

# Improved DTC of Induction Motor with Fuzzy Controller

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**Abstract:** DTC, also known as Direct Torque Control, is a technique employed in variable frequency drives for regulating the torque and speed of three-phase AC electric motors. This method entails determining an approximation of the motor's magnetic flux and torque by analyzing the voltage and current readings of the motor. In order to reduce flux ripples and ensure smooth speed operation, we have suggested the use of two fuzzy logic controllers based on DTC for induction motors. The proposed method offers a faster response compared to conventional DTC for induction motors. The MATLAB simulink software was used to illustrate the comprehensive results.

Keywords: Direct torque controller, two fuzzy method, ripples minimization.

## 1. INTRODUCTION

Direct torque control (DTC) has gained significant global attention in recent years [1, 2]. DTC simplifies the requirements for machine configuration [2, 4]. By employing a DTC hysteresis band, it becomes possible to directly control the flux and torque of the induction motor. When the stator flux exceeds the hysteresis band, the converter switches the stator to the most optimal path towards the desired value [2, 4]. The term "direct torque control" indicates the ability to directly modify the inverter states based on the differences between the reference and estimated torque and flux values, thereby minimizing errors within the predetermined band limits.

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DTC offers several key benefits, including its efficient and rapid torque control across a wide range of speeds. It also eliminates the need for coordinate transformation and the generation of PWM pulses and current regulation. However, one drawback of DTC is the presence of steady-state torque and flux ripples, which can affect the accuracy of speed estimation and contribute to increased acoustic noise and harmonics. To address these issues, there are two techniques commonly employed in DTC drives: the multilevel inverter and space vector modulation (SVM). Extensive literature exists on open and closed loop position and speed estimators in DTC, with this study utilizing modified current-voltage model speed observer models based on an MRAS method to measure rotor speed. Furthermore, an optimized fuzzy controller is implemented to improve the efficiency of the DTC method in minimizing both flux and torque fluctuations.

## 2. DIRECT TORQUE CONTROL

Figure 1 depicts a circuit diagram illustrating the DTC of an induction motor drive, which is powered by a three-phase voltage source inverter (VSI).

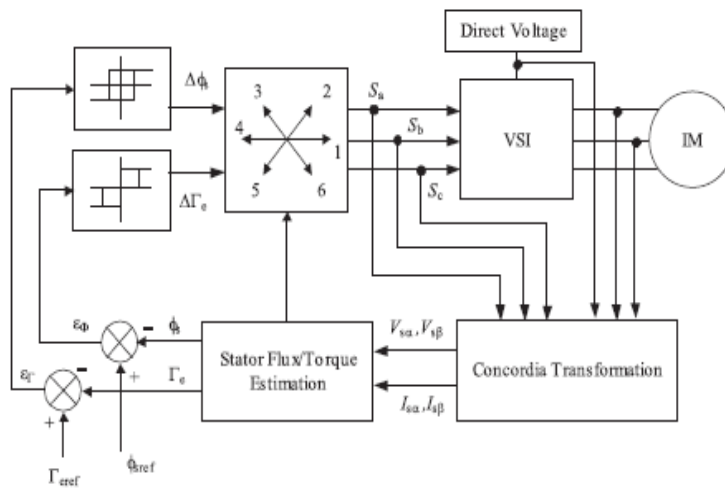


Fig. 1: Model representation of a DTC of Induction Motor (IM).

The DTC is a variable frequency drive technique for controlling the torque (and hence the speed) of a 3-phase electric motor. This method developed by estimating the torque and magnetic flux of IM with help of sensing voltage and currents. The DTC has following properties:

- The references can be altered rapidly to bring about swift changes in torque and flux.
- No overshoot occurred in the step response.
- No coordinate transformations are required; and all computations are conducted in a stationary coordinate system.
- The switch control signals are directly defined by the hysteresis control, eliminating the need for a separate modulator.
- There are no current PI controllers. As a result, no adjusting of the control is necessary.
- The switching frequency of the transistors lacks consistency. By adjusting the width of the tolerance bands, it is feasible to keep the average switching frequency

near its designated value. Consequently, this reduces both current and torque ripple. Consequently, the magnitude of the torque and current ripples is equivalent to that of vector controlled drives operating at the identical switching frequency.

