Revue des Energies Renouvelables Vol. 20 N°2 (2017) 231 - 242
DOI: https://doi.org/10.54966/jreen.v20i2.623

Speed regulator and hysteresis based on artificial intelligence techniques of three-level DTC with 24 sectors for induction machine

Habib Benbouhenni [1*] and Rachid Taleb [2†]

[1] Department of Electrical Engineering, National Polytechnic School Oran, Algeria
[2] Department of Electrical Engineering, University of Chlef, Chlef, Algeria

(reçu le 10 Mai 2017 - accepté le 30 Juin 2017)

Abstract - *Direct torque control (DTC) of induction motor (IM) is important in many applications. In this paper presents a three-level direct torque control with 24 sectors is applied for IM using PI-flou controller and hysteresis regulators based in artificial intelligence techniques. The DTC system is known to offer fast decoupled control between torque and flux via a simple control structure. Nevertheless, DTC system has two major drawbacks, with are the variable inverter switching frequency and high torque output ripple. The validity of the proposed control scheme is verified by simulation tests. The stator flux, torque, and current are determined and compared to the above technique.*

Résumé - *Le contrôle direct de couple (DTC) d'un moteur à induction (IM) est important pour de nombreuses applications. Cet article présente une commande directe du couple à trois niveaux avec 24 secteurs appliquée aux IM en utilisant un contrôleur PI-flou et des régulateurs hysterisis basé sur des techniques d'intelligence artificielle. Le système DTC est connu pour sa capacité à offrir un contrôle découplé rapide entre le couple et le flux à travers une structure de commande simple. Néanmoins, les systèmes DTC ont deux inconvénients majeurs qui sont la variabilité de la fréquence de commutation de l'onduleur, et les ondulations de sorties élevées pour le couple. La validité du schéma de contrôle proposé est vérifiée par des simulations. Le flux du stator, le couple, et le courant sont déterminés et comparés aux techniques précédemment citées.*

Keywords: Induction motor - Direct torque control - PI-flou - Neural hysteresis - Sectors - Fuzzy hysteresis.

1. INTRODUCTION

Induction motors (IMs) are suitable electromechanical systems for a large spectrum of industrial applications. This is due to their high reliability, relatively low cost, and modest maintenance requirements. However, IMs are known as multivariable nonlinear time-varying systems. Thus makes their control so difficult, mainly in variable speed applications [1].

Recent advances in power semiconductor and microprocessor technology have made possible the application of advanced control techniques to alternating current (AC) motor drive systems [2].

There are two must common AC drives control schemes that are being widely researched. One of it is field oriented control (FOC) which was proposed by Takahashi and Noguchi. There are two major drawbacks of FOC compared to the DTC which are torque is controlled indirectly and requirement of the pulse encoder. In FOC method of control the torque indirectly because its control priority is flux vector. FOC needs the pulse encoder in order to obtain the speed and position of the rotor.

This makes the DTC system as an alternative and gained the attention of many researchers lately due to its simple structure by elimination of pulse encoder and simple algorithm with lesser dependency on motor parameters (only requires value of stator

* h.benbouhenni@gmail.com
† rac.taleb@yahoo.fr

resistance R_s and phase current). Over the past years, the utilization of multilevel inverter topology in the DTC system has gained popularity for the medium and high voltage applications [3].

Direct torque control, as one of the high-performance AC drives, was extended to the field of multi-level inverters in the late 20th century. DTC has a relatively simple control structure yet performs at least as good as the FOC technique. It is also known that DTC drive is less sensitive to parameters de-tuning (only stator resistor is used to estimate the stator flux) and provides a high dynamic performances than the classical vector control (fastest response of torque and flux) [4].

The 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 profilent of output waveforms. The output voltage waveform approaches a sine wave, thus having practically no common-mode voltage and no voltage surge to the motor windings. Furthermore, the reduction in dv/dt can prevent motor windings and bearings from failure [5].

Many researches have been performed using the multi-level inverter and, for example, some articles described a novel DTC algorithm suited for a three level inverter, and proposed a very simple voltage balancing algorithm for the DTC scheme [4].

