Five-level DTC based on ANN of IM drives using 13-level hysteresis control to reduce torque ripple comparing with conventional control

Habib Benbouhenni

Abstract— In this paper, the author proposes a new switching table of direct torque control (DTC) of induction machine (IM) fed by five-level Neutral Point Clamped (NPC) inverter. Using the Artificial Neural Network (ANN) applied in switching select voltage. We used the torque hysteresis by using the 13-level hysteresis controller. The proposed DTC control in this paper can reduce the torque ripple, stator flux ripple and the THD (Total Harmonic Distortion) value of stator current. The validity of the proposed DTC control scheme is verified by simulation tests of an IM drive.

Keywords— Induction machine; DTC; Five-level NPC inverter; Artificial neural network; 13-level hysteresis controller; THD.

I. INTRODUCTION

In recent years, many studies have been carried out to develop different solution for the induction motor control having the features of precise and quick torque response and reduction of complexity of the field-oriented algorithms. The direct torque control technique has been recognized as viable solution to achieve these requirements [1]. The DTC method has been proposed in the mid 1980's; the DTC method for AC machines is prevalently utilized in many variable speed drives [2]. It is based on the errors between the reference and the estimated values of torque and flux for to directly control the inverter states in order to reduce the torque and flux errors within the prefixed band limits to this end, it uses tables to select the switching procedure based on the inverter states and reduces the influence of the parameter variation during the operation. The DTC drive contains a pair of hysteresis comparators, a flux, torque estimator and a voltage vector selection table. The torque and flux are controlled simulation eously by applying suitable voltage vectors and by limiting these quantities within their hysteresis bands [3]. DTC provides very quick response with simple control structure and hence, this technique is gaining popularity in industries [4].

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The disadvantages of conventional DTC are high torque ripple and slow transient response to the step changes in torque during start-up. For that reason the application of fuzzy logic and artificial neural network attracts the attention of many scientists from all over the word [5]. This paper is devoted to multilevel DTC and neural DTC of IM.

The reason for this trend is the many advantages which the architecture of ANN has over traditional algorithmic methods. Among the advantages of ANN are the ease of training and generalization, simple architecture, possibility of approximating non linear functions, insensitivity to the distortions of the network, and inexact input data [5].

In this paper, we present the performance of the DTC control with 13-level hysteresis comparator of IM fed by five-level NPC inverter using ANN. The ANN then replaces the switching table of the five-level DTC control. Neural DTC is used to improve dynamic response performance and decrease the torque and stator flux ripples.

II. FIVE-LEVEL DTC CONTROL

The multilevel DTC block diagram is shown in Fig. 1. In every sampling time of the inverter stator voltages and currents are sampled. Using these sampled inputs stator flux, speed, torque and flux angle are estimated in the adaptive motor model. Estimated torque and flux are compared with their respective reference values through hysteresis comparators. Based on torque, flux errors and flux angle apt switching state is generated through the optimal switching table [6]. For speed control based on the DTC, a proportional-integral (PI) controller is used to generate the reference torque from the difference between the reference and measured speeds [7].

DTC does not need a pulse width modulator and a position encoder, which introduce delays and requires mechanical transducers respectively. DTC based drives are controlled in the manner of a closed loop system without using the current regulation loop.