- Because of the hysteresis control loop, the process of switching is by definition random. As a result, peaks in the current spectrum won't exist. This also suggests that the machine produces little audible noise.
- The technique automatically accounts for the voltage change of the intermediate DC circuit (in voltage integration). As a result, dc voltage ripple (aliasing) and dc voltage transients are not a concern.
- Synchronizing with spinning machinery is a simple process thanks to the efficient control system. Just set the torque reference to zero and activate the inverter to initiate synchronization. The initial current pulse will help identify the flux.
- It is crucial for digital control technology to operate at a high speed in order to keep flux and torque within the specified tolerance bands. The control algorithm must typically be run in 10 - 30 microseconds or less. However, because the procedure is simple, the number of calculations required is minimal.
- The current and voltage measurement devices must be of good quality and free of low-pass filtering and noise, as noise and sluggish response wreak havoc with hysteresis control.
- At higher speed, the procedure is not affected by drive characteristics. However, at low speed, the inaccuracy in resistance of the stator used to estimate stator flux becomes crucial.

Even without speed sensors, the direct torque technique performs exceptionally well. On the other hand, the integration of voltages is commonly used to estimate flux. However, due to inherent flaws in voltage measurement and stator resistance calculation at low speeds, the integrals can become inaccurate. Hence, if the variable frequency drive's output frequency is zero, it becomes impossible to regulate the motor. However, with proper structuring of the management system, it becomes feasible to achieve a minimum frequency ranging from 0.5 Hz to 1 Hz. This minimum frequency is adequate to initiate an induction motor with full torque from a standstill. Moreover, if the speed swiftly crosses the zero range, there is a possibility of rotational reversal, which prevents significant divergence in flux estimation. In case continuous operation at low speeds, including zero frequency operation, is necessary, enhancing the DTC system can be done by integrating a speed or position sensor. This sensor ensures excellent torque and speed control accuracy across the entire speed range.

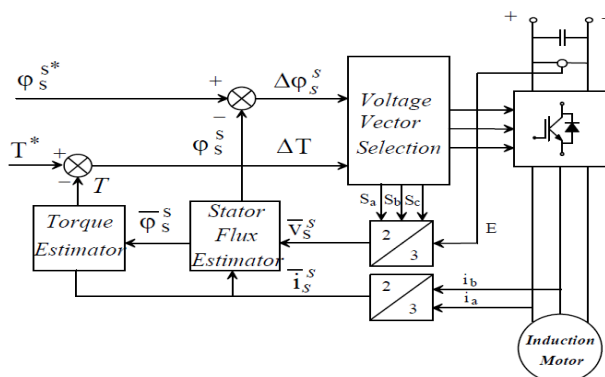


Fig. 2: Layout of DTC.

In general, the DTC technique chooses one of the inverter's 6-nonzero and 2-zero voltage vectors based on the instantaneous inaccuracies in torque and stator flux magnitude.

### 3. PROPOSED FUZZY APPROACH AND TORQUE RIPPLE MINIMIZATIONS

The challenge of torque ripple in DTC induction motor driving arises from the inability of inverter switching vectors to generate the precise stator voltage needed for desired torque and flux variations. As per the DTC operating principle, torque pulsations occur in proportion to the hysteresis band's magnitude. Minimizing torque pulsation is crucial to reduce vibration and acoustic noise. When using high-switching-speed semiconductor devices, it is recommended to prioritize lower flux hysteresis bands as switching losses are generally minimal compared to state losses. This approach can significantly decrease harmonic current in the output. The hysteresis band should be set to a sufficiently large value to keep the inverter switching frequency below a specified threshold, typically determined by the power devices' thermal limitations. Nevertheless, due to the fact that hysteresis bands are tailored for the most unfavorable situations, the performance of the system is unavoidably compromised within a particular range of operation, particularly when operating at lower speeds. The duration for transitioning between the lower and upper limits in the torque hysteresis controller can be adjusted based on the prevailing operating conditions. Most of these approaches require significant computational resources. To reduce torque ripple, a fuzzy technique is presented in the following section. The fuzzy controller determines the appropriate amplitude hysteresis band to achieve this objective.

