetic torque [5].

DTC uses the hysteresis bandwidth to directly control the flux and torque of an induction motor [6] [7]. According to the bandwidth of the hysteresis, voltage vector of the inverter is selected. When the stator flux falls outside the hysteresis band, then the inverter switching stator is changed. So the flux takes an optimal path towards the desired value. The errors between the reference value and the estimated values of torque and flux is possible to directly control the inverter switching states in order to reduce the torque and flux errors within the prefixed band limits. In this paper, we propose two strategiesone is reconstruction of phase current by using single shunt current sensor inorder to reduce the cost. Secondly, FLC is introduced to improve the performance of the induction motor by reducing the estimated stator flux and torque ripples. The simulation of the proposed method is done using MATLAB/simulink.

II. DTC OPERATION

The conventional DTC technique contains hysteresis controllers, torque and flux estimator and a switching table. The basic concept of DTC technique is to control the stator flux linkage and electromagnetic torque of the motor with the help of inverter switching modes. The selection of voltage vector provides the following benefits.

- Fast Torque Response
- Low Harmonic Losses
- Low Inverter Switching Frequency

The DTC controller consists of two hysteresis comparator, one is torque and another one is flux. These two hysteresis are used to select the switching voltage vector to maintain the flux and torque between upper and lower limit.
The stator flux is obtained by,

$$\varphi_s = \int (V_s - R_s I_s)\, dt \qquad (1)$$

Where V_s is applied voltage, I_s is stator current, R_s is stator resistance.
The electromagnetic torque is given as,

$$T_e = \frac{3}{2} p(\varphi_s * I_s) \qquad (2)$$

Where p is number of poles.

In conventional DTC technique, stator current was calculated from the output of the inverter. The stator current is used to estimate the stator flux and electromagnetic torque. It uses more number of sensors for measuring stator current then the cost is high automatically. In order to reduce the cost single current sensor is introduced.

III. SINGLE CURRENT SENSOR

The basic DTC technique uses at least two sensors. In this paper proposes only one shunt resistor for dc-link current measurement. The proposed DTC scheme is shown in the Fig 1. Estimating the three phase current from single dc-link current sensor can be achieved by two modifications.

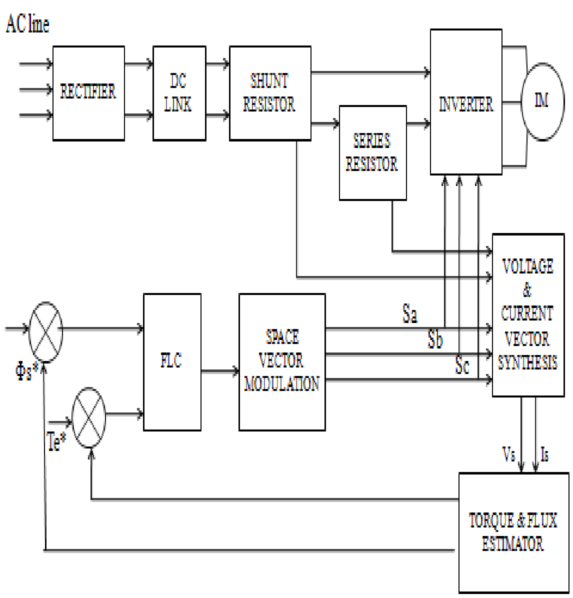

Fig. 1. Proposed DTC Scheme

In first modification, generate more voltage vector. This can be achieved by Discrete Space Vector Modulation (DSPM) technique [8].

By using this technique new voltage vector can be synthesized with respect to those used in the basis DTC technique. It has been proved that subdividing the cycle interval in two equal time intervals. It leads to a substantial reduction of current sensors without the need of complex switching tables. Using DSVM technique with two equal time intervals, 12 new voltage vector can be generated. From that 12 voltage vector we select only six voltage vectors in our proposed DTC scheme. The second modification is that, instead of -30° to 30° select 0° to 60° as the first sector with the help of one shift strategy.

One of the important purposes of simplifies the sampling circuit to single shunt resistor for three phase reconstruction is to reduce the cost. Another advantage of using single shunt measurement is that, sense all the three phases in the same circuit. The values of gain and offset will be same for all the measurements. Therefore, it eliminate the software calibration. Table I shows the modified new DTC switching.