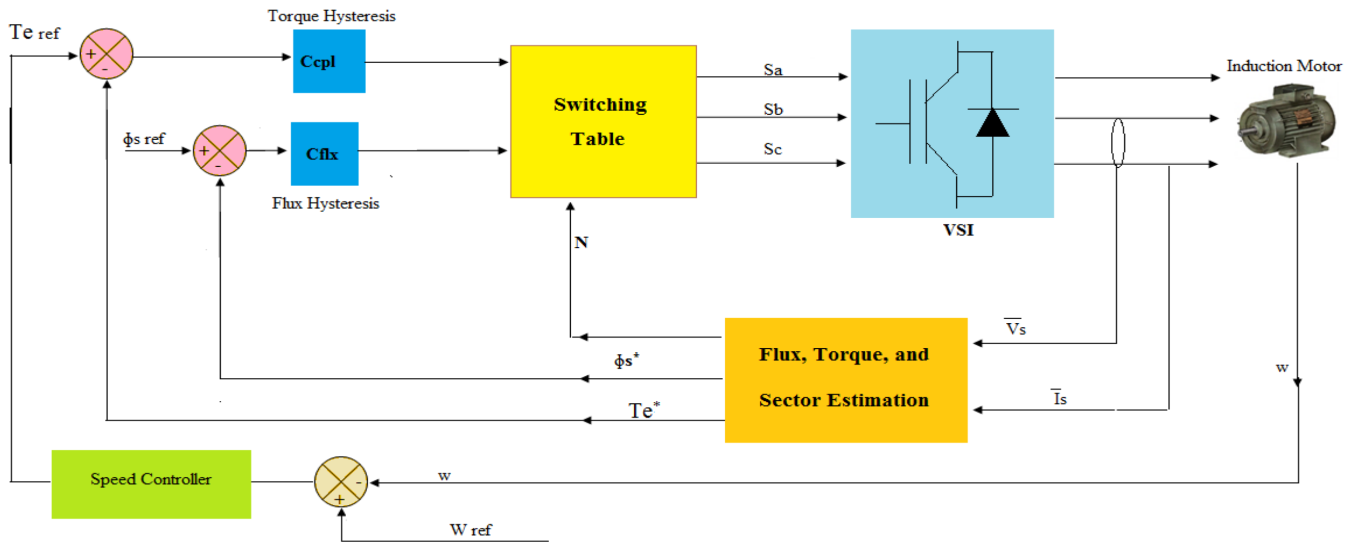


Fig. 1. Block diagram of DTC for IM drives.

The Φs components are estimated using the measured stator voltage and current components:

$$\begin{cases} \Phi_{s\alpha} = \int_0^t (v_{s\alpha} - R_s i_{s\alpha})dt \\ \Phi_{s\beta} = \int_0^t (v_{s\beta} - R_s i_{s\beta})dt \end{cases} \quad (1)$$

The Φs amplitude is given by [9]:

$$\Phi_s = \sqrt{\Phi_{s\alpha}^2 + \Phi_{s\beta}^2} \quad (2)$$

The stator flux angle is calculated by:

$$\theta_s = arctg(\frac{\Phi_{s\beta}}{\Phi_{s\alpha}}) \quad (3)$$

The torque equation is given by:

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

Fig. 2 shows the circuit of a five-level NPC inverter and the switching states of each leg of the inverter. Each leg is compsed of two upper and lower switches with anti-parallal diodes. Four series DC-link capacitors split the DC bus voltage in halef, and 18 clamping diodes confine the voltage across the switches within the voltage of the capacitors, each leg of the inverter can have five possible switching states, 4, 3, 2 , 1 or 0. The NPC can be able to minimize the harmonic distorsion of the stator current. Further the active switches of the converter are operated at low frequency [10]. The five-level NPC inverter derived from three-level NPC inverter.

The representation of the space voltage vectors of a five-level inverter for all switching states is given by Fig. 3 [11].