### 4. A FUZZY APPROACH TO REDUCE RIPPLES in TORQUE

Fuzzy logic has demonstrated its robustness and effectiveness in addressing various problems. A fuzzy controller presents itself as a practical option for evaluating the extent of the torque hysteresis band based on the torque ripple level. The size of the torque hysteresis band is not preset in this research, but instead established by the fuzzy controller. The selection of two inputs, namely speed error variation and stator current fluctuation, is based on the investigation conducted in section (B).

$$e_1(k) = \hat{\omega}(k) - \hat{\omega}(k - 1)$$

$$e_2(k) = I_s(k) - I_s(k - 1)$$

That the torque hysteresis band amplitude is obtained:

$$b_\Gamma(k) = b_\Gamma(k - 1) + \Delta b_\Gamma(k)$$

The fuzzy controllers that have been designed were developed through a combination of intuition and simulations. In order to determine the values for reducing torque and flux ripple, different values of motor speed and current were examined. These values were then used to create a training set, from which the table rule  $_b(e_1; e_2)$  was extracted. To further refine the membership functions, simulations and testing were conducted. The rule sets can be seen in Table-1. These rules were formulated based on analytical data obtained from a system simulation that involved varying torque hysteresis band values. Setting the amplitude  $b$  too low may lead to overshooting and hitting the top band, potentially selecting

a reverse voltage vector. Consequently, torque would rapidly decrease, resulting in an undershoot in torque response and ultimately maintaining high torque ripple.

Table-1: Fuzzy rules of Torque hysteresis controllers.

$e_1$ $e_2 \Delta b_T$	NH	NM	NS	ZE	PS	PM	PH
N	N	N	NS	ZE	PS	PS	P
ZE	N	N	NS	ZE	PS	P	P
P	N	NS	NS	ZE	PS	P	P

PH stands for positive high, NH stands for negative high.

PM stands for positive medium, and NM stands for negative medium.

PS stands for positive small, NS stands for negative small, and ZE stands for zero.

The following are examples of linguistic rules:

example:

- If ( $e_1 = NM$  or  $NH$  and  $e_2 = N$ ), then ( $_b = N$ ):

This instance pertains to a notable increase in torque error, leading to substantial torque ripple. The value of  $_b$  needs to be decreased in order to reduce the torque ripple.

- If ( $e_1=PH$ ) and ( $e_2=P$ ), then ( $_b=P$ ):

In this case, the torque error overshoot can potentially exceed the upper limit, leading to the activation of a reverse voltage vector. Consequently, the torque experiences a rapid decrease, causing an undershoot in the torque response below the hysteresis zone. To prevent this problem, it is important to ensure that  $_b$  is not excessively small, and it is set to Positive.

## 5. RESULTS OF SIMULATION

The Matlab/Simulink simulation program was utilized to carry out simulations for the DTC induction motor drive. An assessment of the speed control performance was performed in the absence of a fuzzy controller. The simulation outcomes, depicted in Figure 6, present the computed speed, torque, stator and rotor flux, as well as stator current employing the DTC scheme and MRAC method. In particular, Figure 6 showcases the speed transition from 157rd/s to 50rd/s at rated torque load. The predicted speed closely aligns with the reference speed.