This paper is devoted to three-level inverter DTC 24 sectors with speed regulator and hysteresis based in artificial intelligence techniques of an IM. The present paper structure is as follows. Firstly, the model of the IM is presented in the second section. In the third section, the three-level inverter modelingis described.

In the fourth section, the classical DTC strategy. Next, a breif introduction to the fuzzy and neural networks is presented in the fifth section. The sixth section introduces the three-level DTC 24 sectors with speed regulators and hysteresis based in artificial intelligence approach. Finally, conclusion is drawn in the last section.

2. MODEL OF INDUCTION MACHINE

The model of IM in the α, β reference can be written in the following from [6, 7],

$$\begin{cases} x(t) = Ax(t) + Bu(t) \\ y(t) = cx(t) \end{cases} \tag{1}$$

with,

$$X = \left(I_{\alpha s}.I_{\beta s}.\Phi_{\varepsilon s}.\Phi_{\beta s}\right)^T \; ; \; U = \left(v_{\alpha s}.v_{\beta s}.0.0\right)^T$$

$$T_r = \frac{L_r}{R_r} \; ; \; \sigma = 1 - \frac{M^2}{L_s.L_r} \; ; \; K = \frac{M}{\sigma.L_s.L_r} \; ; \; \lambda = \left(\frac{1}{T_s} + \frac{M^2}{T_r.L_r.L_s}\right)$$

$$A = \begin{bmatrix} -\frac{\lambda}{\sigma} & 0 & \frac{\sigma K}{T_r} & K w_r \\ 0 & -\frac{\lambda}{\sigma} & -K w_r & \frac{\sigma K}{T_r} \\ \frac{M}{T_r} & 0 & \frac{-1}{T_r} & -w_r \\ 0 & \frac{M}{T_r} & w_r & \frac{M}{T_r} \end{bmatrix} \; ; \; B = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 \\ 0 & \frac{1}{\sigma L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \; ; \; U = \begin{bmatrix} v_{\alpha s} \\ v_{\beta s} \\ 0 \\ 0 \end{bmatrix}$$

3. MODELING OF THE THREE-LEVEL INVERTER

The three-level NPC inverter consists of twelve pairs of transistors-diodes and six clamping diodes (figure 1). The simple voltage of each phase is entirely defined by the state of the four transistors constituting each arm. The median diodes of each arm permits to have the zero level of the inverter output voltage. Only three sequences of operation are retained and done in work. Each arm of the inverter is modeled by a perfect switch with three positions (0, 1, and 2) [5].

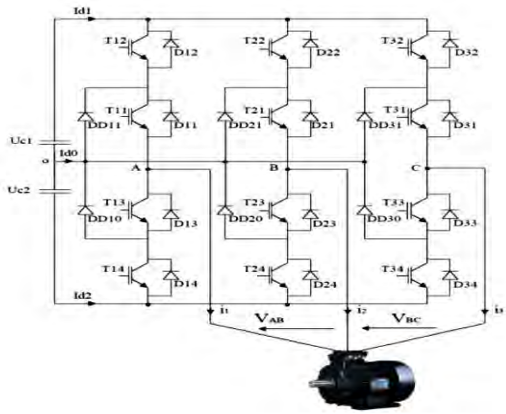


Fig. 1: Schematic diagram of a three-level inverter

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

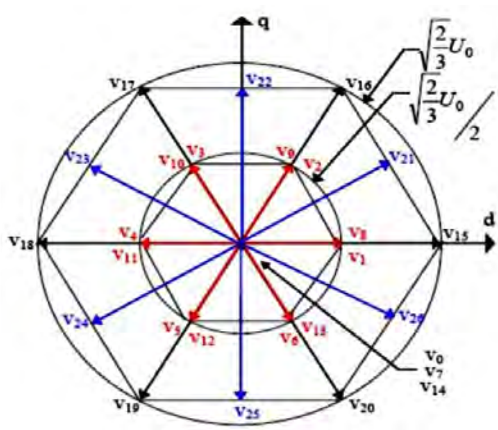


Fig. 2: Space vector diagram of three-level inverter

4. DTC CONTROL

The basic of DTC induction motor scheme is shown in figure 3. At each sample time, the two stator currents I_{sa} and I_{sb} and the DC bus voltage V_{dc} are sampled. Using the inverter voltage vector, the α, β components of the stator voltage space vector in the stationary reference frame are calculated as follows [8].

