International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 3, March-2014, pp: (284-295), Impact Factor: 1.252, Available online at: www.erpublications.com

DTC two level and three level inverters of Induction Motor with speed control using Fuzzy Logic Controller

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Abstract: This paper is to present and to compare the DTC applied to an induction motor (IM) fed by two-level and three level inverters voltage. Direct torque control (DTC) of induction motors fed by a two level inverters has drawbacks like more torque, flux and current ripples in steady state. All these drawbacks can be overcome by DTC of induction motor fed by a three level inverters. Three level inverters has several advantages over the standard two-level, such as a greater number of levels in the output voltage waveforms, lower dV/dt, less harmonic distortion in voltage and current waveforms and lower switching frequencies.
In this paper, a fuzzy logic controller is proposed instead of a PI classic corrector to improve the speed performance of the drive. To demonstrate the great advantages of using a three-level inverters type NPC and a fuzzy logic controller of speed of induction motor, simulation results using Power System Blocset (PSB) of Matlab / Simulink are presented.

Keywords: Induction motor, DTC, two level inverters, three level inverters, PI corrector, Fuzzy logic controller.

Introduction

The command with variable speed of the three-phase asynchronous motor was so successful last year, due to the level of it's alimentation by power converters and the development of complicated command's algorithms.
The direct torque control (DTC) method has emerged as an alternative to Field Oriented Control (FOC) method for high performance ac drives since it was firstly proposed in the 1980 [1-2]. The merits of DTC are fast torque response, simple structure (no need of complicated coordinate transformation, current regulation or modulation block), and robustness against motor parameter variation [3-4]
The direct torque control is one of the most strategies applied to improve certain aspect of Induction Motor (IM) as reducing the distortion of the flux and to have good dynamic performance. This kind of technique is based on the direct control of the stator vector flux and the electromagnetic torque.

One of the characteristics of the DTC method is the table of localisation that helps to determent the vector voltage which depends on the position of the stator flux and electromagnetic torque.
This method is very simple and allows decoupled control to flux and torque without resorting to use the technique of width modulation and pulse current regulators. Such of command involves non linear correctors of hysteresis type that introduce limitations at large switching and non controllable frequency.
On the other hand, multi-level inverters have become a very attractive solution for high power application areas [5-6].
The three-level Neutral Point Clamped (NPC) inverter is one of the most commonly used multi-level inverter topologies in high power ac drives. By comparing to the standard two-level inverter, the three-level inverter presents its superiority in terms of lower stress across the semiconductors, lower voltage distortion, less harmonic content and lower switching frequency [7].
The three level inverters present a big interest in the field of the high voltages and the high powers of the fact that they introduce less distortion and weak losses with relatively low switching frequency.

Also, the use of three level inverter associated with DTC control can contribute to more reducing harmonics and the ripple torque and to have a high level of output voltage. In that case, the space of voltages is subdivided into twelve sectors (instead of six with the classic DTC) and by considering the method of the virtual vectors, three sections with small, medium and large vectors can be exploited. We can also subdivide the space of voltages into only six sectors by adopting a technique which employs only twelve active voltage space vectors, corresponding to the small and large vectors and consequently without using the null or the medium space vector In addition, independently of the reconstructor speed adopted, the principal blocks in the algorithm of control speed, without mechanical sensor of the IM are: the speed controller and the control adopted for torque control.

Indeed, the PI controller is conventionally used as a speed controller for the IM, as its synthesis is based on very simple methods (placement of poles, Ziegler Nichols) [8]. However, it can not cope with the imprecise identification of the moment of inertia, the excesses of the electrical parameters, dynamics not modelled (filters, actuator ...), and the strong non- linearity of torque [9], [10]. To avoid these shortcomings, many control strategies based on artificial intelligence have been proposed in the literature to control the speed of IM. The use of fuzzy controller (FLC) very closes to the human resentment and does not require mathematical modelling of nonlinear systems [11], [12], [13]. In fact, the use of FLC instead of PI, improve, no doubt, the performance speed control of IM, but it is at the expense of a considerable increase in computation time [14], [15].

In this case, this work consists firstly to compare a Direct Torque Control (DTC) applied for induction motor using two level and three level inverters voltage, secondly comparing the use of a classical PI corrector and a fuzzy logic controller of motor speed. And to demonstrate the great advantages of using three level inverters type NPC with speed regulation using a Fuzzy logic controller.

A. DTC associated with a two level inverters

The DTC is a vectorial command for an inverter voltage feeding an asynchronous motor. The objective is to regulate the stator flux and the electromagnetic torque without having measures of speed, the flux or torque. The only measures used are the voltages and currents supplied to the stator of the machine. The flux and the torque are totally estimated from these measurements. The stator resistance is one of the key parameters of this method of control and its variation may destroy its performance especially in low speeds.

A.1 The Principle of direct torque control

The direct torque has been introduced by I. TAKAHASHI in 1985 from the flux-oriented method and the principle of the direct current motor [16-17]. It's based of non-linear control as states switching of the inverter are imposed through a separate steering stator flux and the electromagnetic torque of the motor. The command of the inverter is instant and it replaces the decoupling through the transformation vectorial. One of the most important features of Direct Torque Control is the regulation of non-linear stator flux and electromagnetic torque structures variables or with hysteresis.
For an efficient control of the torque of an induction machine, adjusting the flux it's so important. In the DTC, we realize the regulation of the stator flux, on the one hand because it is easier to estimate, and partly because it has a faster dynamics than the rotor flux. By adjusting the stator flux, we also adjust the rotor flux. As in the other control methods which use a direct regulation of the flux, we give to this last one a constant reference as nominal value, for speeds lower than the nominal speed. For the superior speeds, we give a reference of flux which decreases proportionally with speed; witch corresponds to a deflection of the machine. On the other hand, the quality of the control of the rotation speed and\or the position of the modern actuators depends directly on the toque.