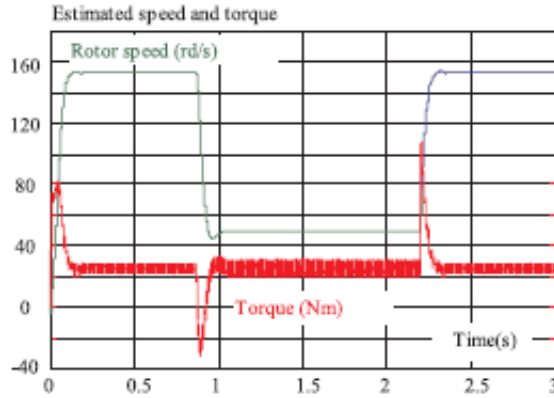


Fig. 3: Speed and Torque response.

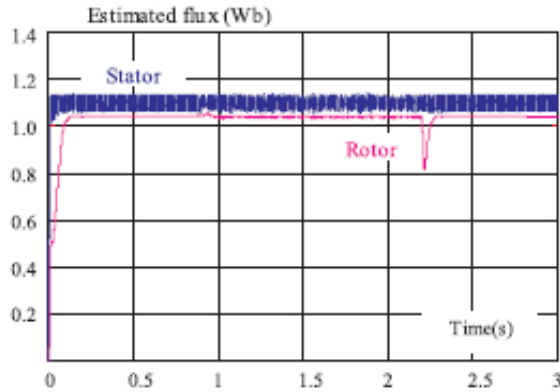


Fig. 4: Response of Flux.

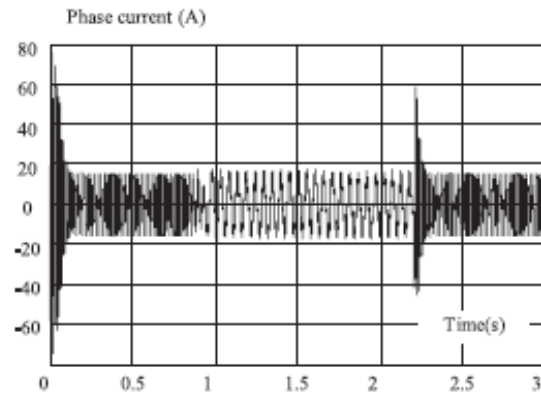


Fig. 5: Response of Phase current.

The simulation results presented in the figure illustrate the performance of the proposed technique under low speed conditions (10rd/s with a rated load of 25 Nm). The fuzzy

controller adjusts the amplitude  $b$  based on the operating conditions, as depicted in the accompanying figure. As a result, the torque ripple, as well as the impact of flux and torque on speed estimation, are significantly reduced. The trajectory of the stator flux demonstrates that the use of a fuzzy controller leads to a reduction in flux ripple.

