Neural speed controller of induction motor with 24 sectors DTC based fuzzy hysteresis comparators

Habib BENBOUHENNI
Ecole Nationale Polytechnique d'Oran Maurice Audin, Oran, Algeria.
E-mail: habib0264@gmail.com

Abstract: *Direct torque control (DTC) of the induction motor (IM) is important in many applications. The DTC system is known to offer fast decoupled control of torque and flux via a simple control structure. In This paper, IM is controlled with three-level DTC using intelligent controllers. These intelligent controllers were used to replace, on the one hand, the conventional hysteresis comparators of torque and flux, on the other hand, and the classic integral proportional (PI) of speed controller in order to reduce torque ripple, stator flux ripple and THD (Total Harmonic Distortion) value of stator current and to improve performance DTC. The validity of the proposed control scheme is verified by simulation tests of the IM. The stator flux, torque and THD value of stator current are determined and compared with the conventional control.*

Keywords: *DTC, IM, Intelligent controllers, hysteresis controllers, PI, THD.*

1. Introduction

The IM has many applications in industries. In order to obtain excellent dynamic performance, many interests are focused on the command algorithm of the IM. The most famous two command methods of IM are the field oriented command (FOC) method and DTC command method.

The direct torque control of the induction machine was introduced in 1986 by I. Takahashi and M. Depenbrock [1]. DTC method is characterized by its simple implementation and a fast dynamic response [2]. The DTC technique is gaining popularity in industries [3]. Though, in the classic DTC the employment of the hysteresis controllers to regulate the stator magnetic flux and torque is natural to have high torque ripples and variable switching frequency, which is varying with speed, load torque, selected hysteresis bands and difficulty to control torque and flux at very low speed. It also results in higher acoustical noise and in harmonic losses [4].

A variety of techniques have been proposed to overcome some of the draw backs present in DTC. Some solution proposed are: DTC with space vector modulation (SVPWM), the use of a duty-ration controller to introduce a modulation between active vectors chosen from the look-up table and the zero vectors, use of artificial intelligence techniques, such as neuro-fuzzy controller with SVPWM. However the complexity of the control is considerably increased [5]. A different approach to improve DTC features is to employ different inverter topologies (Multilevel inverter) from the standard two-level VSI [5].

The multilevel inverters are profaned for high power drive application. Commercially three basic multilevel converters are presented in the literature as diode-clamped converters, cascaded H-bridge converters and flying-capacitor converters [6]. The diode clamed multilevel inverter has been used in AC drives over the last decade, it uses clamping diodes and a group of cascaded DC capacitors to achieve multiple levels in the inverter output voltage for the reduction of dv/dt and THD. The diode clamped inverter also features high operating voltage without switching devices in series. The inverter can be configured as a three-level, four-, or five-level topology, but only the three-level inverter has been widely used in industry [7].

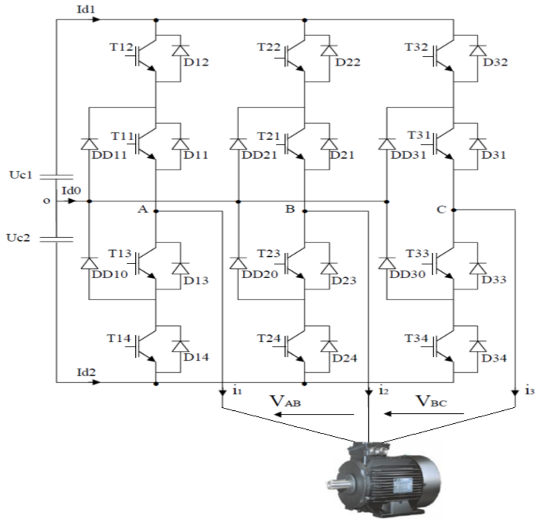
To improve the performance of the IM, a multilevel DTC with intelligence controllers is proposed in this paper, in order to accomplish three objectives: reduce torque ripple, stator flux ripple and reduce THD value of stator current.

In this paper, two different DTC schemes will be compared with each other. These two schemes are three-level DTC with 24 sectors and three-level DTC with intelligence controllers. The proposed control scheme is verified by both the simulation results.