A.2 Stator flux control

The stator flux is estimated from the measure of the sizes of current and voltage and their transformation in the plane $\alpha\beta$. equations (1), (2):

$$\Phi_{s\alpha} = \int_0^t (V_{s\alpha} - R_s I_{s\alpha})dt \qquad (1)$$

$$\Phi_{s\beta} = \int_0^t (V_{s\beta} - R_s I_{s\beta})dt \qquad (2)$$

the stator flux linkage phasor is given by equation (3):

$$\Phi s = \sqrt{\Phi_{s\alpha}^2 + \Phi_{s\beta}^2} \qquad (3)$$

Over a period of sampling T_e, and by neglecting the term $(R_s I_s)$ in equation of stator flux, valid hypothesis for high speeds, the evolution of this last one is given by the vector V_s during T_e, equation (4):

$$\Delta\Phi_s = \Phi_s - \Phi_{s0} = V_s T_e \qquad (4)$$

Φ_{s0} is the initial stator flux linkage at the instant t_0.
For the control of the stator flux, we use a two levels hysteresis comparator.
With this type of controller, we can easily control and maintain the end of vector flux Φ_s in a circular ring as shown in Fig.1

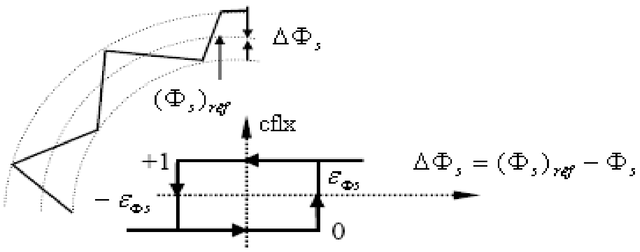

Figure.1 : Flux hysteresis corrector

The output of this corrector is represented by a boolean variable $cflx$ indicates directly if the amplitude of flux must be increased ($cflx = 1$) or decreased ($cflx = 0$) so as to maintain: $\left|(\Phi_s)_{réf} - \Phi_s\right| \leq \Delta\Phi_s$, with $(\Phi_s)_{réf}$ the order of flux and $\Delta\Phi_s$ the hysteresis width of the corrector.

A.3 Torque control

By putting γ the angle between the rotor and stator flux vectors, the expression of electromagnetic torque as given by equation (5):

$$\Gamma_{elm} = p\frac{L_m}{\sigma L_s L_r}\|\Phi_s\|\|\Phi_r\|\sin(\gamma) \qquad (5)$$

We deduct that the torque depends on the amplitude and on the position of stator and rotor vectors flux.
On the other hand, the differential equation which binds the stator flux and the rotor flux of motor is given by equation (6):

$$\frac{d\Phi_r}{dt} + (\frac{1}{\sigma\tau_r} - j\omega)\Phi_r = \frac{L_m}{\sigma\tau_r L_s}\Phi_s \qquad (6)$$

From this equation we deduct that the flux Φ_r follows the variations of the flux Φ_s with a constant of time $\sigma\tau_r$.

If we succeed in controlling perfectly the stator vector flux, from the vector V_s, in module and in position, we can control the amplitude and the relative position of the rotor vector flux and consequently the electromagnetic torque. This is indeed on possible only if the period of command T_e of the voltage V_s is very lower in $\sigma\tau_r$.

The expression of the electromagnetic torque is only obtained from the statorique sizes flux $\Phi_{s\alpha}$, $\Phi_{s\beta}$ and currents $I_{s\alpha}$, $I_{s\beta}$ equation (7):

$$\Gamma_{elm} = p(\Phi_{s\alpha}I_{s\beta} - \Phi_{s\beta}I_{s\alpha}) \qquad (7)$$

For the control of the electromagnetic torque, we use a three levels hysteresis comparator for the two senses of rotation the motor.
The output of this corrector is represented by a boolean variable $Ccpl$ indicates directly if the amplitude of torque must be increased, decreased or maintained $(Ccpl = 1,-1,0)$

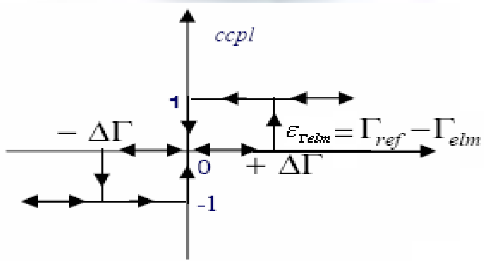

Figure. 2 : Three levels hysteresis comparator

A.4 Control strategy of DTC based two-level voltage inverters

Direct Torque Control of IM is directly established through the selection of the appropriate stator vector to be applied by the inverter. To do that, in first state, the estimated values of stator flux and torque are compared to the respective references, and the errors are used through hysteresis controller.

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The phase plane is divided, when the IM is fed by two-level voltage inverter with eight sequences of the output voltage vector, into six sectors.

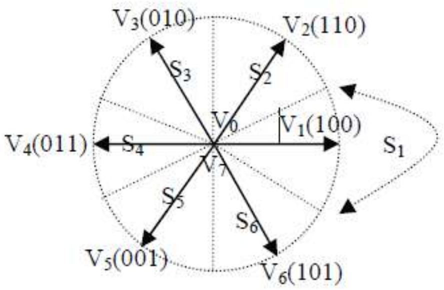

Figure.3: Stator vectors of tensions delivered by a two level voltage inverters

When the flux is in a sector (i), the control of flux and torque can be ensured by the appropriate vector tension, which depends on the flux position in the reference frame, the variation desired for the module of flux and torque and the direction of flux rotation:

Table 1: Selection of vector tension

Vector $\overline{V}_k$	$\overline{V}_{i+1}$	$\overline{V}_{i+2}$	$\overline{V}_{i-1}$	$\overline{V}_{i-2}$
Φ_s	increase	decrease	increase	decrease
Γ_{elm}	increase	increase	decrease	decrease