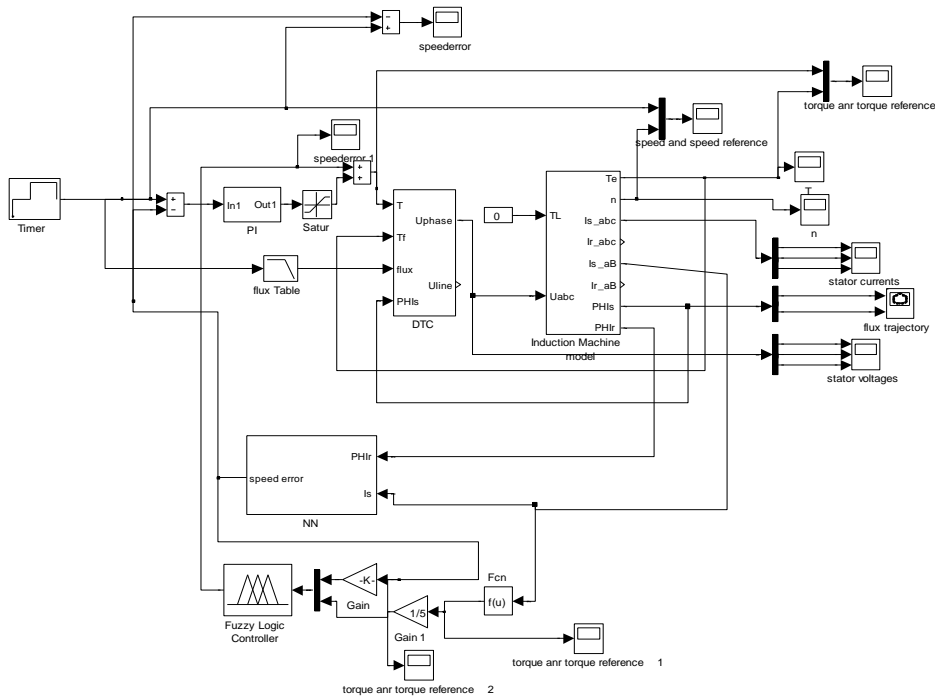
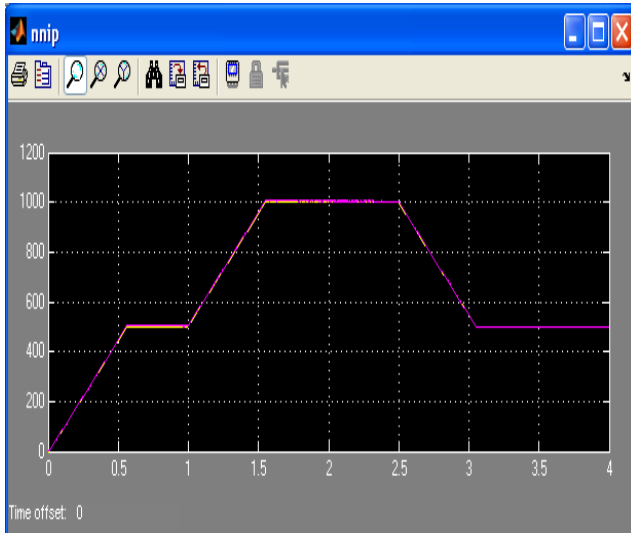


Fig. 6: DTC FUZZY CIRCUIT.

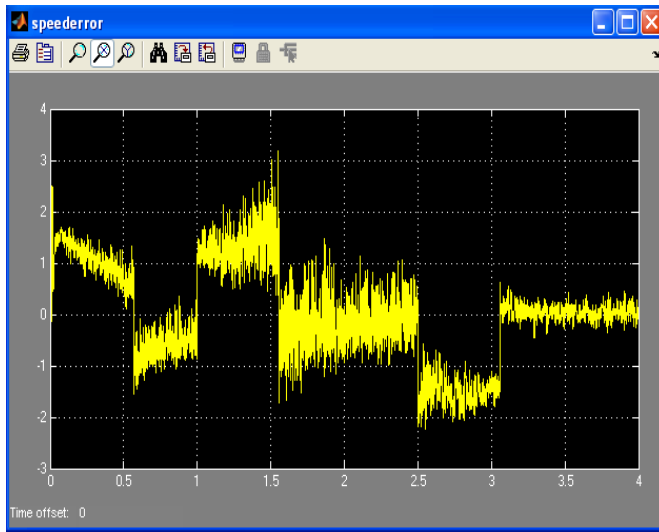
At a halt, respond to a speed transition

To demonstrate the benefits of the enhanced DTC, the control at standstill was subjected to a step change in speed reference (from 157 to 30rd/s) shown in Fig. 7.