2. Modeling of the three-level inverter

Figure. 1 shows the circuit of a three-level diode clamed inverter and the switching states of each leg of the inverter. Each leg is composed of two upper and lower switches with anti parallel diodes. Two series DC-link capacitors split the DC-bus voltage in half, and six clamping diodes confine the voltage across the switches within the voltage of the capacitors, each leg of the inverter can have three possible switching states, 2, 1 or 0 [8].

The representation of the space voltage vectors of a three-level inverter for all switching states is given by Figure. 2. According to the magnitude of the voltage vectors, the voltage vectors can be partitioned into four groups: the zero voltage vectors, the large voltage vectors, the middle voltage vectors, and the small voltage vectors.



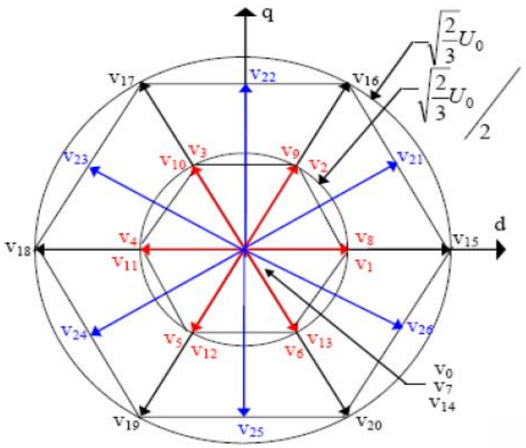


Fig. 1 Schematic diagram of a three-level inverter. **Fig. 2** Space vector diagram of three-level inverter.

3. Three-level DTC with 24 sectors

In the DTC scheme (Figure. 3), the electromagnetic torque and flux signals are delivered to two hysteresis comparators. The corresponding output variable and the stator flux position sector are used to select the appropriate voltage vector from a switching table which generates pulses to control the power switches in the inverter [9].

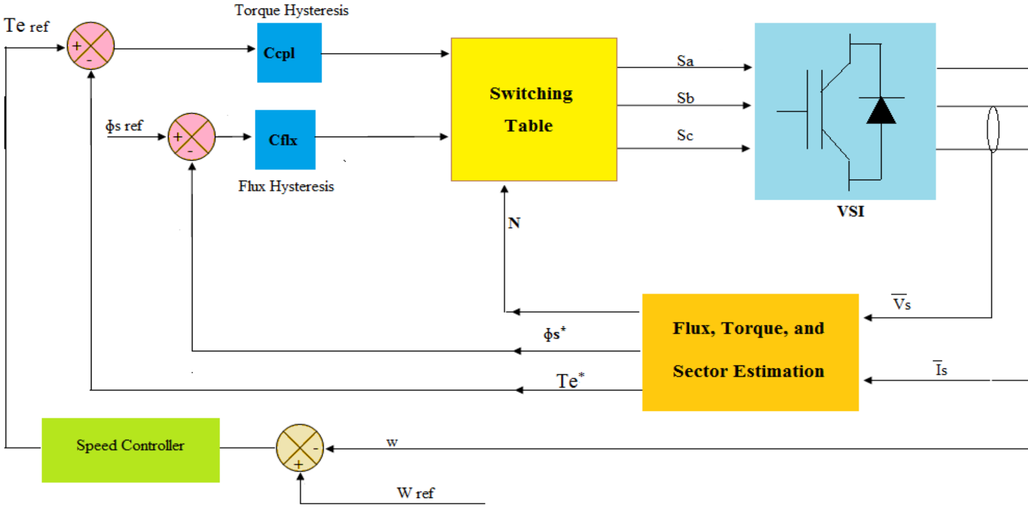


Fig. 3 Block diagram of DTC.

The stator flux can be evaluated by integrating from the stator voltage equation [10]:

$$\Phi_S = \int_0^t \left(V_S - R_S \cdot i_S\right) dt$$

(1)

With:

$$\begin{cases} \Phi_{s\alpha} = \int_0^t (v_{s\alpha} - R_s i_{s\alpha}) dt \\ \Phi_{s\beta} = \int_0^t (v_{s\beta} - R_s i_{s\beta}) dt \end{cases}$$

(2)

The stator flux amplitude is given by:

$$\Phi_S = \sqrt{\Phi_{s\alpha}^2 + \Phi_{s\beta}^2}$$

(3)

The stator flux angle is calculated by :