The components of stator flux can be estimated by,

$$\begin{cases} \Phi_{s\alpha} = \int_0^t (v_{s\alpha} - R_s . i_{s\alpha})\, dt \\ \Phi_{s\beta} = \int_0^t (v_{s\beta} - R_s . i_{s\beta})\, dt \end{cases} \tag{2}$$

The stator flux amplitude is given by,

$$\Phi_s = \sqrt{\Phi_{\alpha s}^2 + \Phi_{\beta s}^2} \tag{3}$$

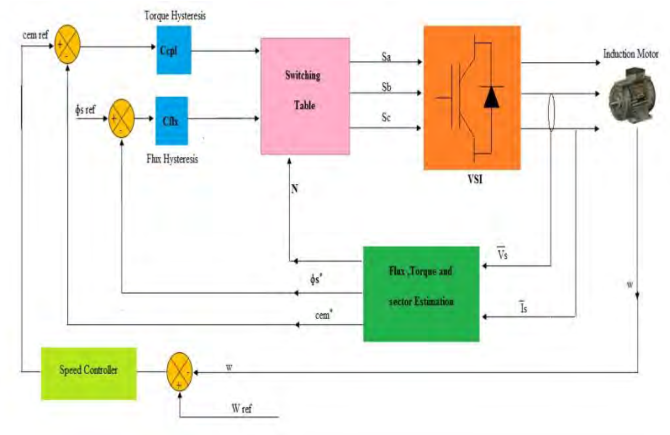


Fig. 3: Block diagram of DTC

The stator flux angle is calculated by,

$$\theta_s = \operatorname{arctg}\left(\frac{\Phi_{\beta s}}{\Phi_{\alpha s}}\right) \tag{4}$$

Electromagnetic torque equation is given by,

$$C_{em} = \frac{3}{2} p\left(\Phi_{\alpha s} . i_{\beta s} + \Phi_{\beta s} . i_{\alpha s}\right) \tag{5}$$

The error ε_{Φ} between the reference flux and its estimated value, respectively Φ_s and Φ_s^*, is used for input to a comparator with hysteresis two-level figure (figure 4**a**).

Similarly, the error ε_{Cem} between the torque reference and its estimated value, respectively C_{em}^* et C_{em}, is used for input to a comparator with two-band upper and lower bands contained two (figure 4**b**). The output of each comparator, represented by variable signs $Cflx$ (or $Ccpl$) indicates directly if the amplitude of the flux(or torque) must be increased or decreased to maintain these two variables within the hysteresis bands desired, ΔC_{em}, $\Delta\Phi_s$.

Three-level torque and two-level flux hysteresis controllers are used according to the outputs of the torque controller and the sector information, appropriate voltage vectors for both the inverters are selected from a switching table as it is shown in **Table 1**.

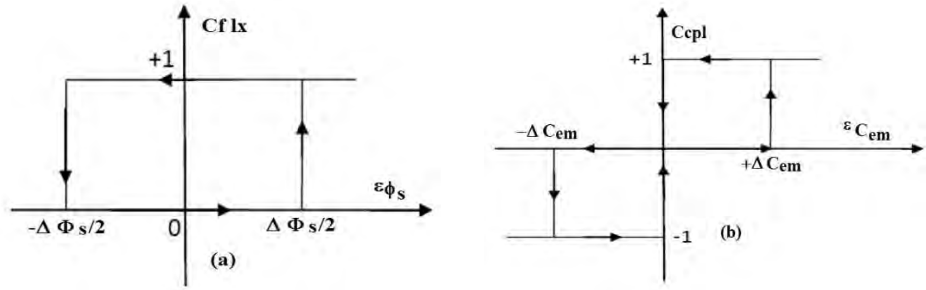


Fig. 4: Hysteresis block

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

Since none of the inverter switching vectors is able to generated the exact stator voltage required to produce the desired changes in torque and flux, torque and flux ripples compose a real problem in DTC induction motor drive [8].

