International Conference on Control, Engineering & Information Technology (CEIT'13)
Proceedings Engineering & Technology - Vol.3, pp. 123-127, 2013

Neural Fuzzy Speed Control For Six Phase Induction Machines

Salima Lekhchine[#1], Tahar Bahi[*2], Youcef Soufi[#3], Hichem Merabet[#4]

[#1,2] *Electrotechnic department, LR3M, Badji Mokhtar University,PBox 12, Annaba, Algeria.*
[1]`slekhchine@yahoo.fr`, [2] `tbahi@hotmail.fr`
[#3] *Department of electrical, Tebessa University, Tebessa, Algeria*
[3]`y_soufi@ yahoo.fr`

[#4] *Unit of research in Industrial Technology,Badji Mokhtar university , Annaba, Algeria.*
[4] `hichem_19@msn.com`

***Abstract*— This paper present the application of the neural networks , fuzzy logic and PI controllers for the speed control of six phase induction motor. The parameters of the classical control changes inevitably during the operation of the machine. Therefore, the performances of the command decline. So, neural fuzzy logic controller is used to resolve this problem and the study scheme and its feasibility are verified by simulation. The vector control method is presented and used for this machine. The simulation results show the robustness and good performance of the proposed controller.**

Keywords*— *Neural network; modeling; six phase induction machine ; vector control; drive.

I. INTRODUCTION

The vector control technique has long time applied to usual three-phase induction machines. It was presented by Blaschke and Hasse [1, 2] which has better dynamic response. The main objective of vector control is the control of separate excitation DC machine. This diagram of decouples the stator current into producing the torque and flux components. The main disadvantages of classical algorithms of control such as PI regulators, is the sensitivity in performance to the system parameter variations and inadequate rejection of internal disturbances and load changes [3]. However, study on accelerated multiphase machines; until the beginning of recent century; it became practical in industries. Therefore, the vector control application to multiphase machine is encouraged for high-power application, because this machine type presents many advantages: reduction of the pulsation torque, minimizing losses rotor, reduction harmonic currents rotor and power segmentation [4-7]. Such segmented structures are very attractive for high-power applications, since they allow the use of lower rating power electronic devices at a switching frequency higher than the one usually used in three-phase AC machine drives [8]. The vector control method is the most popular because of its relative simplicity and low cost of implementation. But, the classical controllers (PID) are used to regulate the currents of the required control an inferior performance because is sensitivity to parameter variations. Recently, many strategies learning for neural control have been proposed and applied to some specified nonlinear control systems to overcome the unknown model and parameters variation problems [9-11]. The results simulation obtained by using Matlab/ Simulink are provided to confirm the validity of the proposed techniques.

II. MATHEMATICAL MODEL OF MACHINE

The stator and rotor equation in arbitrary common reference are as follows [12, 13]:

$$\begin{cases} \frac{d}{dt}\Phi_{ds} = V_{ds} - R_s\, i_{ds} + \omega_s\, \Phi_{qs} \\ \frac{d}{dt}\Phi_{qs} = V_{qs} - R_s\, i_{qs} - \omega_s\, \Phi_{ds} \\ \frac{d}{dt}\Phi_{dr} = V_{dr} - R_r\, i_{dr} + (\omega_s - \omega_r)\Phi_{qr} \\ \frac{d}{dt}\Phi_{qr} = V_{qr} - R_r\, i_{qr} - (\omega_s - \omega_r)\Phi_{dr} \end{cases} \tag{1}$$

Where the expressions for stator and rotor flux are:

$$\begin{cases} \Phi_{ds} = L_s i_{ds} + L_m i_{ds} + L_m i_{dr} \\ \Phi_{qs} = L_s i_{qs} + L_m i_{qs} + L_m i_{qr} \\ \Phi_{dr} = L_r i_{dr} + L_m\, i_{ds} + L_m i_{dr} \\ \Phi_{qr} = L_r i_{qr} + L_m i_{qs} + L_m i_{qr} \end{cases} \tag{2}$$

