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FIVE-LEVEL DTC BASED ON ANN OF IM USING 13-LEVEL HYSTERESIS CONTROL TO REDUCE TORQUE RIPPLE COMPARING WITH CONVENTIONAL CONTROL

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Abstract: In this paper, the author proposes a novel strategy of direct torque control (DTC) of induction machine (IM) fed by five-level NPC inverter using the Artificial neural network (ANN) applied in switching select voltage. I used the torque hysteresis by using the 13-level hysteresis controller. The DTC control proposed in this paper can reduce the torque ripple, stator flux ripple and the THD value of stator current. The validity of the proposed control scheme is verified by simulation tests of an induction machine.
Keywords: Induction machine; DTC; Five-level NPC inverter; artificial neural network; 13-level hysteresis controller; THD

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 drive [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 simultaneously 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]. 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 DTC-ANN of IM.

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

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

FIVE-LEVEL DTC CONTROL

The multilevel DTC block diagram is shown in Figure 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.

The stator flux 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 stator flux 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:

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

Electromagnetic torque equation is given by:

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

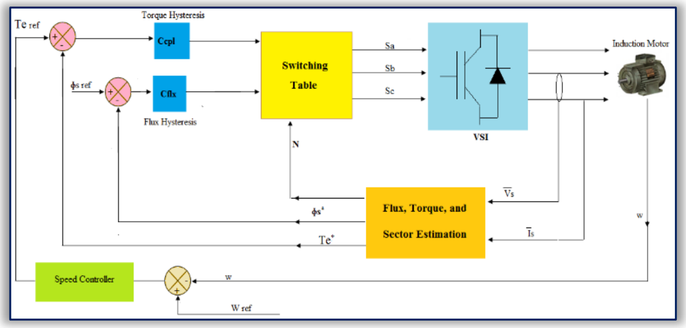


Figure 1. Block diagram of DTC of IM drives

Figure 2 shows the circuit of a five-level diode clamped inverter (NPC) 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 Figure 3 [11].

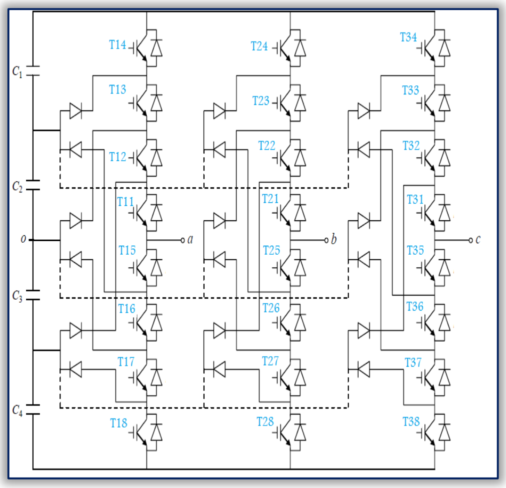


Figure 2. Schematic diagram of a five-level inverter

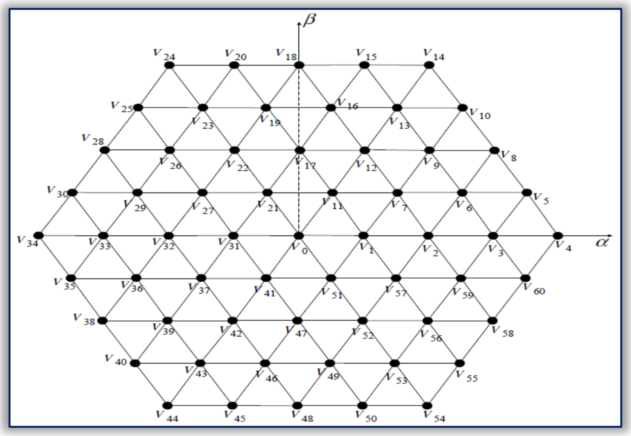


Figure 3. Space vector diagram of five-level inverter

The switching selection block in Figure 1 receives the input signals C_{cpl}, C_{flx} and N generate the desired control voltage vector as given in look-up table shown in Table 1.

Table 1. Switching Table of five-level inverter

C_{flx}	N / C_{cpl}	1	2	3	4	5	6	7	8	9	10	11	12
	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

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 approximations 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 Figure 4. The Artificial neural network replaces the switching table selector block. He uses a dense interconnection of computing nodes to approximate nonlinear function [14].