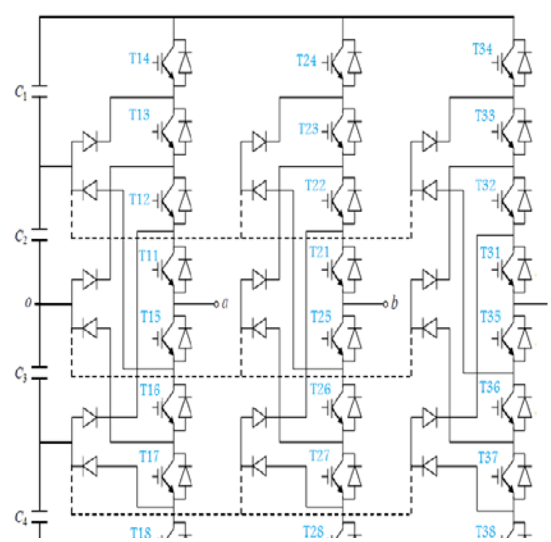


Fig. 2. Schematic diagram of a five-level inverter

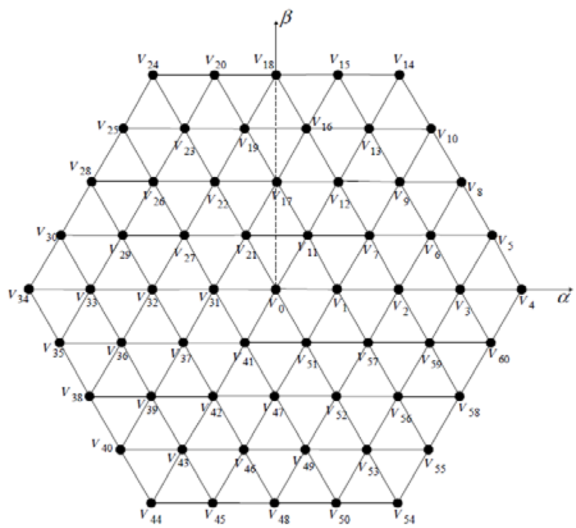


Fig. 3. Space vector diagram of five-level inverter.

The switching selection block in Fig. 1 receives the input signals Ccpl, Cflx and N generate the desired control voltage vector as given in switching table shown in Table 1(See Appendix).

III. Five-level DTC control with ANN

In ordre to improve the five-level DTC performance a complimentary use of neural network is proposed. ANN is part of the family of statistical learning methods inspired by biological nervous system and are used to estimate and approximate functions that depends only on a large number of inputs [12].

ANN's have been proven to be universal approximators of non-linear dynamic systems. They are able to emulate any complex non-linear dynamic system by using an appropriate multilayer neural network. Many applications have been reported in power electronics, including fault detection and diagnosis in electrical machines, power converter control and the high performance control of electrical drives [13]. The general structure of the IM with DTC-ANN using a five-level inverter is represented by Fig. 4. The artificial neural network replaces the switching table selector block. He uses a dense interconnection of computing nodes to approximate nonlinear function [14].

The structure of the ANN to perform the five-level DTC applied to IM satisfactorily was a ANN with 3 linear input nodes, 64 neurones in the hidden layer, and 3 neurones in the output layer, as shown in Fig. 5.

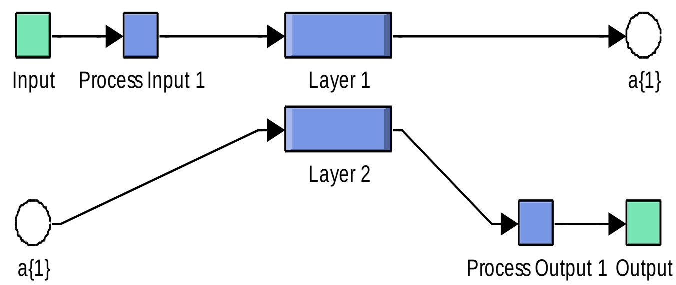


Fig. 5. Neural structure for five-level DTC.

