24 sectors DTC control of IM drive using ANFIS controller for minimize torque ripple

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Abstract—Direct torque control (DTC) is a control technique in AC drive systems to obtain high-performance torque control. Three-level neutral-point-clamped (NPC) inverters are very appropriate for high-power adjustable-speed drive applications. In this paper DTC control is applied for three-level NPC inverter fed induction machine (IM) drives. DTC drives utilizing hysteresis comparators suffer from high torque ripple and variable switching frequency. The most common solution to those problems is to use the intelligent techniques. In this paper, the ANFIS technique is applied to three-level inverter control in the proposed DTC-based IM drive system, thereby dramatically reducing the torque ripple and stator flux ripple. The validity of the proposed control scheme is verified by simulation tests of an IM drive. The THD value of stator current, stator flux ripple and torque ripple are determined and compared with the above techniques using Matlab-Simulink environment.

Keywords—DTC; IM; Intelligent technique; ANFIS; Hysteresis comparators; THD; Three-level NPC inverter.

I. Introduction

Induction motors are today the most widely used AC machines due to the advantageous merits of cost, reliability, and performances. Induction motor is characterized by complex, highly non-linear, time varying dynamics, inaccessibility of some states and output for mesurments and hence can be considered as a challenging engineering problem. The advent of torque and flux control techniques have partially solved induction motor control problems, because they are sensitive to drive parameters variations and performance may deteriorate if conventional controllers are used [1].

There are two most common AC drives control schemes that are being widely researched. One of it is field oriented control (FOC) which was proposed by F. Blaschke. Second scheme is Direct Torque Control (DTC) which was proposed by I. Takahashi and T. Noguchi [2]. DTC is simpler than field-oriented control and less dependent on the motor model, Since the stator resistance value is the only machine parameter used to estimate the stator flux [3]. The name direct torque control is derived from the fact that on the basis of the errors between the reference and the estimated values of torque and flux it is possible to directly control the inverter states in order to reduce the torque and flux errors within the prefixed band limits [4]. The advantage of DTC system are its high dynamic performance and fast torque response.

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The disadvantage of DTC system is high torque ripples due to the stator change during switching operation [5]. Combination of DTC with artificial intelligence (AI) opened an immensely promising avenue for motor control. Fuzzy logic, with its adjustable membership functions, provided a way to incorporate human expert knowledge in the control process. Neural networks offered the advantage of a training mechanism, a trait that would prove very useful inconfronting the nonlinearity that besets modern motor control methods. The culmination of this trend was the combination of fuzzy logic and neural networks into neuro-fuzzy controllers, the most popular configuration of which uses the Adaptive Neuro-Fuzzy Inference System (ANFIS) [6]. The feeding of the IM is generally assured by one twolevel inverters. However, for the high power, multilevel inverter are often required. Since the advantages of multilevel inverters and IM complement each other. In the other hand, multilevel inverter fed electric machine systems are considered as a promising approach in achieving high power/high voltage ratings. Moreover, multilevel inverters have the advantages of overcoming voltage limit capability of semiconductor switches, and improving 2 harmonic profiles of output waveforms [7]. Commercially three basic multilevel converters are presented in the literature as diode-clamped converters cascade H-bridge converters and flying-capacitor converters [8]. In this paper two different DTC control schemes will be compared with each other. These two schemes are conventional DTC with three-level inverter, DTC with ANFIS technique. The proposed scheme is described clearly and simulation results are reported to demonstrate its effectiveness. The entire control scheme is implemented with Matlab/Simulink.

II. Modeling of the Three-Level Inverter

Multilevel inverter structures have been developed to overcome shortcomings in solid-state switching device ratings so they can be applied to higher voltage systems [9]. In 1980, early interest in multilevel power conversion technology was triggered by the work of Nabae, who introduced the neutral-point-clamped (NPC) inverter topology [10]. The main concept of this inverter is to use diodes to limit the power devices voltage stress [11]. The topology that have been used in this paper is a three phase full bridge three levels diode clamped inverter and this topology is shown in Fig. 1 [12].

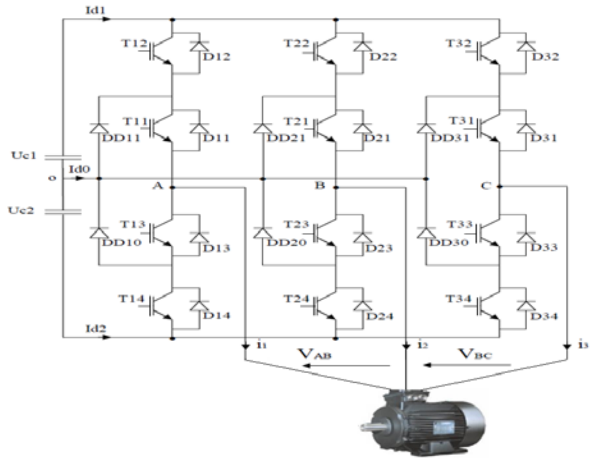


Fig. 1. Schematic diagram of a three-level inverter

The space vector diagram of a three-level inverter is shown in Fig. 2 [13].