5. DIRECT TORQUE CONTROL BASED ON INTELLIGENCE ARTIFICIELS STRATEGY'S

The principle of artificial intelligence techniques direct torque control is similar to traditional three-level DTC. However, the hysteresis controllers of torque and flux are replaced by the fuzzy controller and neural networks. The PI controller of speed is replaced by the fuzzy controller. The general structure of the IM with three-level DTC 24 sectors with artificial intelligence techniques is represented by figure 5.

5.1 Hysteresis controller of flux based on neural networks

Neural networks have self- adapting compatibilities which makes them well suited to handle non-linarites, uncertainness and parameter variations. A multilayer feed forward neural network constructs a global approximations to non- linear input-output mapping. Neural networks are capable of generalization in regions of the input space, where little or no training data are available [9]. The structure of the proposed neural networks used in this paper, is shown in figure 6.

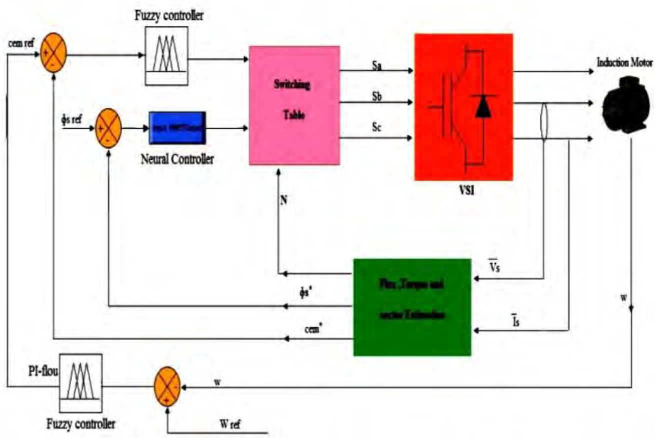


Fig. 5: Three-level DTC with 24 sectors based on artificial intelligence technics of an induction machine

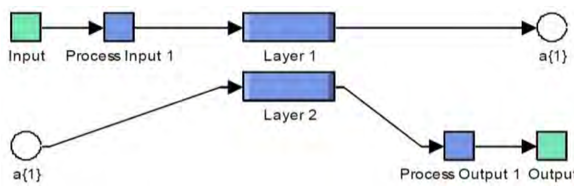


Fig. 6: Structure of proposed artificial neural networks

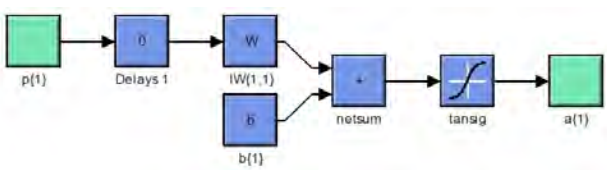


Fig. 7:Structure of layer 1

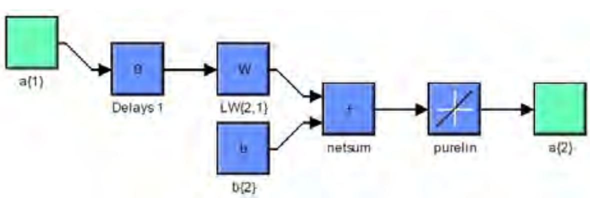


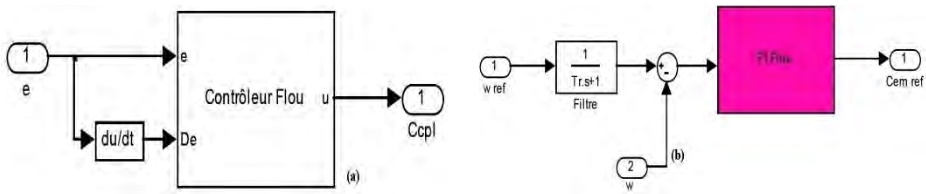
Fig. 8: Structure of layer 2

The proposed neural networks have three layers, i.e. input layer, hidden layer and the output layer. Input layer has 1 neuron, output layer has only one neuron and hidden layer has 3 neurons.