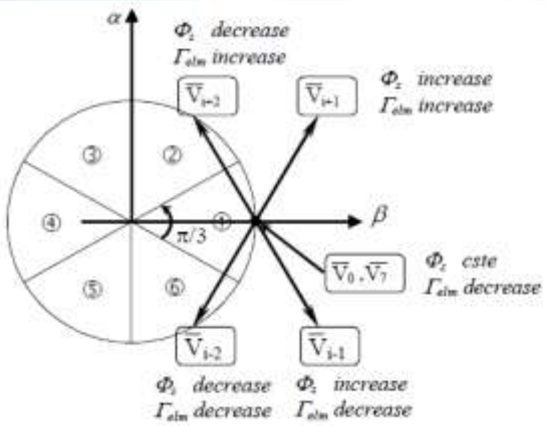

Figure.4: Selection of vector tension

The null vectors (V_0, V_7) could be selected to maintain unchanged the stator flux. According to the table 2, the appropriate control voltage vector (imposed by the choice of the switching state) is generated:

Table 2: Voltage vector selected

S		S_1	S_2	S_3	S_4	S_5	S_6
cflx	*ccpl*						
1	**1**	V_2	V_3	V_4	V_5	V_6	V_1
	0	V_7	V_0	V_7	V_0	V_7	V_0
	-1	V_6	V_1	V_2	V_3	V_4	V_5
0	**1**	V_3	V_4	V_5	V_6	V_1	V_2
	0	V_0	V_7	V_0	V_7	V_0	V_7
	-1	V_5	V_6	V_1	V_2	V_3	V_4

The following Figure.5 shows the selected voltage vector for each sector to maintain the stator flux in the hysteresis bound.

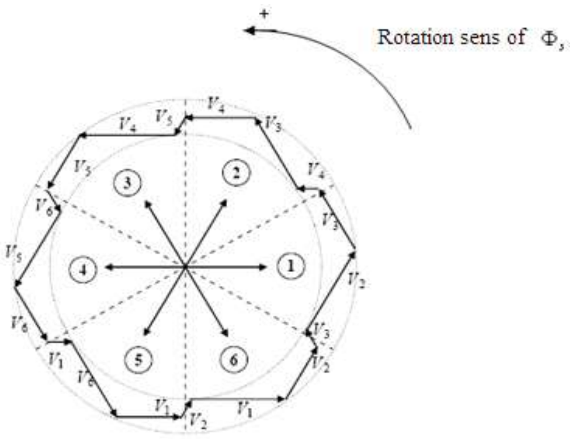

Figure.5: Selection of vector tension

A.5 Structure of the variator DTC with two level inverters

The structure adopted for a DTC variator is represented in Fig. 6. It's constitutes mainly of a block of estimation of the stator flux and the electromagnetic torque, the switching table and a block of regulation the speed of the motor. In our case, three-phase rectifier associated to a two levels inverter is used for the alimentation of the motor. The regulation of speed is made by corrector PI.

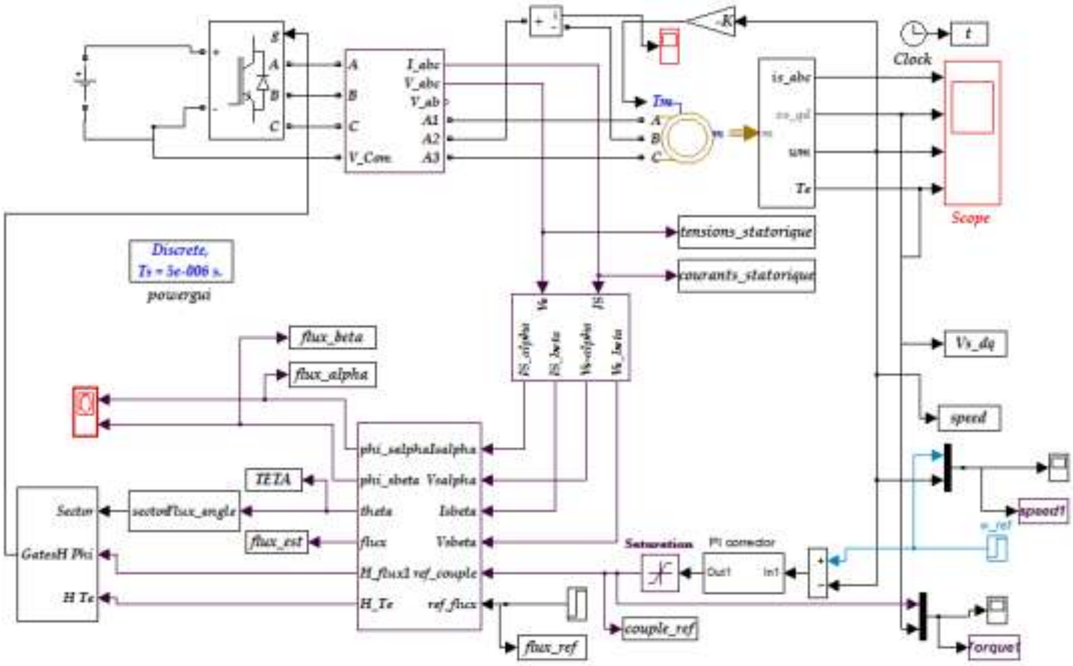

Figure.6: General structure of induction motor with DTC two level inverters

B. DTC three level inverters

B.1 Vectors tensions and phase level sequences of a three level inverters

Multilevel inverters present a big interest in the field of the high voltages and the high powers of the fact that they introduce less distortion and weak losses with relatively low switching frequency.

The three-level inverters presented in Figure.7 has several advantages over the standard two-level inverter, such as a greater number of levels in the waveforms, lower dV/dt, less harmonic distortion and lower frequencies [18].