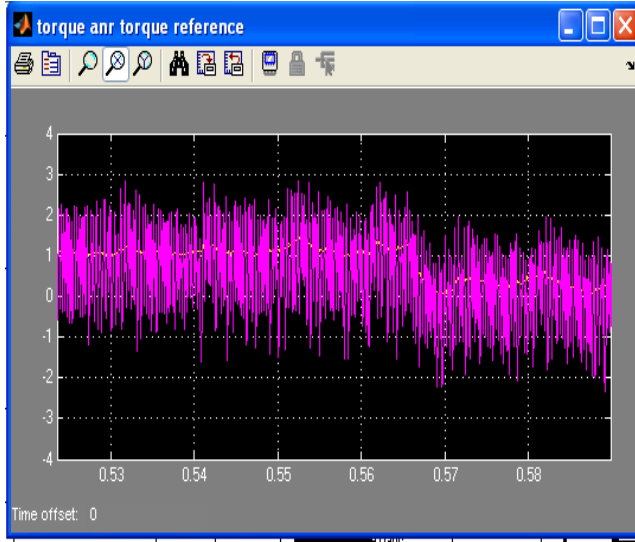
The calculated speed, torque, stator and rotor flux, and current are shown in Figures 7b and 7c. In Figure 8c, there is a notable reduction in torque ripple, especially at low speeds. Figure 7a illustrates how the fuzzy controller modifies the amplitude according to the torque ripple level and operating condition. The DTC-with fuzzy controller exhibits superior steady state performances compared to the DTC-without fuzzy controller, as depicted in Figure 7. The modified DTC exhibits comparable dynamic performance to the basic DTC.



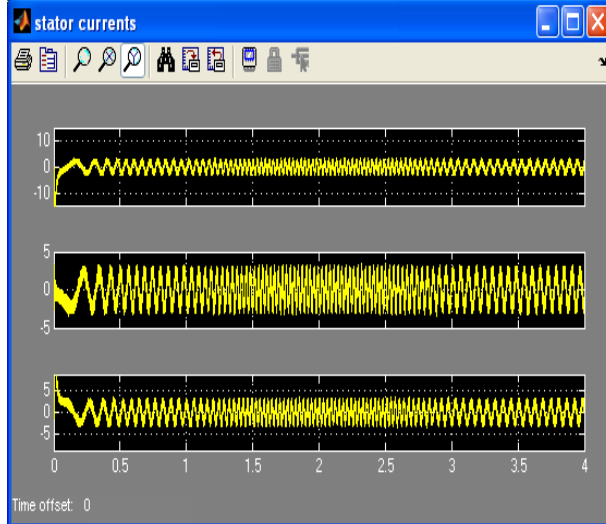
**Fig7 (a): Speed response.**



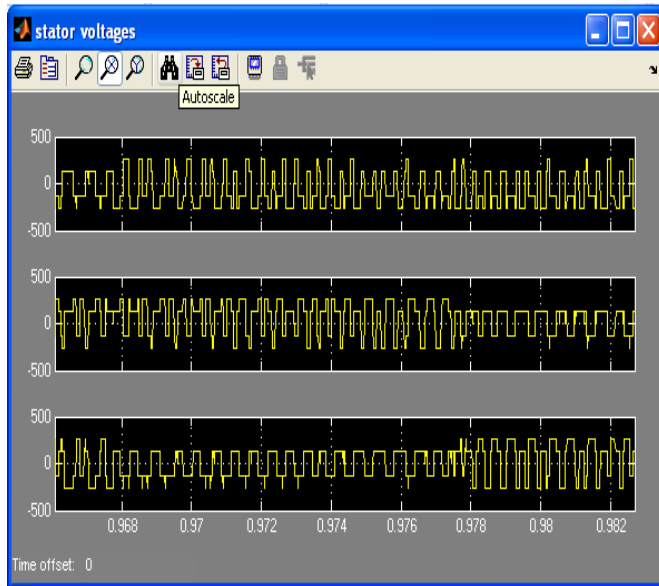
**Fig. 7(b): Speed Error.**



**Fig. 7(c): Response of reference and generated torque.**



**Fig. 7(d): Stator Currents.**



**Fig. 7(e): Stator Voltages.**

## 6. CONCLUSION

The present investigation puts forth a velocity reaction employing a fuzzy controller for DTC driving. This controller establishes the desired range of the torque hysteresis band. It has been proven that this suggested approach enhances the stator flux and torque responses during stable operating conditions. The primary advantage lies in the augmentation of torque and flux ripple attributes at lower velocities, enabling the motor to function with minimal switching loss and noise.

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