The structure of Layer 1 is shown in Fig. 6

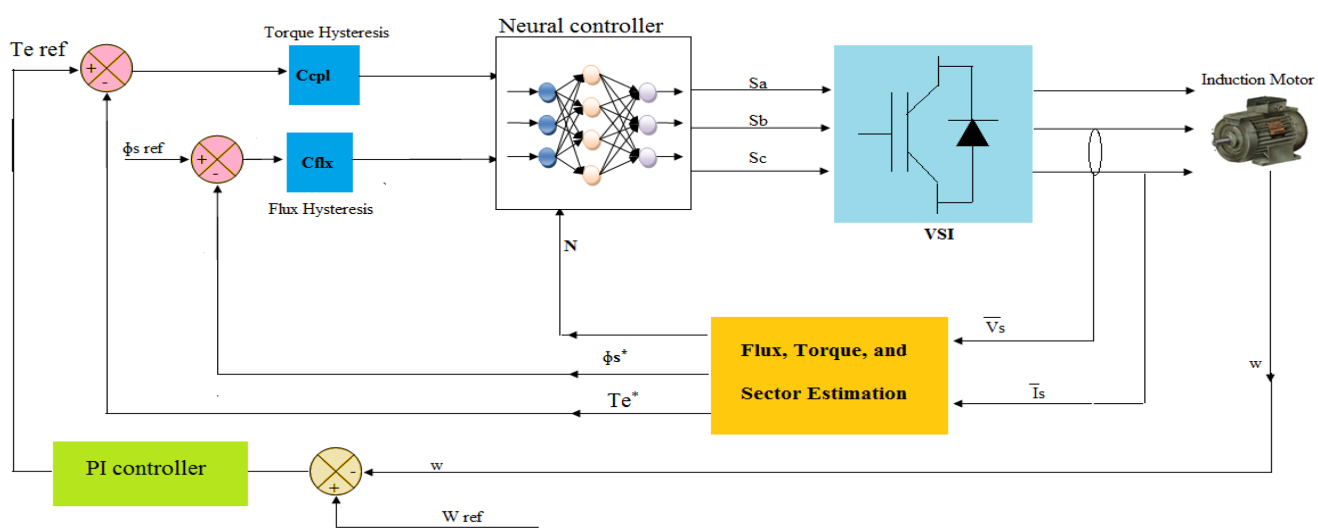


Fig. 4. Block diagram of DTC with ANN for IM drives.

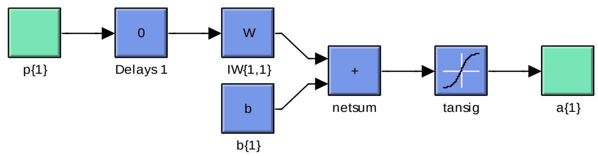


Fig. 6. Architecture of Layer 1.

IV. SIMULATION RESULTS AND DISCUSSIONS

The simulation results of neural DTC with five-level NPC inverter of IM drive are compared with conventional five-level DTC control. The performance analysis is done with THD value of stator current, stator flux and torque plot. The dynamic performance of the five-level DTC for IM is shown Fig. 7. The dynamic performance of the five-level DTC-ANN control is shown Fig. 8.

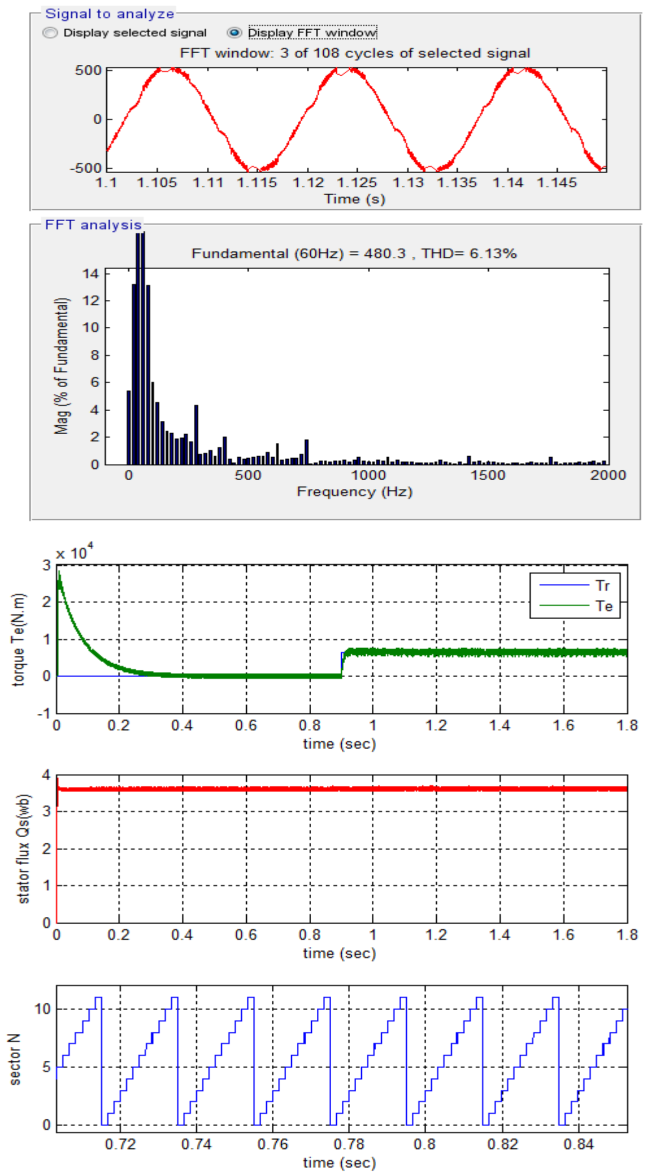


Fig. 7. Dynamic responses of five-level DTC.