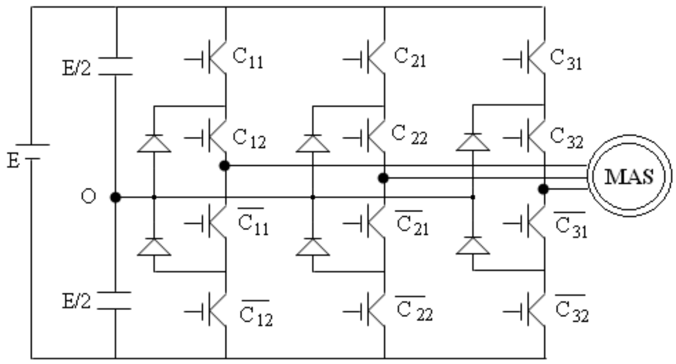

Figure.7: Three level inverters voltage feeding an induction motor

To analyze the potential generated by this inverter 3 states, every arm is schematized by three switches allow to connect independently the borders of the stator to three potential of the source (E/2, 0 and –E/2).

By making a transformation of the sizes in the plane $\alpha\beta$, we define a vector voltage resulting partner in the spatial position of the stator flux, and it follows itself that shade of states different from this vector is 19.

The following Figure.8 shows the various discreet positions, in the plane $\alpha\beta$, of the vector tension generated by the three levels inverter.

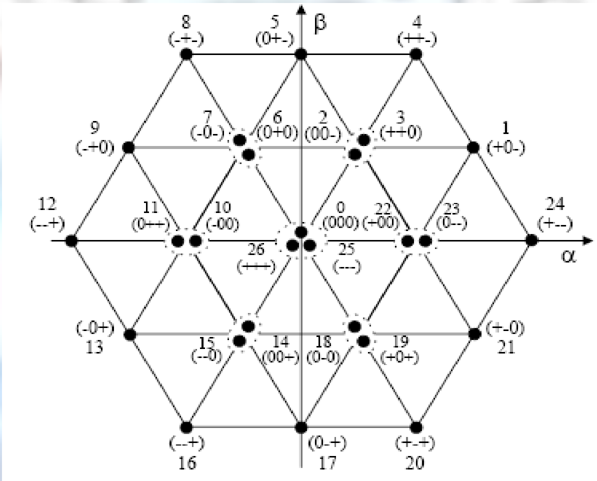

Figure.8: Vectors tensions generated by the 3 - level inverters

B.2 Selection of voltages vectors necessities in the control of the amplitude of the stator flux.

The complex plane in Figure.9 is divided into 12 sectors **i** (instead of six with the classical DTC), with **i**= [1, 12] of 30° each.

When the stator flux vector is in a sector **i**, the control of the flux and the torque can be assured by selecting one of 27 voltages vectors possible.

Depending on the stator flux position (sector) and the values of the outputs of torque and flux controller, $\varepsilon_{\Phi s}$ and $\varepsilon_{\Gamma elm}$ respectively, the optimal vector is selected, from all vectors available in Figure.9, the notation (+, 0, -) means phases a, b, c of the inverter output are connected respectively to the positive, neutral and negative bus bars of the DC-link.

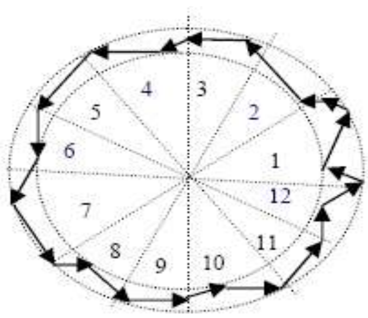

Figure.9: Selection of vectors tensions Vs corresponding to the control of the flux Φ_s for a 3 - level inverters

B.3 Elaboration of the control switching table

The elaboration of the command structure of the three level inverters NPC feeding an induction motor is based on the hysteresis controller output relating to the variable flux (Cflx) and the variable torque (Ccpl) and the sector N corresponding to the stator flux vector position.

The exploitation of the first degree of freedom of the inverter, is made by the choice of vectors apply to the machine among 19 possibilities, during a period of sampling [17]. For chosen the sequence of the levels of phase, among all the what establishes the second degree of freedom which must be necessarily used [17, 19]. The truth table is given by the Table.3.

Table 3: The switching table for 3-level inverters

S		1	2	3	4	5	6	7	8	9	10	11	12
Cflx = 1	Ccpl = 1	V_1	V_4	V_5	V_8	V_9	V_{12}	V_{13}	V_{16}	V_{17}	V_{20}	V_{21}	V_{24}
	Ccpl = 0	V_{25}	V_0	V_{26}	V_{25}	V_0	V_{26}	V_{25}	V_0	V_{26}	V_{25}	V_0	V_{26}
	Ccpl = -1	V_{21}	V_{24}	V_1	V_4	V_5	V_8	V_9	V_{12}	V_{13}	V_{16}	V_{17}	V_{20}
Cflx = 0	Ccpl = 1	V_9	V_{12}	V_{13}	V_{16}	V_{17}	V_{20}	V_{21}	V_{24}	V_1	V_4	V_5	V_8
	Ccpl = 0	V_{26}	V_0	V_{25}	V_{26}	V_0	V_{25}	V_{26}	V_0	V_{25}	V_{26}	V_0	V_{25}
	Ccpl = -1	V_{13}	V_{16}	V_{17}	V_{20}	V_{21}	V_{24}	V_1	V_4	V_5	V_6	V_9	V_{12}

C. Fuzzy logic speed controller (FLC)

The Figure.10, shows the diagram block of a controller FLC, who can be used for the control speed of the IM.

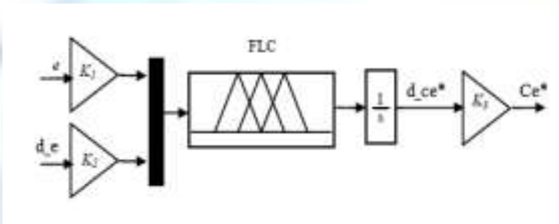

Figure.10: The block diagram of a fuzzy logic controller FLC

This fuzzy controller consists of a fuzzy controller BASIC, an integrator and Scale factors (FEs). The inputs of the fuzzy block are the values of the speed error and its derivative (e & $d_{\_e}$) multiplied respectively by FEs (K1) and (K2), and its output is the change in the reference torque (d_Ce*), which after integration and multiplication by the FE (K3) gives the reference torque Ce*. The seven functions Memberships (FAs), which we used to fuzzifier inputs and the output of FLC, Mamdani type are respectively shown in Figures (11) and (12). Indeed, FAs of the inputs are snuff triangular with non-uniform distribution, such as (NG) negative big, (NM) negative medium, (NP) negative small, (EZ) equal zero, (NP) positive small, (PM) positive medium, (PG) positive big.