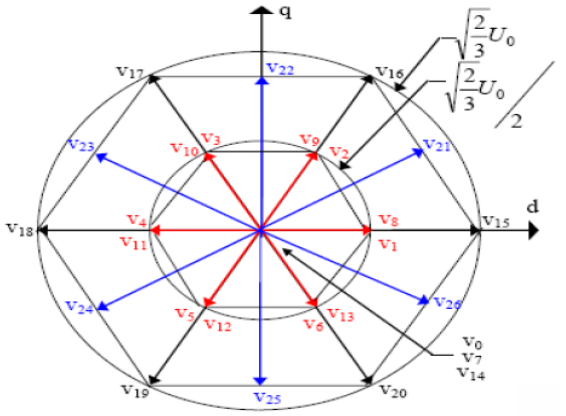


Fig. 2. Space vector diagram of three-level inverter

The stator flux can be evaluated by integrating from the stator voltage equation [16]:

$$\Phi_S = \int_0^t \left(V_S - R_S \cdot i_S\right) dt \qquad (1)$$

The magnitude of the stator flux can be estimated by

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

The stator flux sector is determined by the components $\Phi_{s\alpha}$ and $\Phi_{s\beta}$. The angle between the referential and Φ_S is equal to [17]:

$$\theta = arctg\left(\frac{\Phi s\beta}{\Phi s\alpha}\right) \qquad (3)$$

Torque can be calculated using the components of the estimated flux and measured currents:

$$Te = \frac{3}{2} p\left(\Phi_{s\alpha}\, i_{s\beta} - \Phi_{s\beta}\, i_{s\alpha}\right) \qquad (4)$$

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

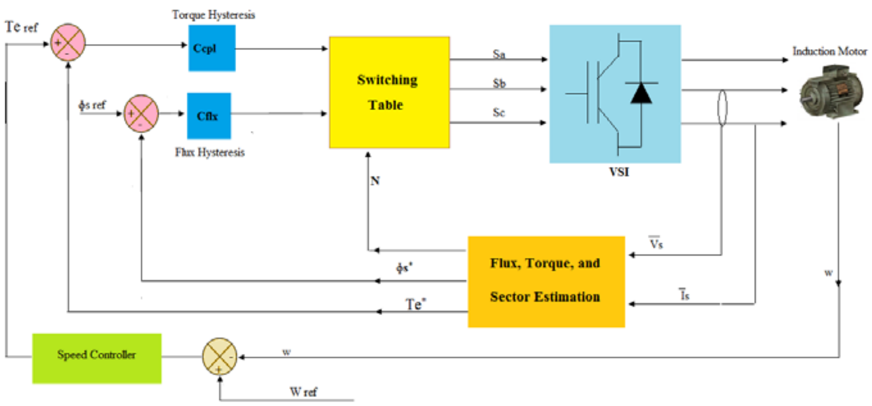


Fig. 3. Block diagram of DTC of IM drives.

III. CONVENTIONAL DTC WITH 24 SECTORS

Direct torque control method is based on applying a switching series, which shall directly eliminate errors, which shall occur in torque, through the reference given as value and the calculated flux, to the power switching elements in the inverter [14]. As shown in Fig. 3, stator flux and torque can be controlled directly and independently by properly selecting the inverter switching configuration [15].

TABLE I. TABLE DE VÉRITÉ DE STRATÉGIE PROPOSÉE DE LA COMMANDE DTC TROIS NIVEAUX

N	Cflx									
	0					1				
	Ccpl									
	-2	-1	0	1	2	-2	-1	0	1	2
1	25	5	0	3	17	20	13	0	2	22