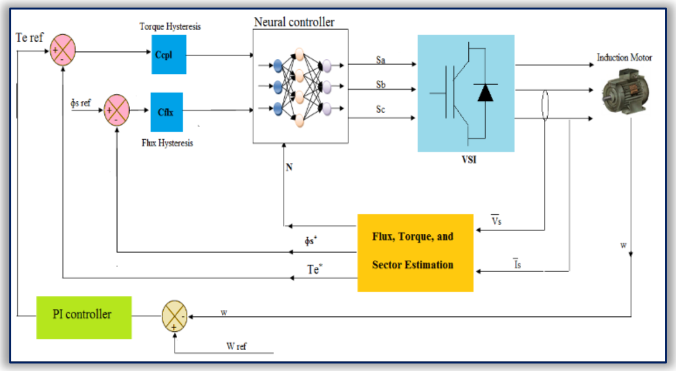


Figure 4. Block diagram of DTC-ANN of IM drives

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

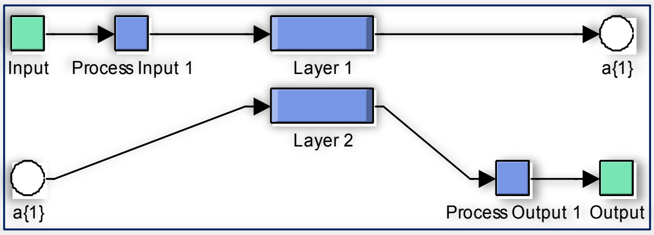
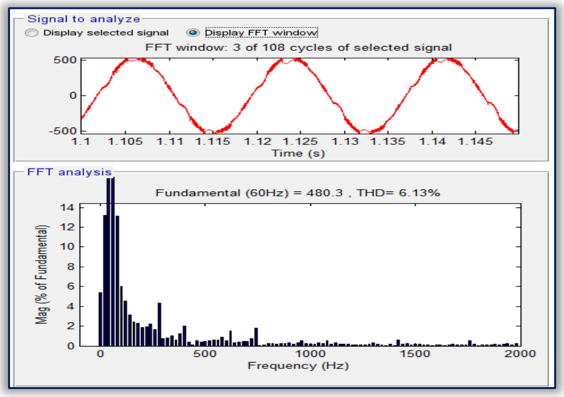


Figure 5. Neural network structure for five-level DTC



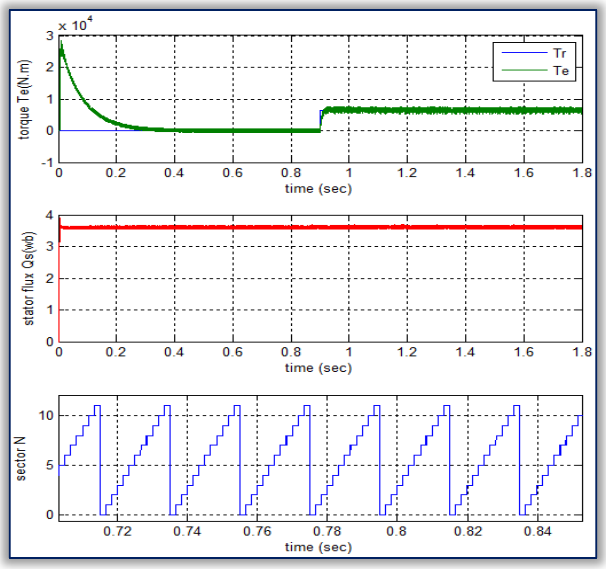
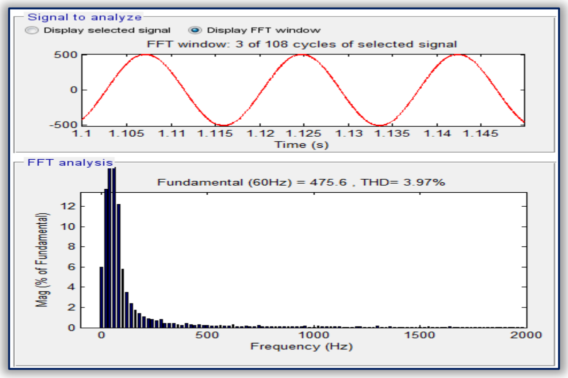


Figure 6. Dynamic responses of five-level DTC

SIMULATION RESULTS

The simulation results of five-level DTC-ANN of IM are compared with conventional five-level DTC. The performance analysis is done with stator current, stator flux and torque plot. The dynamic performance of the five-level DTC for IM is shown Figure 6. The dynamic performance of the five-level DTC-ANN control is shown Figure 7.