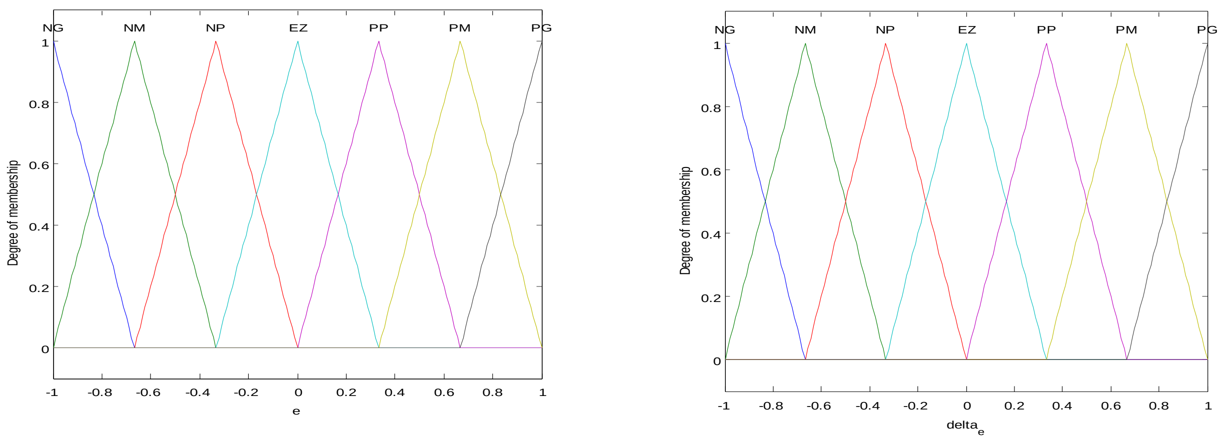

Figure.11: FAs, used for the inputs of the FLC

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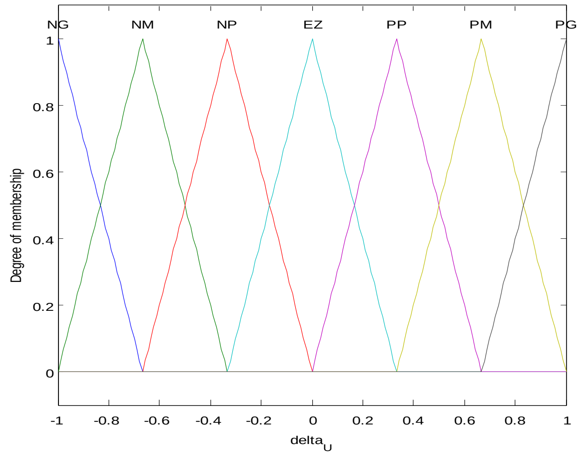

Figure.12: FAs, used for the ouput of the FLC

From the speed behavior analysis, the table 4 has been developed to obtain a good performance in the speed closed loop. Whereas, from the membership functions of inputs and the output, and the rules presented in this table, the FLC elaborates the electromagnetic torque reference to be developed by the IM.

Table.4: Fuzzy speed controller rules

d_{-e} \ e	NG	NM	NP	EZ	PP	PM	PG
NG	NG	NG	NG	NG	NM	NP	EZ
NM	NG	NG	NG	NM	NP	EZ	PP
NP	NG	NG	NM	NP	EZ	PP	PM
EZ	NG	NM	NP	EZ	PP	PM	PG
PP	NM	NP	EZ	PP	PM	PG	PG
PM	NP	EZ	PP	PM	PG	PG	PG
PG	EZ	PP	PM	PG	PG	PG	PG

In our case, the fuzzy controller has 47 rules, and the method used is the method défuzification weighted sums. The choices we have made on the distribution of FAs and the table rules give rise to a surface, fuzzy rules, non-linear form as shown in the following figure.13:

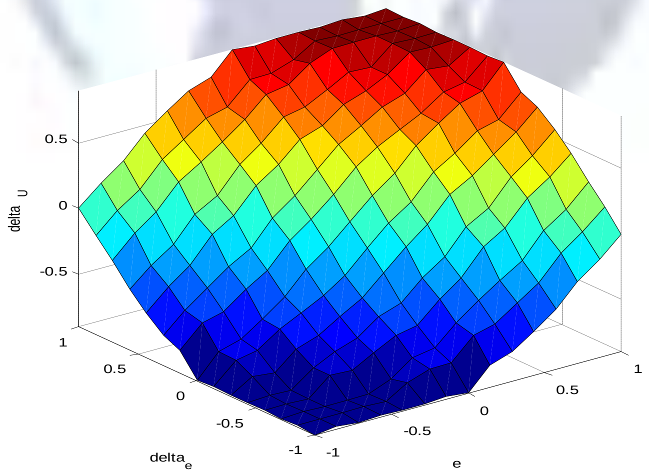

Figure.13: FAs, used for the inputs of the FLC

To exploit the universe of discourse, K1 is chosen such that the product (e × K1) remains within the interval [-1, 1]. Indeed, K1 was chosen equal to the inverse of the maximum variation of the speed reference. Because one depends on the other, K2 and K3 were adjusted manually in several tests (test-error). The values adopted are those that have culminated in a response time speed equal to 0.2 (sec). The numerical values of the FEs used are as follows: K_1 = 4.1 e^{-3}, K_2 = 1e^{-3}, K_3 = 3.7 e^{3}.

Simulations Results

The study of the performances of the DTC three level of induction motor with fuzzy logic controller of speed was made by simulation using Power System Blocset (PSB) of Matlab / Simulink and fuzzy logic tools.