5.2 Hysteresis controller of couple and PI controller based on fuzzy

Fuzzy logic is recently getting increasing emphasis in drive control applications. Recent years, fuzzy logic control has found many applications in the past two decades. This is so largely increasing because fuzzy logic control has the capability to control nonlinear uncertain systems even in the case where no mathematical model is available for the control system [8].

The main preference of the fuzzy logic is that is easy to implement control that it has the ability of generalization [10]. The block diagram for fuzzy logic based speed regulator and torque hysteresis is shown in figure 9. The fuzzy logic rules are written by absorbing the performances of the PI controller and torque hysteresis.



a- Fuzzy hysteresis of torque **b**- Fuzzy logic control of speed regulation

Fig. 9: Fuzzy control of speed and hysteresis regulation

The membership function definition for the input variables 'Error in speed and Error in torque hysteresis' is shown in figure 10**a**, 'Change in Error of speed and torque hysteresis' is shown in figure 10**b**, 'Control' is shown in figure 10**c** [11].

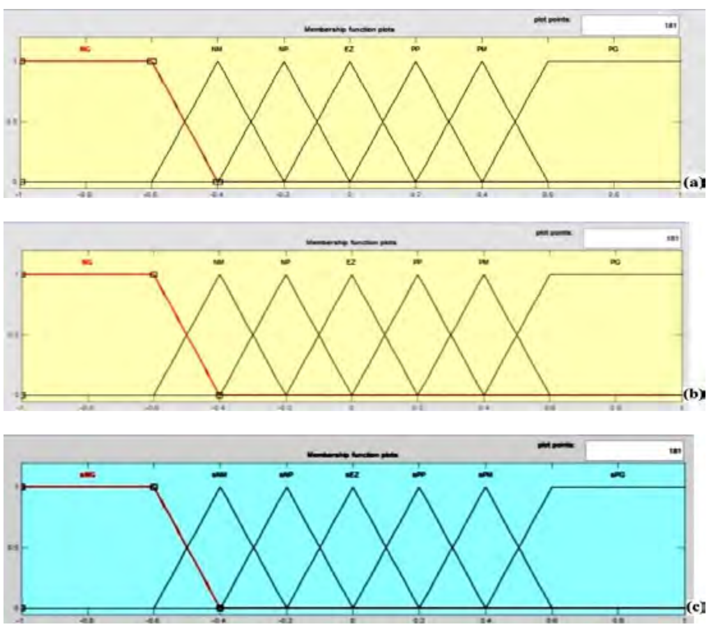


Fig. 10: Membership function for error, change in error and control of speed and hysteresis flou controller

The fuzzy logic rules for the proposed system are given in **Table 2**.