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

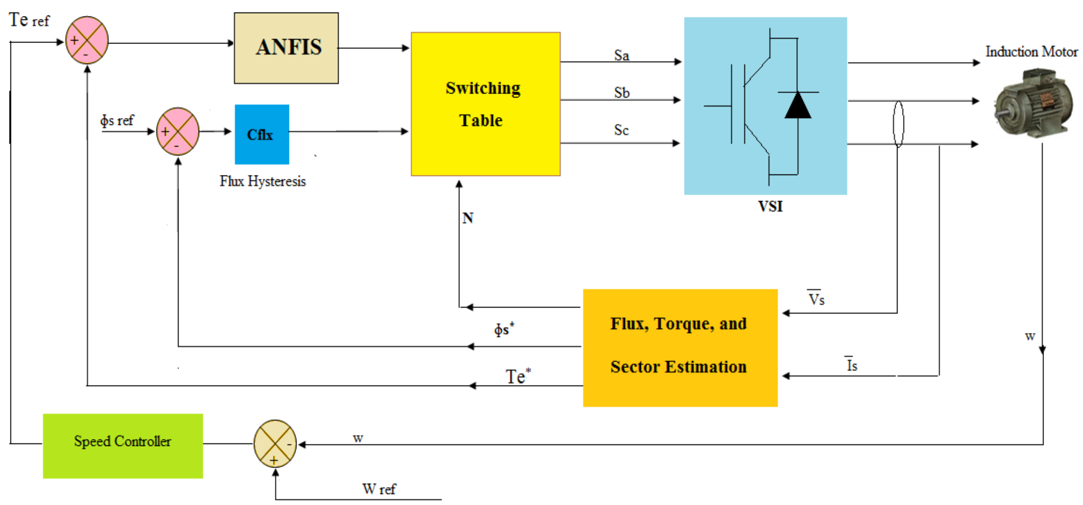


Fig. 4. DTC scheme with ANFIS hysteresis controller.

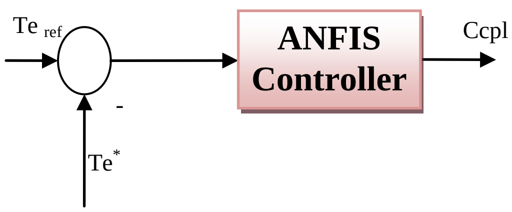


Fig. 5. ANFIS control of torque hysteresis controller.

IV. Three-level DTC using ANFIS controller

ANFIS is one of the popular neuro-fuzzy methods that is the hybrid combination of artificial neural networks (ANNs) and is based on Takagi–Sugeno fuzzy inference system (FIS) [18]. The Adaptive Neuro-Fuzzy Inference System is developed using Matlab ANFIS editor [19].

The principle of ANFIS techniques direct torque control is similar to conventional 24 sectors DTC. However, the hysteresis controller of torque are replaced by the ANFIS controller. The general structure of the IM with 24 sectors DTC with ANFIS technique is represented by Fig. 4.

The block diagram for ANFIS based torque hysteresis controller is shown in Fig. 5.

Then the designed ANFIS has two inputs namely, the reference torque and estimated torque while the output is the Ccpl. The structure of ANFIS torque controller is shown in Fig. 6.

V. Simulation results

The simulations of the three-level DTC (24 sectors DTC) with ANFIS controller of IM drive are compared with conventional DTC with 24 sectors. A 3-phase, 3 pole, induction motor with parameters of Rs=0.228Ω, Rr=0.332Ω, Ls=0.0084H, Lr=0.0082H, Lm=0.0078H, J=20 Kg.m2 are considered.