The torque reference value is deduced from the regulation of the IM speed using a PI corrector for a DTC two levels and a Fuzzy controller for a DTC three levels. We have chosen to present the results corresponding to the rotation speed evolution, the electromagnetic torque, the flux evolution in the $\alpha\beta$ subspace and the stator currents.

The obtained simulation results show that:

- Phase current obtained by this strategy is quasi sinusoidal (Figure.15 (a) for a DTC two level inverters and Figure.16 (a') for a DTC three level inverters).
- Trajectory of the stator flux, represented by its two components in the $\alpha\beta$ phase plane, is in a circular reference (Figure.15 (c) for a DTC two level inverters and Figure.16 (c') for a DTC three level inverters)
- Overshoot on torque is limited by saturation on the reference value (Figure.15 (d) for a DTC two level inverters and with not saturation on the reference Figure.16 (d') for a DTC three level inverters)
- Speed tracks its reference with good performance (Figure.15 (e) for a DTC two level inverters and Figure.16 (e') for a DTC three level inverters).

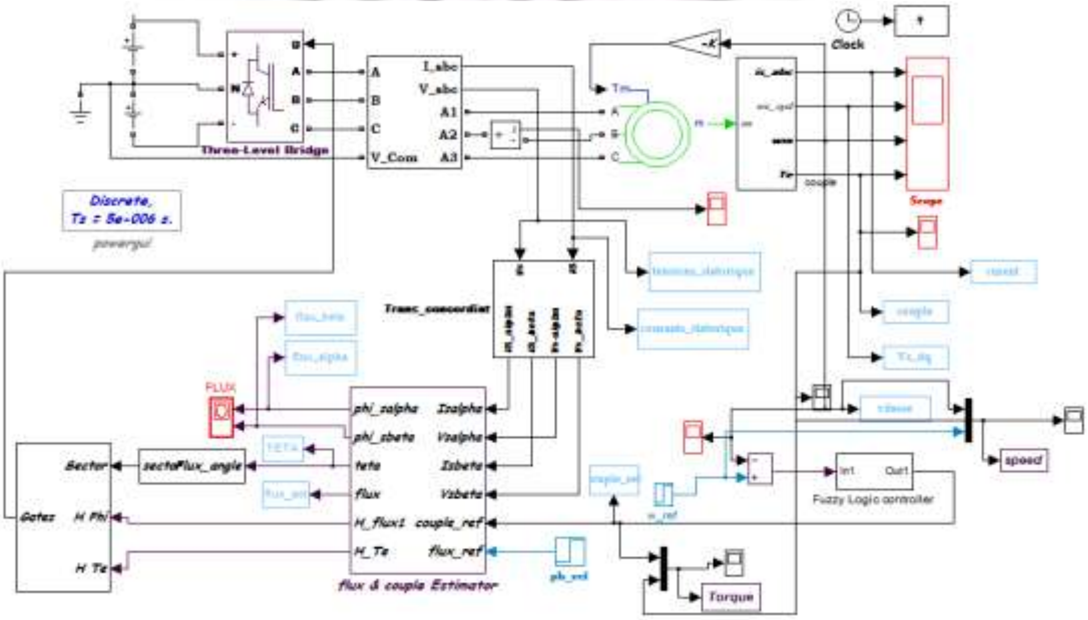

Figure 14: General structure of induction motor with DTC three level voltage inverters

Table 4: Induction Machine parameters

Rated Power P	$3{,}7KW$
Voltage V	$220/380V$
Nuber of Pair Poles n_p	2
Stator Resistance R_s	$1{,}115\Omega$
Rotor Resistance R_r	$1{,}083\Omega$
Stator Self-Inductance L_s	$0{,}006H$
Rotor Self-Inductance L_r	$0{,}0059H$
Mutual Inductance M	$0{,}20H$
Total inertia J	$0{,}02Kg.m^2$
Friction coefficient f	$0{,}0057N.m.s$

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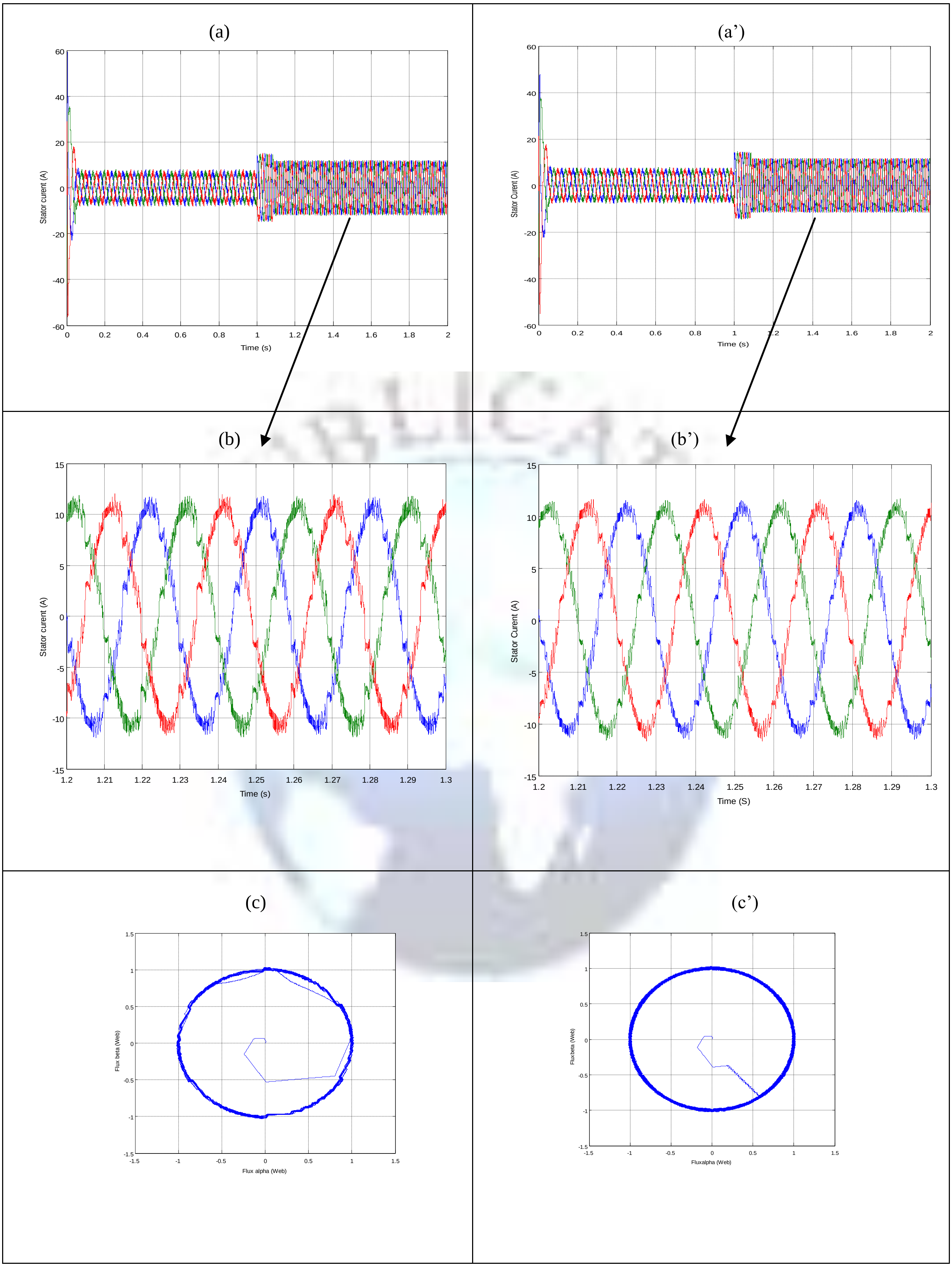