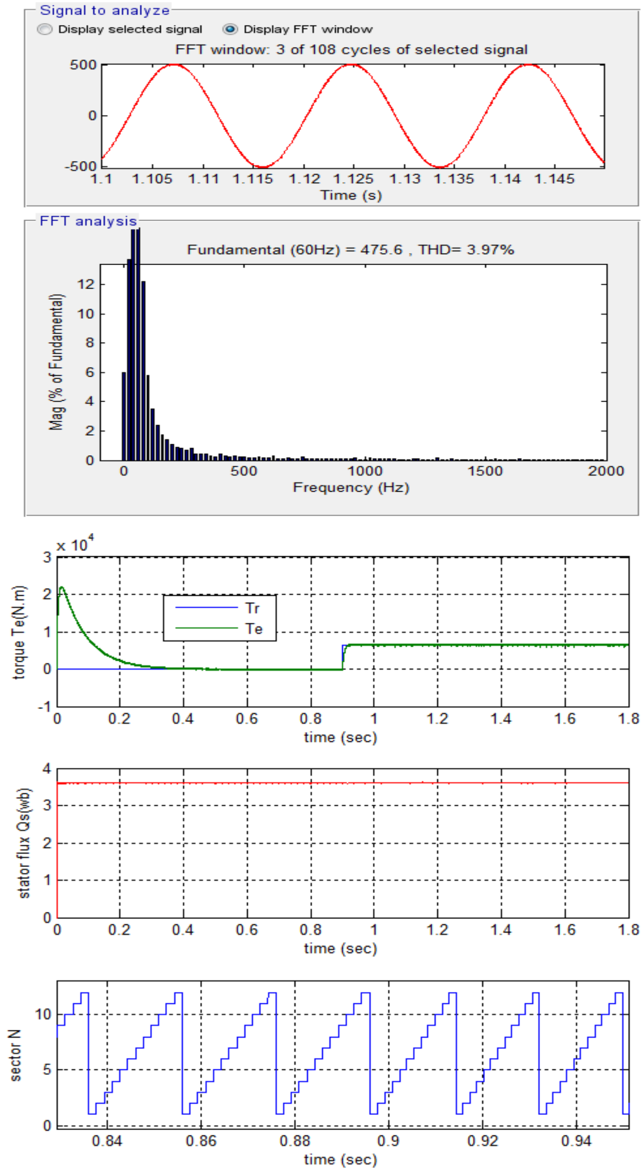


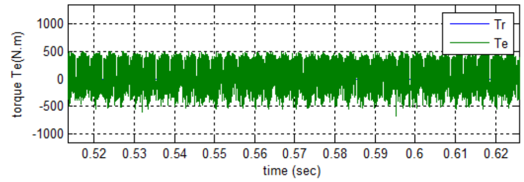
Fig. 8. Dynamic responses of five-level DTC-ANN.

Figs. 7-8 shows that the THD value of stator current in the five-level DTC-ANN scheme has been reduced significantly. Table 2 shows the comparative analysis of THD value of stator current.

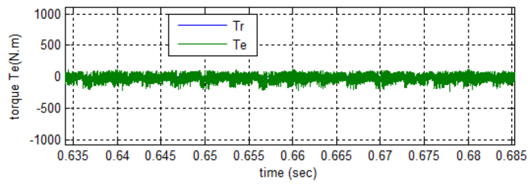
TABLE 2. COMPARATIVE ANALYSIS OF THD VALUE OF STATOR CURRENT

Five-level DTC	Five-level DTC-ANN
6.13%	**3.97%**

The use of ANN has improved the band electromagnetic torque is shown in Fig. 9.