The mechanical equation can be expressed as:

$$\frac{J}{p}\frac{d}{dt}\omega_r = T_{em} - T_l - \frac{k_f}{p}\omega_r \qquad (3)$$

And, the torque as follows:

$$T_{em} = pL_m\left(i_{qs}i_{dr} - i_{ds}i_{qr}\right) \qquad (4)$$

Where, the various symbols denote the following:

V_{ds} , V_{qs}: stator voltages in “d” and “q” axis ;
V_{dr} , V_{qr}: rotor voltages in “d” and “q” axis ;
i_{ds} , i_{qs}: stator currents in “d” and “q” axis ;
Φ_{ds} , Φ_{qs}: stator fluxes in “d” and “q” axis ;
Φ_{dr} , Φ_{qr}: rotor fluxes in “d” and “q” axis ;
ω_s: synchronous speed ;
ω_r: electrical rotor speed;
J: moment of inertia;
k_f: viscous friction coefficient;
T_{em}: electromagnetic torque;
T_l: load torque.

III. MODELING SIX-PHASE VOLTAGE SOURCE INVERTER

Power circuit topology of a six-phase voltage source inverter (VSI) is shown in Fig. 1.

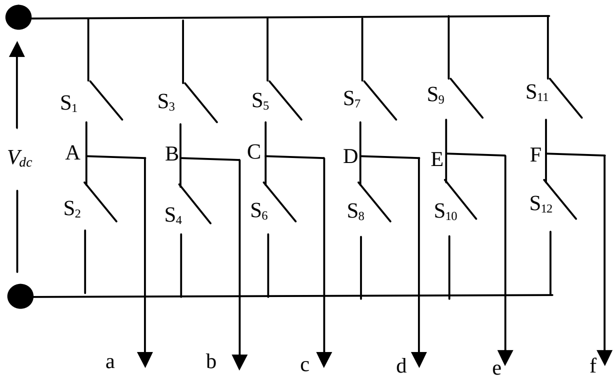

Fig. 1 Six-phase voltage source inverter power circuit

The inverter input dc voltage V_{dc} is regarded supposed constant and each switch ($S_{1\text{-}12}$) is assumed to conduct for 180°. Phase delay between firing of two switches in any subsequent two phases is equal to 60°. One complete cycle of operation of the inverter can be divided into six distinct intervals indicated in the time domain waveforms of leg voltages shown in Fig. 2 and summarized in Table 1. It follows from Fig. 2 and Table 1 that at any instant in time there are six switches those are ‘on’ and six switches those are ‘off’. In this mode of operation there are three conducting switches from the upper six and three from the lower six, this mode of operation leads to, as shown shortly, a square wave phase-to-neutral output voltage waveform, the reason being the spatial displacement between the six-phases of 60° [14].