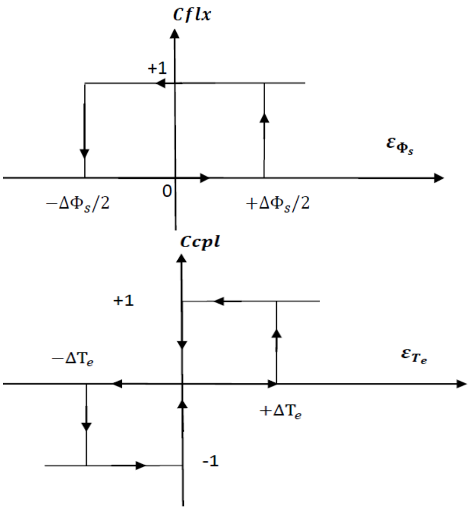
$$\theta_S = arctg(\frac{\Phi_{s\beta}}{\Phi_{s\alpha}})$$
(4)

Electromagnetic torque equation is given by [11]:

$$Te = \frac{3}{2} p\left[\Phi_{s\alpha} i_{s\beta} - \Phi_{s\beta} i_{s\alpha}\right]$$
(5)

In the three-level DTC with 24 sectors, it employs a pair of hysteresis controllers, one utilizes a two-level hysteresis controller (Figure. 4a) for controlling the flux and the other one uses a three-level hysteresis controller for controlling the torque (Figure. 4b).

The output status of hysteresis controllers (Ccpl and Cflx) and stator flux position (sector (N)) are used to tabulate a look-up table. So the appropriate voltage vectors able to control both torque and stator flux, respectively [12].



a) Hysteresis controller of stator flux **b)** Hysteresis controller of torque

Fig. 4 Hysteresis controllers.

The switching selection block in Figure. 3 receives the input signals Ccpl, Cflx and N generate the desired control voltage vector as given in look-up table shown in Table 1.

Table 1. Three-level DTC switching table with 24 sectors

N	Cflx					
	1			0		
	Ccpl					
	1	0	-1	1	0	-1
1	16	8	20	17	11	19
2	16	8	20	17	11	19
3	22	9	26	23	12	25
4	22	9	26	23	12	25
5	17	9	15	18	12	20
6	17	9	15	18	12	20
7	23	10	21	24	13	26
8	23	10	21	24	13	26
9	18	10	16	19	13	15
10	18	10	16	19	13	15
11	24	11	22	25	8	21
12	24	11	22	25	8	21
13	19	11	17	20	8	16
14	19	11	17	20	8	16
15	25	12	23	26	9	22
16	25	12	23	26	9	22
17	20	12	18	15	9	17
18	20	12	18	15	9	17
19	26	13	24	21	10	23
20	26	13	24	21	10	23
21	15	13	19	16	10	18
22	15	13	19	16	10	18
23	21	8	25	22	11	24
24	21	8	25	22	11	24

4. 24 sectors DTC with intelligent controllers

In order to improve the three-level DTC performances a complimentary use of intelligent controllers is proposed. The principe of intelligent controller direct torque control is similar to traditional DTC. The difference is using a neural network controller to replace the classic PI of speed and using the fuzzy logic controllers to replace the hysteresis comparators. As shown in Figure. 5.