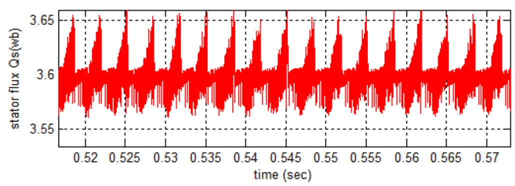
a)Five-level DTC



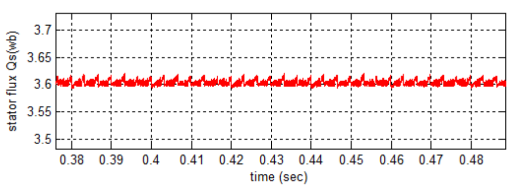
b) Five-level DTC-ANN

Fig. 9. Zoom in the torque.

From the simulation results presented in Fig. 10, it is apparent that the stator flux ripple for the neural DTC with five-level inverter is considerably reduced. In other hands, the stator flux was restored correctly its reference.



a)Five-level DTC.



b) Five-level DTC-ANN

Fig. 10. Zoom in the stator flux.

V. Conclusion

In this paper, the five-level direct torque control principle is presented and it is shown that with ANN technique for induction machine. The simulation results obtained for the neural DTC with five-level inverter illustrate a considerable reduction in torque ripple, stator flux ripple and THD value of stator current compared to the classical DTC with five-level NPC inverter.

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APPENDIX

Table 1. Proposed switching table of five-level inverter

N		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cflx	**Ccpl**												
	6	14	14	24	24	34	34	44	44	54	54	4	4
	5	15	20	25	30	35	40	45	50	55	60	5	10
	4	18	18	28	28	38	38	48	48	58	58	8	8
	3	13	13	23	23	33	33	43	43	53	53	3	3
	2	9	19	16	26	19	29	36	39	46	49	59	6
	1	12	12	22	22	32	32	42	42	52	52	2	2
1	**0**	0	0	0	0	0	0	0	0	0	0	0	0
	-1	52	52	2	2	12	12	22	22	32	32	42	42
	-2	56	59	6	9	16	19	26	29	36	39	46	49
	-3	53	53	3	3	13	13	23	23	33	33	43	43
	-4	58	58	8	8	18	18	28	28	38	38	48	48
	-5	55	60	5	10	15	20	25	30	35	40	45	50
	-6	54	54	4	4	14	14	24	24	34	34	44	44
	6	17	17	27	27	37	37	47	47	57	57	7	7
	5	17	17	27	27	37	37	47	47	57	57	7	7
	4	17	17	27	27	37	37	47	47	57	57	7	7
	3	11	11	21	21	31	31	41	41	51	51	1	1
	2	11	11	21	21	31	31	41	41	51	51	1	1
	1	11	11	21	21	31	31	41	41	51	51	1	1
0	**0**	0	0	0	0	0	0	0	0	0	0	0	0
	-1	0	0	0	0	0	0	0	0	0	0	0	0
	-2	41	41	51	51	1	1	11	11	21	21	31	31
	-3	47	47	57	57	7	7	17	17	27	27	37	37
	-4	42	42	52	52	2	2	12	12	22	22	32	32
	-5	46	49	56	59	6	9	16	19	26	29	36	39
	-6	43	43	53	53	3	3	13	13	23	23	33	33
	6	24	24	34	34	44	44	54	54	4	4	14	14
	5	25	30	35	40	45	50	55	60	50	10	15	20
	4	28	28	38	38	48	48	58	58	8	8	18	18
	3	23	23	33	33	43	43	53	53	3	3	13	13
	2	19	26	29	36	39	46	49	56	59	6	9	16

	1	22	22	32	32	42	42	52	52	2	2	12	12
-1	**0**	0	0	0	0	0	0	0	0	0	0	0	0
	-1	42	42	52	52	2	2	12	12	22	22	32	32
	-2	46	49	56	59	6	9	16	19	26	29	36	39
	-3	43	43	53	53	3	3	13	13	23	23	43	43
	-4	48	48	58	58	8	8	18	18	28	28	38	38
	-5	45	50	55	60	5	10	15	20	25	30	35	40
	-6	44	44	54	54	4	4	14	14	24	24	34	34