TABLE I
DTC SWITCHING TABLE

Flux	**Torque**	**Switching Vectors**					
		S1	**S2**	**S3**	**S4**	**S5**	**S6**
1	1	V_{56}	V_{61}	V_{12}	V_{23}	V_{34}	V_{45}
	0	V_{34}	V_{45}	V_{56}	V_{61}	V_{12}	V_{23}
0	1	V_{61}	V_{12}	V_{23}	V_{34}	V_{45}	V_{56}
	0	V_{23}	V_{34}	V_{45}	V_{56}	V_{61}	V_{12}

According to the switching table of DTC, the particular switching vector is selected to calculate the stator current. From the stator current, torque and flux of the induction motor is estimated.

IV. FUZZY LOGIC CONTROL IN DTC

DTC of an induction motor directly controls the stator flux and electromagnetic torque. DTC control has many good features such as simple implementation, fast torque response and insensitive to parameter variations. However, a torque and flux ripple plays a major problem in the conventional DTC. Therefore, fuzzy logic controller is employed to solve this issue.

A. ANALYSIS OF TORQUE RIPPLE

Most of the inverter switching vectors is not able to produce exact stator voltage required to produce desired change in torque and flux. The real problem in DTC induction motor drive is flux and torque ripples. According to DTC principle, the pulsation of torque is directly related to the amplitude of its hysteresis band. The pulsation of torque is required to be as small as because it causes acoustic noise and vibration.

A small hysteresis bands of the should be chosen, when high switching speed semiconductor devices are utilized because their switching losses are usually negligible with respect on state losses. In this way the harmonic of the output current can be reduced [9].

The hysteresis band has to be set large enough to limit switching frequency of the inverter below a certain level. It is usually determined by thermal restriction of power devices. Since the hysteresis bands are set to deal with the worst case, the system performance is predictably degraded in a certain operating range, particularly in a low speed region.

In torque hysteresis controller, an elapsing time is to move from lower to upper limit can be changed according to operating condition of DTC. Most of these methods are computationally intensive. In the next section a fuzzy logic approach is proposed to reduce the torque ripple. This fuzzy logic control determinates the desired amplitude of torque hysteresis band.

B. DESIGN OF FUZZY LOGIC CONTROL

In this paper, Mamdani type FLC is developed in order to reduce the ripples in the developed motor torque. The FLC is used as a non linear function producing a suitable bandwidth of the torque hysteresis controller in order to keep the minimum torque ripples [10]. The amplitude of the torque hysteresis band is fixed in the conventional DTC technique. In this proposed scheme, the FLC controls the upper and lower limits of the torque hysteresis band. According to the faraday's electromagnetic theory, the stator flux linkage is proportional to stator current. Therefore, the estimated torque variation and stator current variation are selected as the input to the FLC to attain desired hysteresis bandwidth. Figure 2 shows the fuzzy logic controller.

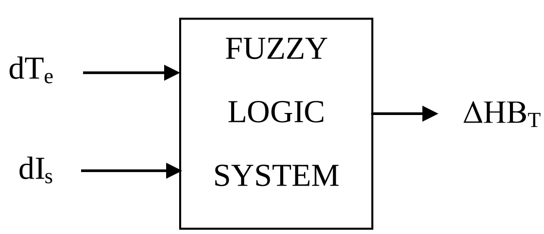

Fig.2. Fuzzy Logic Controller

In this paper, FLC uses two input variables such as change in torque (dT_e) and change in stator current (dI_s). One input (dT_e) uses five membership functions such as (NH, NL, ZE, PL, PH) and another input (dI_s) uses three membership functions such as (N, ZE, P). Therefore, total number rule is fifteen. In particular, Gaussian membership functions are preferred for the output so that the hysteresis bandwidth will be changed efficiently. The proposed rule for the fuzzy logic controller is shown in the Table II.

TABLE II
FUZZY RULES

Torque Variation / Stator Current Variation	**NH**	**NL**	**ZE**	**PL**	**PH**
N	NH	NH	ZE	PS	PH
ZE	NH	NH	ZE	PH	PH
P	NH	NS	ZE	PH	PH

Where NH- Negative High, NL- Negative Low, ZE- Zero, PL- Positive Low, PH- Positive High, NS- Negative Small, PS- Positive Small, N- Negative, P- Positive.