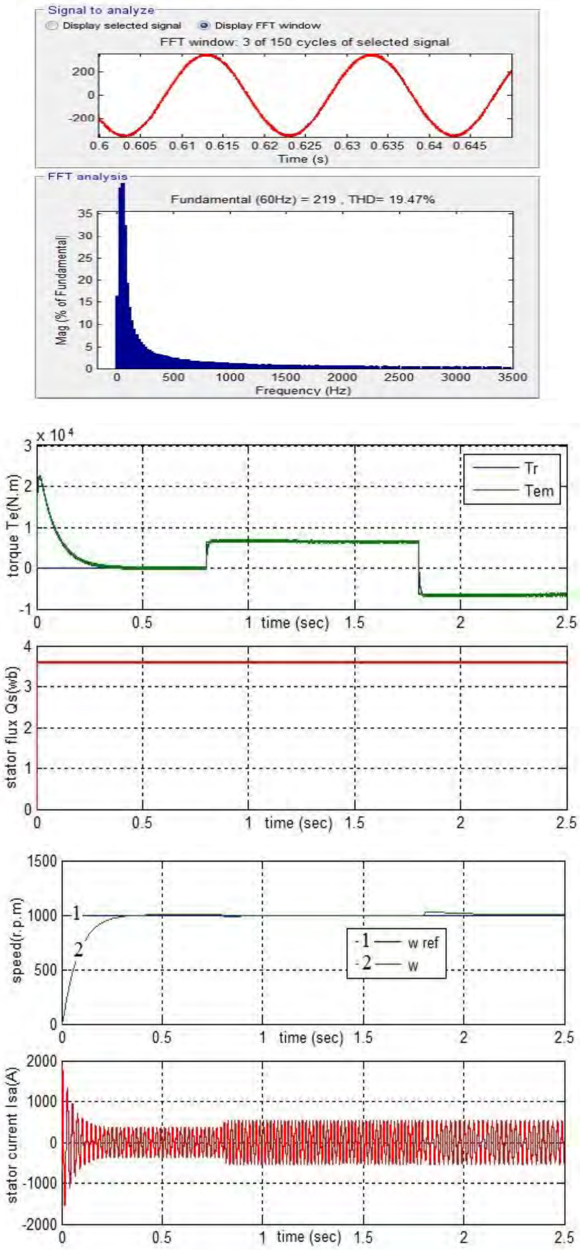
Table 2: Fuzzy logic rules of PI controller and torque hysteresis

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

6. SIMULATION RESULTS AND DISCUSSION

The direct torque control with 24 sectors of an IM is implemented with simulation tools of Matlab. The speed regulator is used as classical PI, PI-flou separately. The hysteresis controllers are used as neural hysteresis and fuzzy hysteresis. The performance analysis is done with speed, torque, flux, and current. The dynamic performance of the three-level DTC with 24 sectors of an induction motor is shown in figure 11.

The dynamic performance of the three-level DTC with 24 sectors based on artificial intelligence techniques for the induction motor is shown in figure 12.



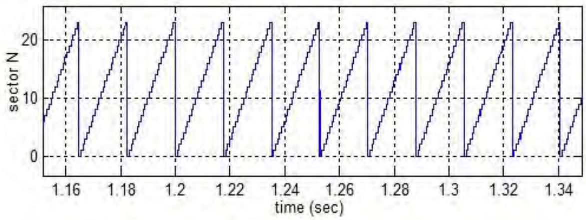
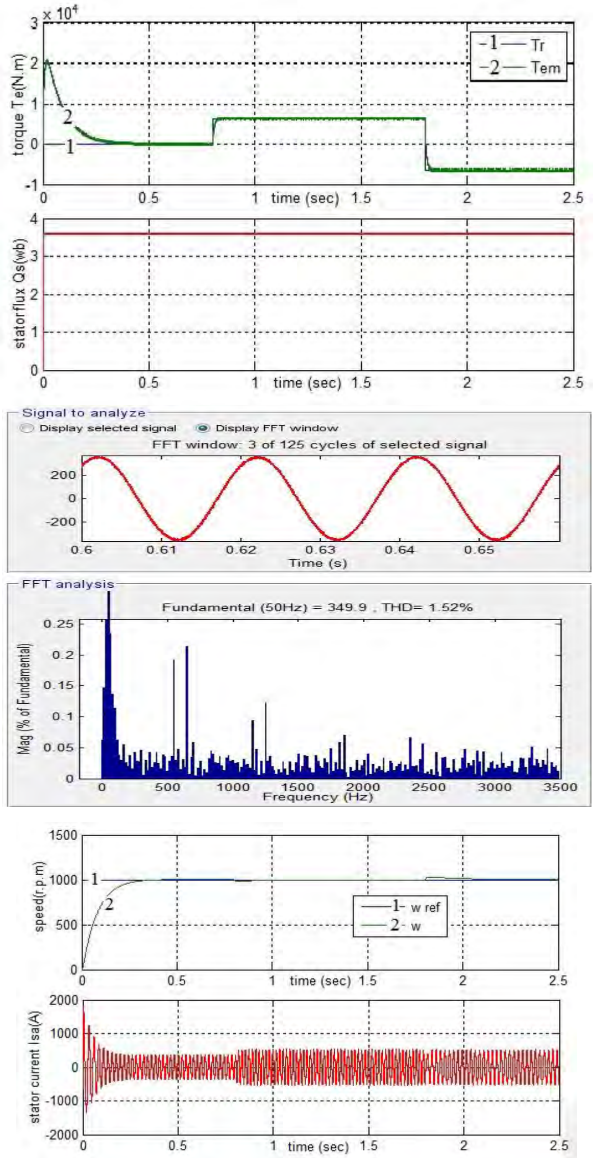