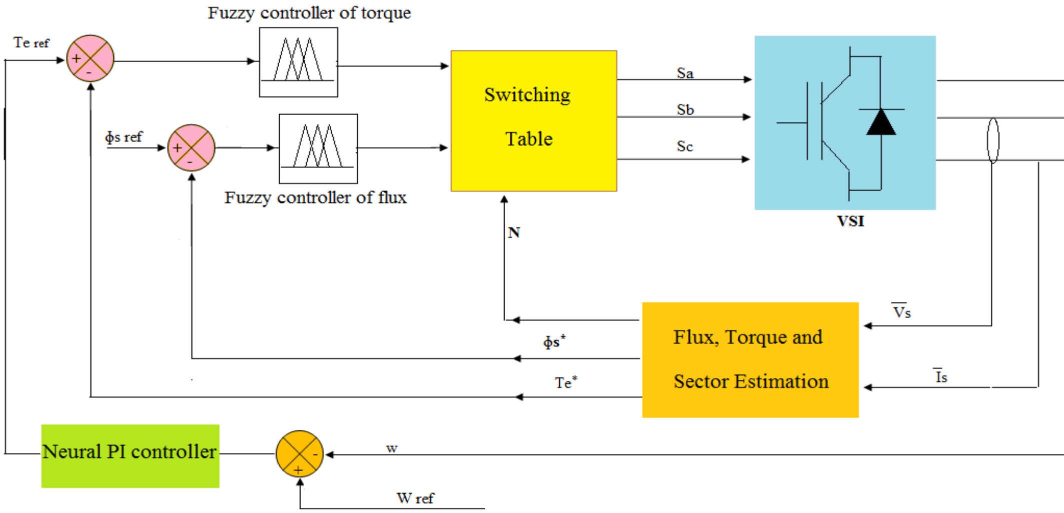


Fig. 5 24 sectors DTC with intelligent controllers.

4.1 Design of speed controller based on artificial neural network

Neural network consists of simple elements similar to biological nervous systems. These networks can be trained by adjusting the value of connections and weights between the elements to perform a specific function. The training is done based on comparison of output and target until the output matches the target. The neural networks is developed using Matlab-neural network fitting toolbox [13].

The block diagram for neural network based classic PI controller of speed is shown in Figure. 6. The network is trained with Levenberg-Marquardt back-propagation algorithm (LM) [14]. The structure of the neural network controller of speed was a neural network with one linear input node, 4 neurons in the hidden layer, and one neuron in the output layer, as shown in Figure. 7.

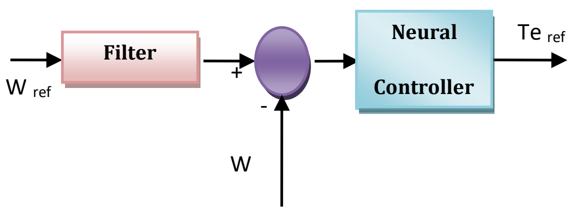


Fig. 6 Neural network control of PI controller of speed.

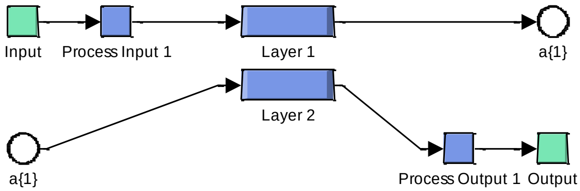
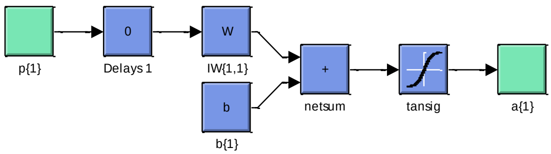


Fig. 7 Neural network structure for classic PI of speed.

The structure of layer 1 is shown in Figure. 8, and layer 2 is shown in Figure. 9.



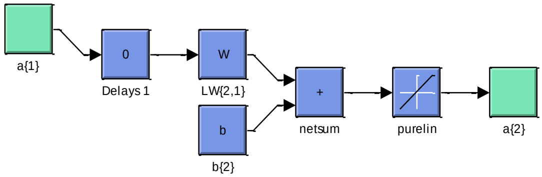
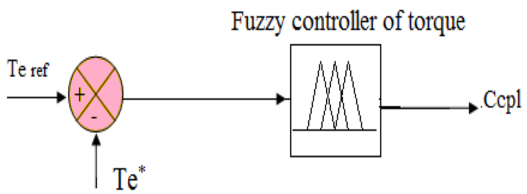


Fig. 8 Architecture of layer 1.

Fig. 9 Architecture of layer 2.

4.2 Design of hysteresis comparators based on fuzzy logic controllers

Lotfi A. Zadeh from the university of California first introduced fuzzy logic theory in 1965 [15]. Fuzzy control also allows controlling systems without knowing the plant mathematic model. It uses the intuition and experience of the designer to build its control rule base [16]. Fuzzy logic is an expert based system and fuzzy variables can have membership values in between 0 to 1 [17]. In this section, a fuzzy approach is proposed to reduce torque ripple and THD value of stator current. In this paper, the hysteresis comparators of torque and flux are replaced by fuzzy controllers. The block diagram of the torque fuzzy hysteresis is shown in Figure. 10, and flux fuzzy hysteresis is shown in Figure. 11.