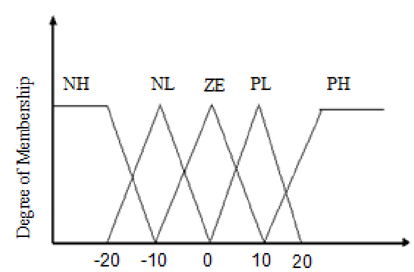

Fig. 3. Membership function for input variable torque

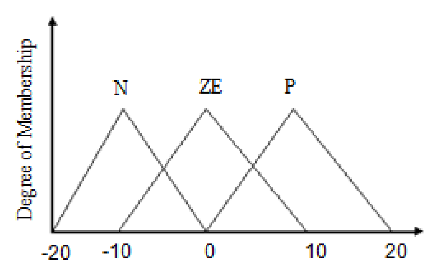

Fig. 4. Membership function for input variable stator current

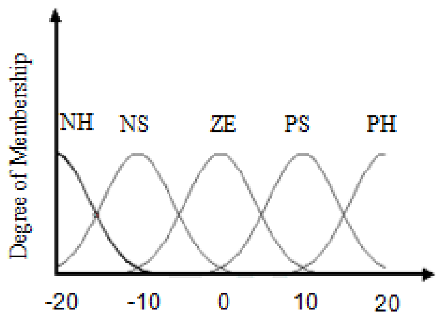

Fig. 5. Membership functions for output variable hysteresis bandwidth

The estimated change in motor torque (dT_e) and change in stator current (dI_s) over a sampling period are chosen as the input to the FLC. The input membership function for input variable is shown in Fig 3. Figure 4 shows the membership function for input variable stator current. The membership function for output variable hysteresis bandwidth is shown in fig 5. It can be defined by the following equations:

$$dT_e = T_e[s] - T_e[s-1] \quad (3)$$

$$dI_s = I_s[s] - I_s[s-1] \quad (4)$$

Where $T_e[s]$ and $T_e[s-1]$ represents the present and previous samples of motor estimated torque. Similarly, $I_s[s]$ and $I_s[s-1]$ represent the present and previous samples of stator current respectively. By neglecting the friction coefficient, the motor mechanical equation can be written as

$$T_e - T_L = J \frac{d\omega r}{dt} \quad (5)$$

If the amplitude bandwidth is set too small, then the overshoot may touch the upper band which will cause a reverse voltage vector to be selected. This voltage will rapidly reduce the torque causing undershoot in torque response. Therefore the torque ripple will remain high. By reducing the motor torque ripples, it directly reduces the motor speed ripples.

V. SIMULATION RESULT

MATLAB/SIMULINK model based on power system tool box was developed to reduce the torque ripple and reconstruction of phase current in order to improve the performance of induction motor drive. The dc voltage and current are measured from the dc link. With the help of these two parameters stator current was measured. The motor torque and stator current are used as a input to the FLC. By using two input fuzzy rules was framed. In this paper, for fuzzy input triangular membership function is used and for fuzzy output Gaussian membership function is used. The fuzzy logic controller is used to reduce the torque and flux ripple hence the performance of induction motor is improved.

The simulation parameters of induction motor are as follows:

Three phase voltage source - 415V, 50Hz
Mechanical input for motor - torque
Rotor type - Squirrel cage induction motor
Motor poles - 4
Motor speed - 1430rpm
Horse power - 5.4HP
Motor power - 4KW
Stator resistance - 1.405 Ohms
Rotor resistance - 1.395 Ohms