Fig. 11: Dynamic responses of three-level DTC for an induction motor



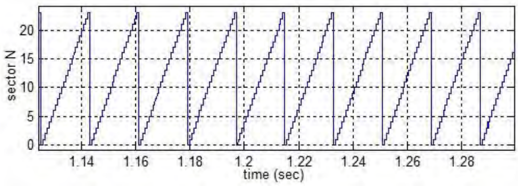


Fig. 12: Dynamic responses of three-level DTC with controller of speed and regulators hysteresis based in artificial intelligence techniques for an induction motor

The speed reaches its reference without overrun at empty start for all strategies. And the torque flow the load torque. The dynamics of the components of the stator flux are not affected by the application of these load guidelines.

Torque and stator flux response comparing curves are shown in figure 13.

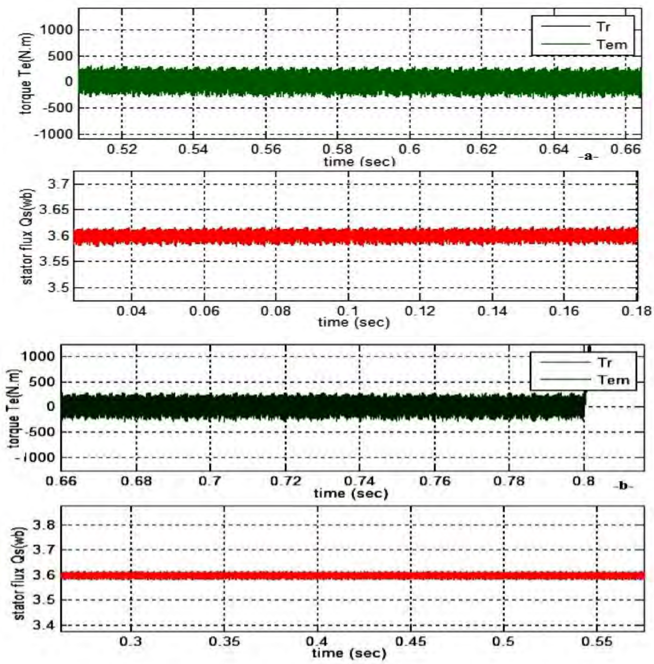


Fig. 13: Zooms of torque and flux: **a)** three-level DTC with 24 sectors, **b)** three-level DTC with 24 sectors based on artificial intelligence techniques

Figure 13 shows the zoom results for motor torque and flux response for three-level DTC with and without artificial intelligence techniques for a reference speed of 1000 rpm. The motor is allowed to run without load torque. As observed, the transient and steady state ripple are high for three-level DTC without artificial intelligence techniques.

In **Table 3**, we summarize the simulation results obtained by conventional three-level DTC and the proposed control of three-level DTC with 24 sectors.

Table 3: Comparison between proposed controls

Control	Three-level DTC with 24 sectors	Three-level DTC with 24 sectors based on artificial intelligence techniques
Ias THD (%)	19.47	1.52
Dynamic response of flux (ms)	4	3.7

It can be seen that three-level DTC with 24 sectors based on artificial intelligence techniques THD% is low as compare to conventional three-level DTC.