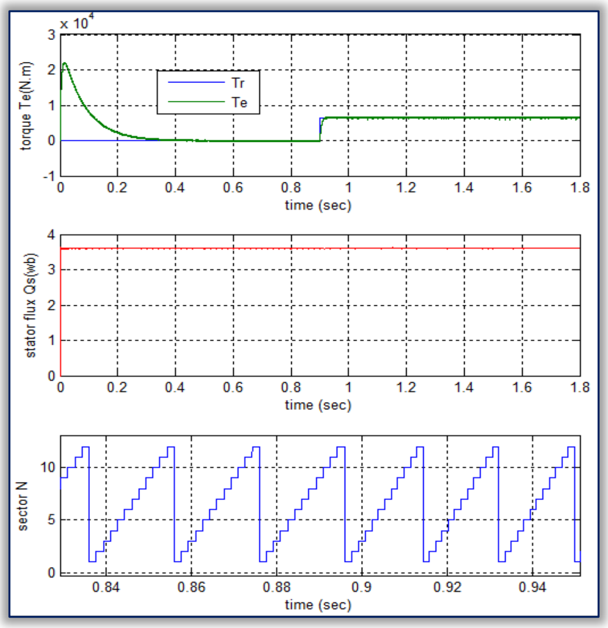


Figure 7. Dynamic responses of five-level DTC-ANN

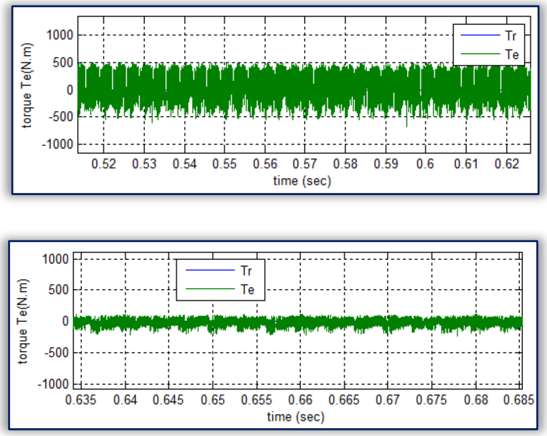
Figures 6-7 show that the THD value of stator current in the five-level DTC-ANN scheme has been reduced significantly. Table 2 shows the comparative analysis of THD value of stator current.

Table 2. Comparative analysis of THD value of stator current

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

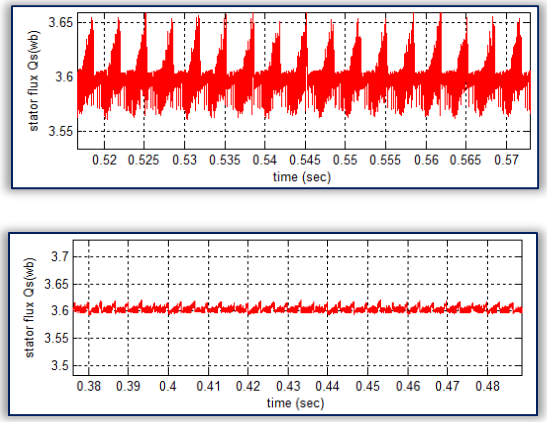
The use of ANN has improved the band electromagnetic torque are shown in Figure 8.

From the simulation results presented in Figure 9, it is apparent that the stator flux ripple for the five-level DTC-ANN is considerably reduced. In other hands, the stator flux was restored correctly its reference.



a) b)

Figure 8. Zoom in the torque.
a) Five-level DTC; b) Five-level DTC-ANN



a) b)

Figure 9. Zoom in the stator flux.
a) Five-level DTC; b) Five-level DTC-ANN

CONCLUSIONS

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

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