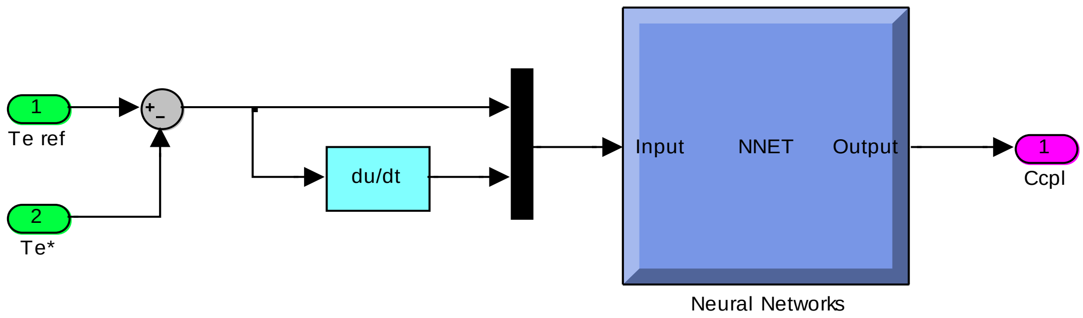
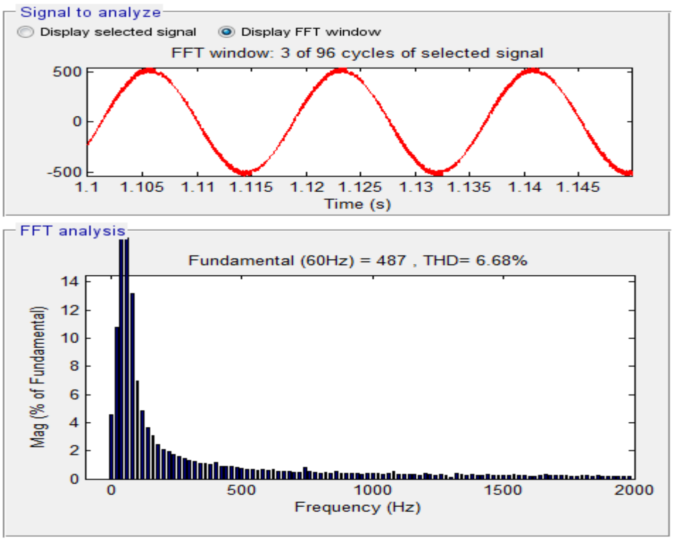
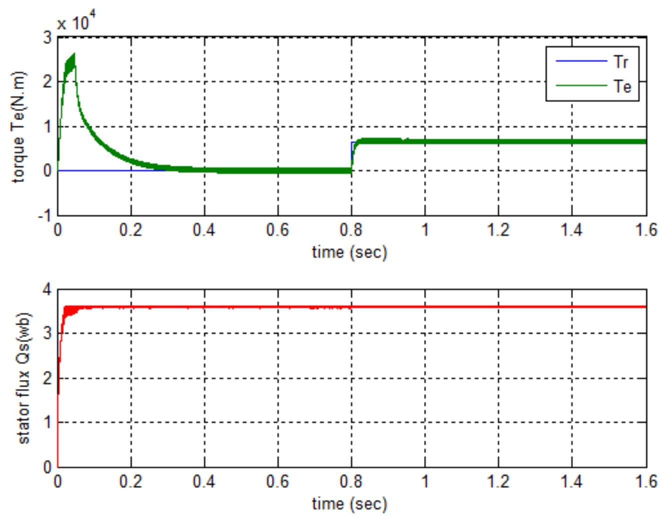


Fig. 6. ANFIS structure for three-level DTC with 24 sectors.

The performance analysis is done with stator current (THD), stator flux and torque plot. The dynamic performance of the three-level DTC control with induction motor is shown Fig. 7. The dynamic performance of the three-level DTC control with ANFIS controller is shown Fig. 8.





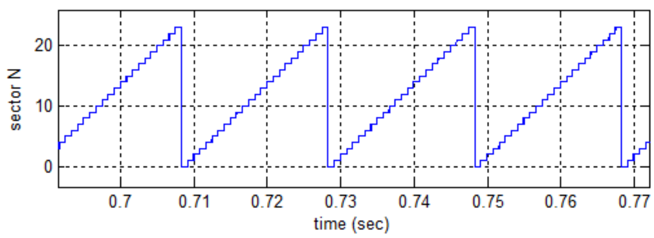
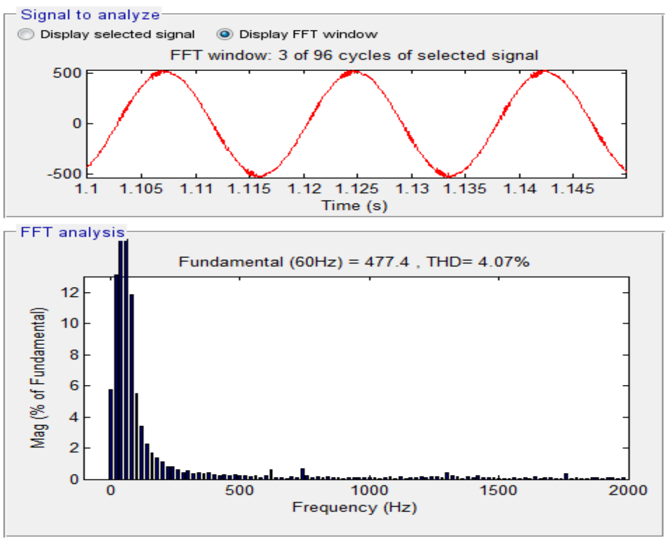
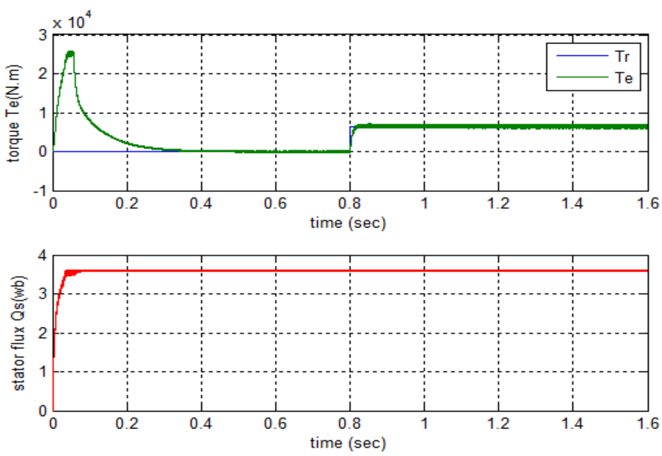