7. CONCLUSION

The present paper has presented a sensor less speed three-level DTC drive 24 sectors with artificial intelligence techniques applied to an IM is presented, fuzzy logic and neural networks. This techniques determinates the desired amplitude of torque, flux hysteresis band and speed controller.

It is shown that the flux and torque responses under steady state condition. The main advantage is the improvement of torque and flux ripple characteristics at low speed region, this provides an opportunity for motor operation under minimum switching loss and noise.

APPENDIX

The parameters of 3 phase induction machine employed for simulation purpose is given below:

Table 4: Implementation parameters

Parameters	Values
Nominal power	1 MW
Line to line voltage	791 V
Frequency	60 Hz
Stator resistance	0.228 Ω
Stator inductance	0.0084 H
Rotor resistance	0.332 Ω
Rotor inductance	0.0082 H
Mutual inductance	0.0078 H
Inertia	20 kg.m^2
Friction	0.008 Nms
Number of poles	3

REFERENCES

[1] F. Benessek, W. Bourbia and B. Bensaker, '*Flatness Based non Linear Sensorless Control of Induction Motor Systems*', International Journal of Power Electronics and Drive System, 'IJPEDS', Vol. 7, N°1, pp. 265 - 278, 2016.

[2] C. El Mehdi, M. Ahmed, M. Abdelkader and G. Abderrahmane, '*Sensorless Direct Torque Control of Induction Machine with MRAS Speed Estimator*', Computer Science and Engineering, Vol. 3, N°1, pp. 8 - 13, 2013.

[3] S. a/I Ramahlingam, A. Bin Jidir, T. Sutikno and L.L. Raj, '*Improvise 3-Level DTC of Induction Machine using Constant Switching Frequency Method by Utilizing Multiband Carrier*', International Journal of Power Electronics and Drive System, 'IJPEDS', Vol. 7, N°3, pp. 638 - 647, 2016.

[4] B. Naas, L. Nezli, B. Naas, M.O. Mahmoudi and M. Elbar, '*Direct Torque Control Based Three Level Inverter-Feed Double Star Permanent Magnet Synchronous Machine*', Energy Procedia, Vol. 18, pp. 521 - 530, 2012.

[5] E. Benyoussef, A. Meroufel and S. Barkat, '*Three-Level DTC Based on Fuzzy Logic and Neural Network of Sensorless DSSM Using ExtendeKalmanFiltre*', International Journal of Power Electronics and Drive System, 'IJPEDS', Vol. 5, N°4, pp. 453 - 463, 2015.

[6] B. Sebti, '*Commande par DTC d'un Moteur Asynchrone , Apport des Réseaux de Neurones*', Mémoire de Magister, Université de Batna, 2013.

[7] E.O.D. Aissa, '*Etude de Stratégies De Commande pour la Régulation des Courants de la Machine Asynchrone*', Mémoire de Master Académique, université de KasdiMerbah, Ouargla. 2013.

[8] A. Idir and M. Kidouche, '*Direct Torque Control of Three Phase Induction Motor Drive Using Fuzzy Logic Controllers for Low Torque Ripple*', Proceedings Engineering & Technology, Vol. 2, pp. 78 - 83, 2013.

[9] N. Vahdatifar, Ss. Mortazavi and R. Kianinezhad, '*Neural Network Based Predictive DTC Algorithm for Induction Motors*', International Journal of Computer, Electrical, Automation, Control and Information Engineering, Vol. 4, N°11, 2011.

[10] Z. Boudjema, A. Meroufel, E. Bounadja and Y. Djerriri, '*Nonlinear Control of a Doubly Fed Induction Generator Supplied by a Matrix Converter for Wind Energy Conversion Systems*', Journal of Electrical Engineering, 'JEE', Vol. 13, N°4, pp. 60 - 68, 2014.

[11] M. Abdelhafidh, '*Stratégies de Commande DTC-SVM et DPC Appliquées à une MADA utilisée pour la Production d'Energie Eolienne*', Thèse de Doctorat, Ecole Nationale Polytechnique, Alger, 2014