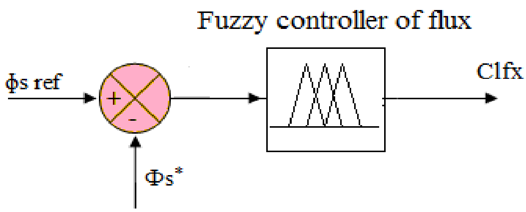
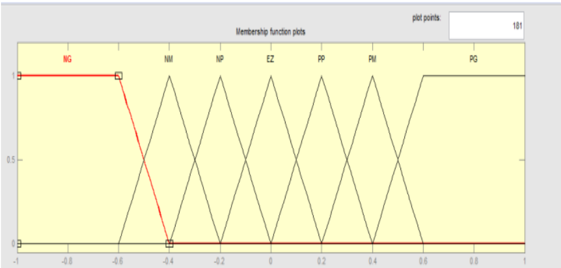
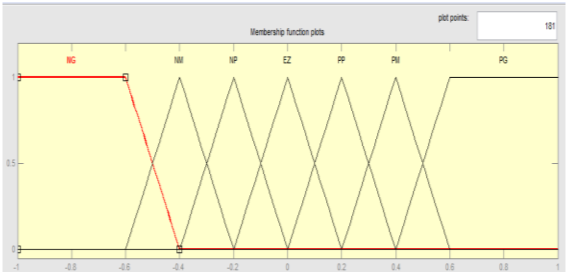


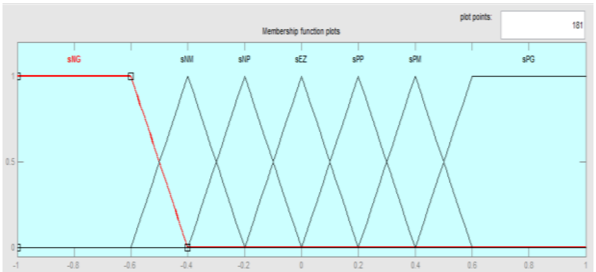
Fig. 10 Torque hysteresis controller **Fig. 11** Flux hysteresis controller

One possible initial rule base, that can be used in drive systems for a fuzzy logic controller, consist of 49 linguistic rules, as shown in Table 2 [18], and gives the change of the output of fuzzy logic controller in terms of two inputs: the error (e) and change of error (de). The membership function definition for the input variables “Error in torque and error in flux” is shown in Figure. 12a, “change in error of torque and flux” is shown in Figure. 12b, “Output variable membership function” is shown in Figure. 12c.





a)Error in torque and flux b) Change in error



c)Output variable memership function

Fig. 12 The membership function.

In Table. 2, the following fuzzy sets are used: NL negative large, NM negative medium, NS negative small, ZR zero, PS positive small, PM positive medium and PL positive large [19].

Table 2. Fuzzy rules base

e Δe	NL	NM	NP	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NP	EZ
NM	NL	NL	NL	NM	NP	EZ	PS

NP	NL	NL	NM	NP	EZ	PS	PM
EZ	NL	NM	NP	EZ	PS	PM	PL
PS	NM	NP	EZ	PS	PM	PL	PL
PM	NP	EZ	PS	PM	PL	PL	PL
PL	EZ	PS	PM	PL	PL	PL	PL

5 Simulation results

The 24 sectors DTC control with intelligent controllers of an IM is implemented with simulation tools of Matlab. The speed regulator is used as classical PI, neural PI separately. The torque and flux comparators are used as fuzzy hysteresis controllers. The performance analysis is done with torque, stator flux and THD value of stator current.