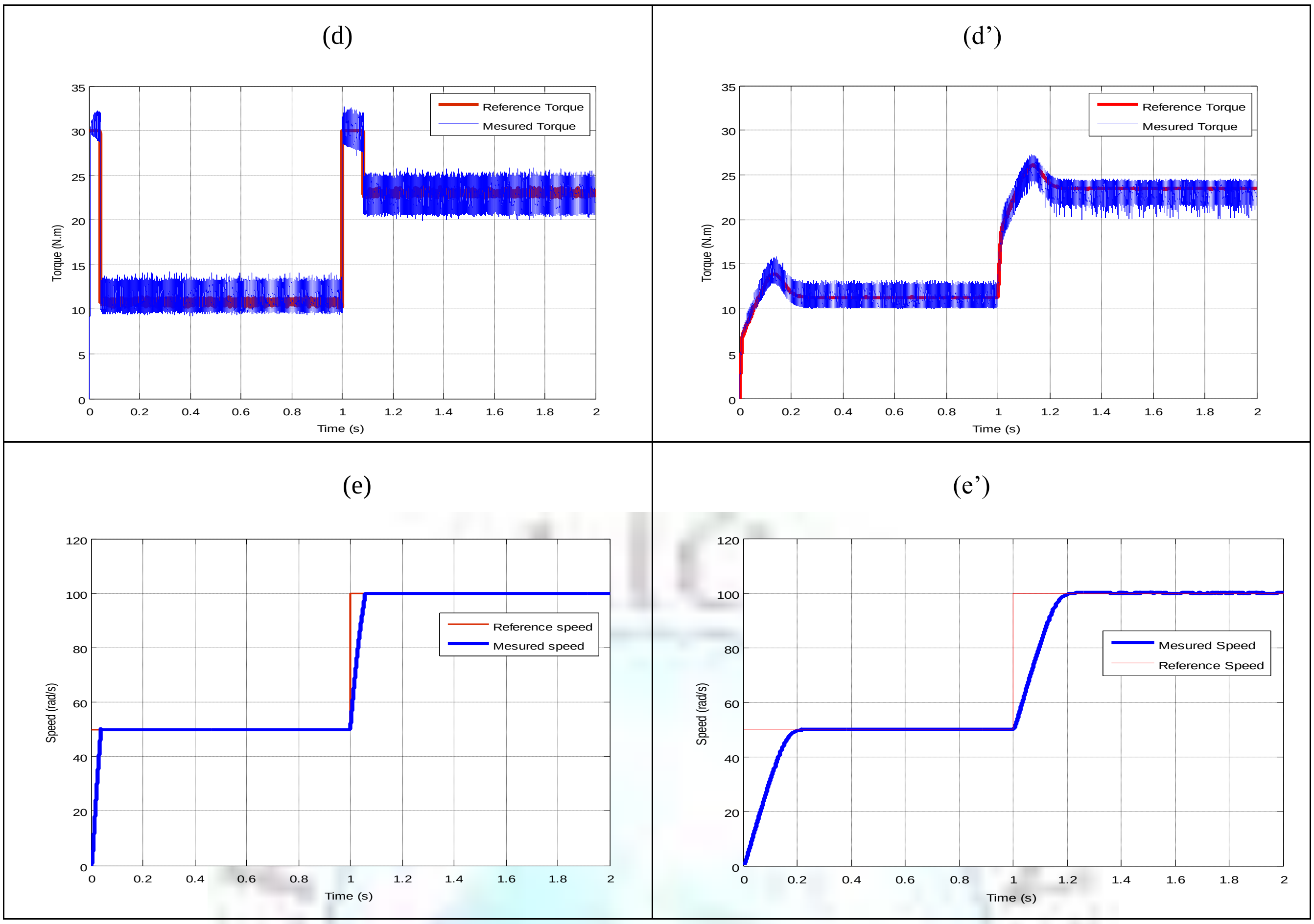

Figure.15: Simulation results of DTC two level voltage inverters with PI classic corrector of speed: (a) stator current time evolution, (b) zoom of stator current time evolution, (c) Stator flux in the $\alpha\beta$ phase plane, (d) Time evolution of Torque, (e) Time evolution of speed.

Figure.16: Simulation results of DTC three level voltage inverters with Fuzzy logic controller of speed: (a') stator current time evolution, (b') zoom of stator current time evolution, (c') Stator flux in the $\alpha\beta$ phase plane, (d') Time evolution of Torque, (e') Time evolution of speed.