Fig. 7. Dynamic responses of five-level DTC for IM





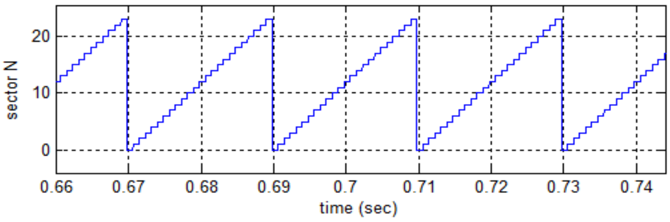


Fig. 8. Dynamic responses of five-level DTC with ANFIS controller for IM.

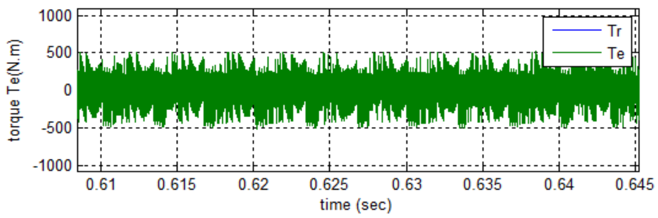
Table 2 shows the comparative analysis of THD value for stator current.

TABLE II. COMPARATIVE ANALYSIS OF THD VALUE

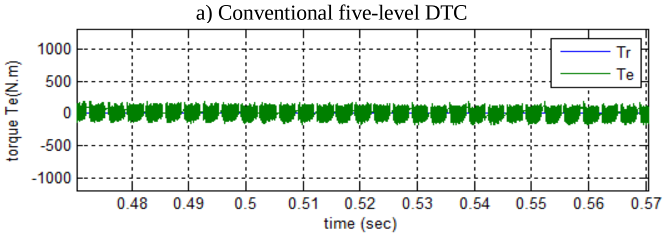
Three-level DTC	Three-level DTC with ANFIS
6.68%	**4.07%**

From the Table 2 it is apparent that the THD value of stator current for the three-level DTC with ANFIS is considerably reduced.

Torque response comparing curves are shown in Fig. 9. See figure the torque ripple is significantly reduced when the ANFIS controller is in use.

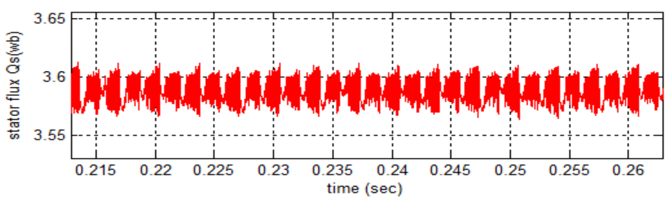


a) Conventional five-level DTC

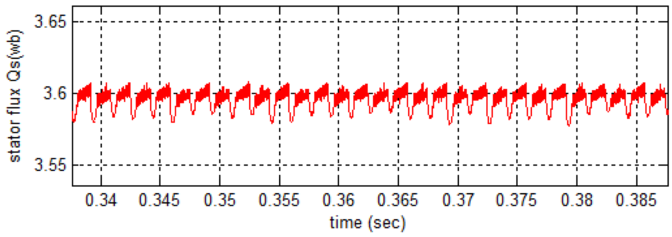


b) Three-level DTC with ANFIS
Fig. 9. Zoom in the torque

Fig. 10 shows the stator flux responses of both the conventional and three-level DTC with ANFIS controller. It is found that the proposed variable band torque hysteresis controller based DTC scheme exhibits smooth response and lesser ripple in stator flux as compared to the conventional three-level DTC control.



a) Conventional five-level DTC



b) Three-level DTC with ANFIS
Fig. 10. Zoom in the flux

VI. CONCLUSION

In this paper, we proposed an ANFIS controller for torque hysteresis comparator of IM controlled by three-level DTC with 24 sectors. Using ANFIS controller reduced the THD value of stator current, stator flux and torque ripple of IM performance compared to obtain with a classical hysteresis controller. The simulation results obtained were satisfactory, and system stability has been insured.

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