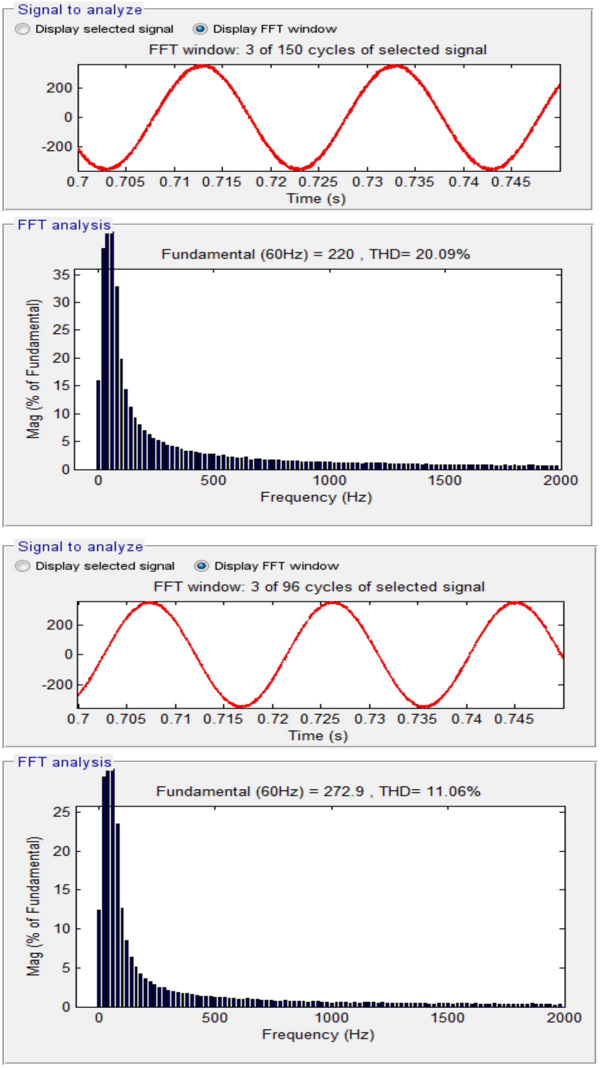
From the simulation results presented in Figure. 13 it is apparent that the THD value of stator current for the 24 sectors DTC with intelligent controllers utilizing a three-level inverter is considerably reduced. Table 3 shows the comparative analysis of THD value of stator current.

Table 3. Comparative analysis of THD value

THD value in classical DTC with 24 sectors	THD value in DTC with intelligent controllers
20.09%	**11.06%**

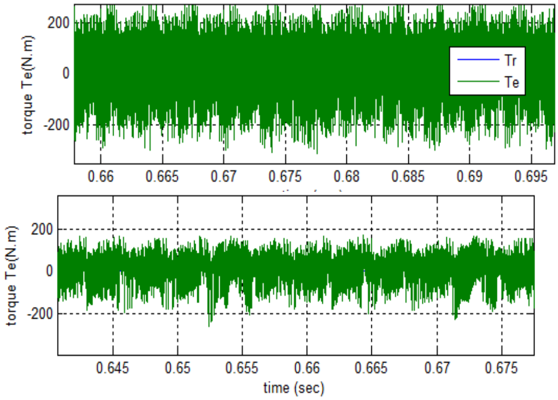
Torque response comparing curves are shown in Figure. 14. See figure the torque ripple is significantly reduced when the intelligent controllers are in use.

Figure. 15 show the flux responses of both the classical DTC with 24 sectors and three-level DTC with intelligent controllers. It is found that the proposed intelligent controllers based DTC scheme exhibit smooth response and lesser ripple in stator flux as compared to the conventional three-level DTC scheme.



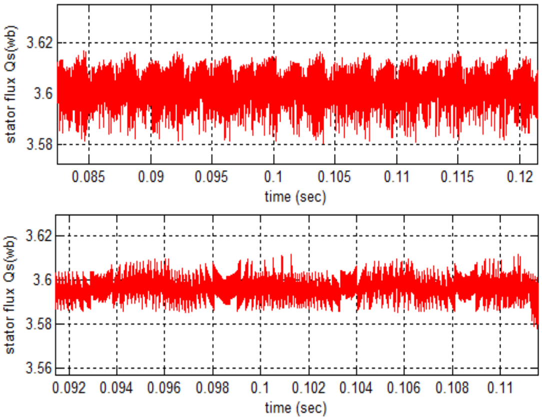
a) Classical DTC with 24 sectors **b)** 24 sectors DTC with intelligent controllers

Fig. 13 THD value of stator current.



a) Classical DTC with 24 sectors **b)** 24 sectors
DTC with intelligent controllers

Fig. 14 Zoom in the electromagnetic torque.



a) Classical DTC with 24 sectors **b)** 24 sectors
DTC with intelligent controllers

Fig. 15 Zoom in the stator flux.

6 Conclusion

In this paper, the 24 sectors DTC principle is presented and it is shown that with intelligent controllers for a three-level inverter. The simulation results obtained for the three-level DTC with intelligent controllers illustrate a considerable reduction in torque ripple, THD value of stator current and stator flux ripple compared to the classical 24 sectors DTC utilizing three-level inverter.

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