It is interesting to note that, the torque pulsations and the stator flux ripples in the case of DTC three level with fuzzy controller of speed, as it is shown in figure (16.(d')) and figure (16.(c')) , are smaller than in the case of DTC two level with PI corrector shown in figure (12.(d)) and figure (15.(c)). It's seen that the current DTC two level Figure (15.(b)) presented a ripples more than the current DTC three level Figure (16.(b)).

On the other hand, the PI correction requires a limitation of the reference torque (30 Nm) in our case, otherwise there will be a problem of a large excess of torque and speed, against the fuzzy controller does not require a limitation and does not cause any excess, in addition a fuzzy controller adapts much practice because it takes into account the change the parameters of motor. In addition, three level inverters present a big interest in the field of the high voltages and the high powers of the fact that they introduce less distortion and weak losses with relatively low switching frequency.

Conclusion

In this paper, we presented the results of simulation, using the blocks PSB of Matlab / Simulink, the DTC applied to induction motor and supplied by two level voltage inverters and three level voltage inverters. The Direct Torque Control (DTC) is an important alternative method for the induction motor drive, with its high performance and simplicity. The DTC applied to induction motor fed by a three level inverters presents good performance and undulations reduction. In this case, some techniques were developed in order to replace the conventional DTC switching table adapted for a NPC inverter. The speed control of the motor is realized by a corrector PI for a DTC two level and by a Fuzzy logic controller for a DTC three level.
We can conclude that the DTC method applied to an induction motor fed by a three level NPC inverters and using a Fuzzy controller of speed present most interest and contribute to improvement of system response performances.

References

[1]. I. Takahashi, T. Noguchi, "A new quick-response and high- efficiency control-strategy of an induction motor", IEEE Transactions on Industry Applications, Vol. IA 22, No. 5, pp. 820-827, 1986.
[2]. M. Depenbrock, "Direct self-control (DSC) of inverter-fed induction machine", IEEE Transactions on Power Electronics, Vol. 3, No. 4, pp. 420-429, 1988.
[3]. G. Abad, M. A. Rodriguez, J. Poza, "Two-level VSC based predictive direct torque control of the doubly fed induction machine with reduced torque and flux ripples at low constant switching frequency", IEEE Transactions on Power Electronics, Vol. 23, No. 3, pp. 1050-1061, 2008.
[4]. M. K. Sahu, B. P. Panigrahi, A. K. Panda, "An utility friendly direct torque control technique of three phase induction motor with two-level inverter using 180 degree conduction mode", International Journal of Engineering Science and Technology, Vol. 3, No. 5, pp. 4120-4130,2011.
[5]. J. Rodriguez, S. Bernet, B. Wu, J. O. Pontt, S. Kouro, "Multilevel voltage-source-converter topologies for industrial medium-voltage drives", IEEE Transactions on Industrial Electronics, Vol. 54, No. 6, pp.2930-2945, 2007.
[6]. Y. Zhang, Z. Zhao, "Study on capacitor voltage balance for multilevelinverter based on a fast SVM algorithm", Proceeding of the CSEE(in Chinese), Vol. 26, No. 18, pp. 71-76, 2006.
[7]. L. Dalessandro, S. D. Round, J. W. Kolar, "Center-point voltage balancing of hysteresis current controlled three-level PWM rectifiers", IEEE Transactions on Power Electronics, Vol. 23, No. 5, pp. 2477-2488, 2008.
[8]. SM. Gadoue, D. Giaouris, JW. Finch. Artificial intelligence-based speed control of DTC induction motor drives, a comparative study. Electric Power Systems Research,79 :210-219, 2009.
[9]. D. Vasanthi, B. Pranavamoorthy, N. Pappa. Design of a self-tuning regulator for temperature control of a polymerization reactor. ISA Transactions, 51(1): 9-22, 2012.
[10]. YM. Zhao, WF. Xie, XW. Tu. Performance-based parameter tuning method of model-driven PID control systems. ISA Transactions, 51(3): 393–399, 2012.
[11]. T. Orlowska, K, M. Dybkowski, and K. Szabat. MRAS-Type Speed and Flux Estimator with Additional Adaptation Mechanism for the Induction Motor Drive. IEEE TRANS ON Electrical Engineering, 1 (1): 7-12, 2012.
[12]. M. Uddin Nasir, H. Wen. Development of a self-tuned neuro-fuzzy controller for induction motor drives. IEEE Transactions on Industry Applications, 43(4):1108-1116, 2007.
[13]. I. Pan, S. Das, A. Gupta. Tuning of an optimal fuzzy PID controller with stochastic algorithms for networked control systems with random time delay. ISA Transactions, 50(1): 28-36, 2011.
[14]. A. Lokriti, Y.Zidani, S.Doubabi. Fuzzy logic control contribution to the direct torque and flux control of an induction machine. ICMCS conf, 2011, pp. 1-6.
[15]. A. Lokriti et al. Induction motor speed drive improvement using fuzzy IP-self-tuning controller. A real time implementation. ISA Transactions, 52(3):) 406-417, 2013.
[16]. Barbara H.Kennynasa, "Stator and Rotor Flux Based Deadbeat Direct Torque Control of Induction Machines", IEEE Industry Applications Society, Annual Meeting, Chicago, September 30-Octoer 4, 2001.
[17]. X. Roboan, "Variateur de vitesse pour machine asynchrone, Contrôle de la vitesse sans capteur mécanique", Thèse Doctorat de L'INPT, Toulouse.1991.
[18]. N.Schibili, T.Nguyen, A.Rufer, "Three-Phase Multilevel Converter for High-Power Induction Motors", IEEE trans. On Power Elect. Vol. 13 N°.5, 1998.
[19]. D.Casadei, Profumo, G.Serra, A.Tani, "FOC and DTC: Tox Viable Schemes For Induction Motors Torque Control", IEEE trans.Power Electronics. On PE, Vol.17, N°.5, Sept 2002.