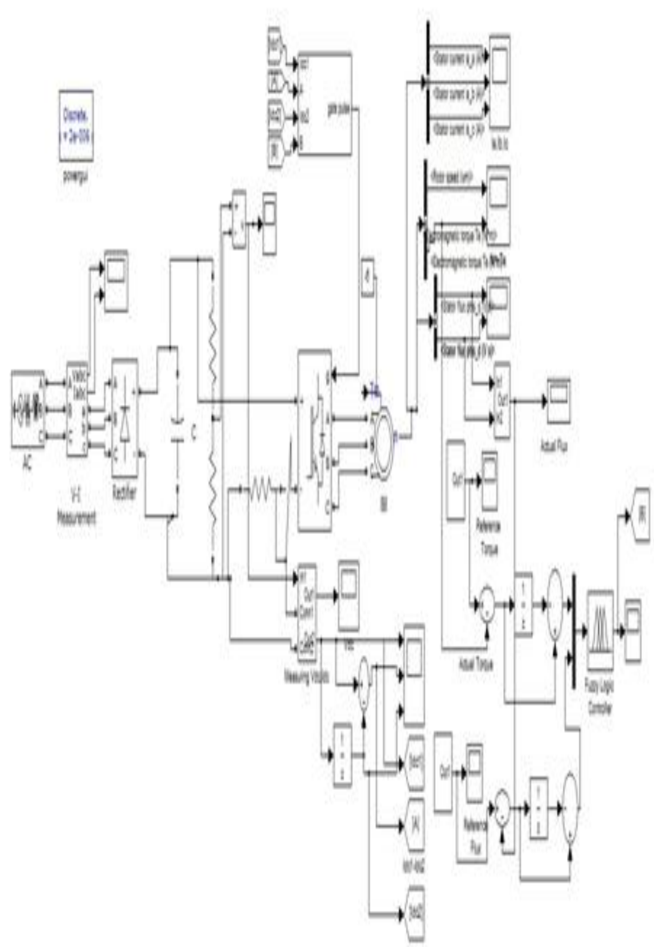

Fig. 6. Simulation circuit of proposed DTC

When an induction motor runs at a speed of 1000 rpm, the corresponding torque response is shown in Fig 7. Figure 8 shows the Developed flux response of an IM drive. when speed is 1000rpm.The peak value of torque is 51 Nm and the torque settles at 4 Nm. The flux reaches at 0.8 Wb.

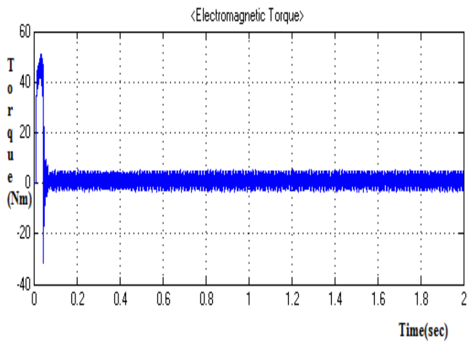

Fig. 7. Developed torque response of an IM drive when speed is 1000rpm

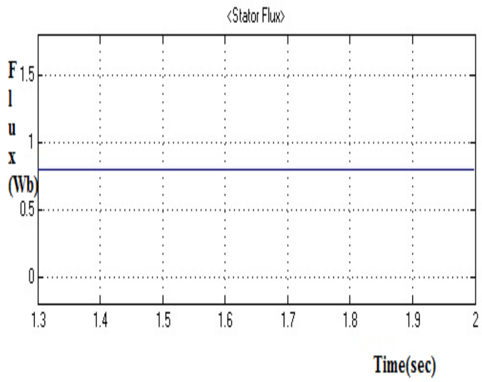

Fig. 8. Developed flux response of an IM drive when speed is 1000rpm

When the induction motor runs at a speed of 1400 rpm, the corresponding torque response is shown in Fig 9. Similarly the flux response is also noted when motor runs at a speed of 1400 rpm is shown in Fig 10. The peak value of torque is 50 Nm and the torque settles at 3 Nm. The flux reaches at 0.8 Wb.

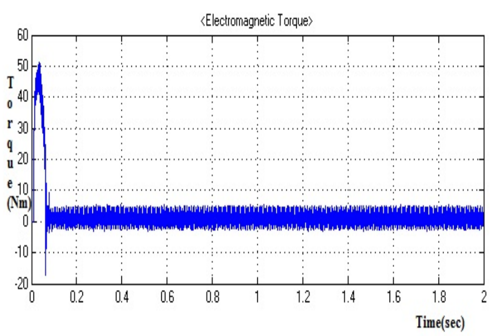

Fig. 9. Developed torque response of an IM drive when speed is 1400rpm

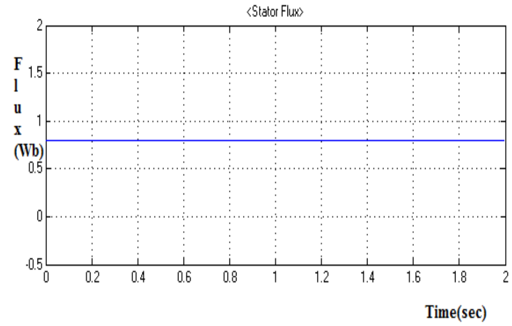

Fig. 10. Developed flux response of an IM drive when speed is 1400rpm

From the above figs the developed torque and flux response of an induction motor drive, reduces the torque and flux ripples, the response of the torque is fast. The improvement of the paper also includes no flux dropping due to circular trajectory sector changes, switching loss and its noise is less and low cost.

VI. CONCLUSION

In this paper, a new fuzzy based direct torque control of induction motor using single current sensor has been presented using single shunt resistor inserted in the path of dc link, for phase current reconstruction. The proposed fuzzy logic controller is used to adjust the bandwidth of the torque hysteresis controller in order to reduce the torque ripple of the motor. The motor torque ripple directly reduces the speed ripple also. The proposed variable torque hysteresis band controller exhibits smooth response and lesser ripple in torque and flux.

The main improvements of this paper are:

- Reduction of torque and flux ripples
- Torque response is fast
- No flux dropping due circular trajectory sector changes
- Low switching loss and noise
- Low cost

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