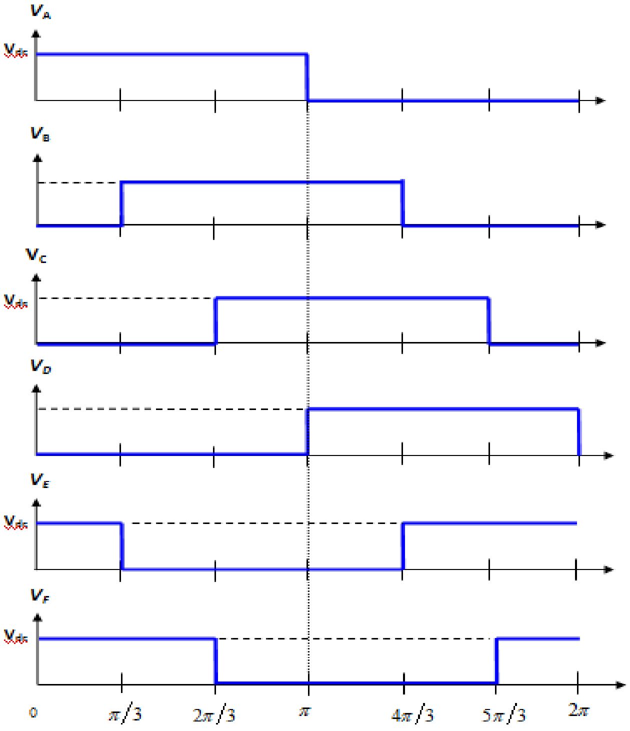

Fig. 2 Leg voltages of six-phase VSI

TABLE I
THE LEG VOLTAGES OF SIX PHASE VSI

Mode	**I**	**II**	**III**	**IV**	**V**	**VI**
Switches ON	**S_1,S_3,S_6** **S_1,S_3,S_6**	**S_1,S_3,S_5** **S_8,S_{10},S_{12}**	**S_3,S_5,S_7** **S_2,S_{10},S_{12}**	**S_5,S_7,S_9** **S_2,S_4,S_{12}**	**S_5,S_9,S_{11}** **S_2,S_4,S_6**	**S_1,S_9,S_{11}** **S_4,S_6,S_8**
V_A	V_{dc}	V_{dc}	0	0	0	V_{dc}
V_B	V_{dc}	V_{dc}	V_{dc}	0	0	0
V_C	0	V_{dc}	V_{dc}	V_{dc}	0	0
V_D	0	0	V_{dc}	V_{dc}	V_{dc}	0
V_E	0	0	0	V_{dc}	V_{dc}	V_{dc}
V_F	V_{dc}	0	0	0	V_{dc}	V_{dc}

If an ideal sinusoidal six-phase supply is considered, similar to space vector, it is defined as:

$$\underline{v} = \sqrt{2/6}\left(v_a + \underline{a}v_b + \underline{a}^2 v_c + \underline{a}^3 v_d + \underline{a}^4 v_e + \underline{a}^5 v_f\right) \qquad (5)$$

$$\underline{a} = e^{\frac{J\pi}{3}} \qquad (6)$$

However, the phase-to-neutral voltages of a star connected load again a voltage difference between the star point n of the load and the negative rail of the dc bus N is defined by:

$$\begin{cases} v_a = \alpha\, v_A - \left(v_{nN} - (1-\alpha)v_A\right) \\ v_b = \alpha\, v_B - \left(v_{nN} - (1-\alpha)v_B\right) \\ v_c = \alpha\, v_C - \left(v_{nN} - (1-\alpha)v_C\right) \\ v_d = \alpha\, v_D - \left(v_{nN} - (1-\alpha)v_D\right) \\ v_e = \alpha\, v_E - \left(v_{nN} - (1-\alpha)v_E\right) \\ v_f = \alpha\, v_F - \left(v_{nN} - (1-\alpha)v_F\right) \end{cases} \tag{7}$$

Where,

α=5/6 and v_{nN} is defined by:

$$v_{nN} = (1-\alpha)\left(v_A + v_B + v_C + v_D + v_E + v_F\right) \tag{8}$$

Hence the values of the phase-to-neutral voltages in the six distinct intervals of 60 degrees duration can be determined using the values of the leg voltages in Table 1 [14]. For controlling the SPIM by using the Clark's transformation (9) [14-17]:

$$T_6 = \begin{bmatrix} 1 & \cos\theta & \cos\frac{2\pi}{3} & \cos\left(\theta+\frac{2\pi}{3}\right) & \cos\frac{4\pi}{3} & \cos\left(\theta+\frac{4\pi}{3}\right) \\ 0 & \sin\theta & \sin\frac{2\pi}{3} & \sin\left(\theta+\frac{2\pi}{3}\right) & \sin\frac{4\pi}{3} & \sin\left(\theta+\frac{4\pi}{3}\right) \\ 1 & \cos(\pi-\theta) & \cos\frac{4\pi}{3} & \cos\left(\frac{\pi}{3}-\theta\right) & \cos\frac{2\pi}{3} & \cos\left(\frac{5\pi}{3}-\theta\right) \\ 0 & \sin(\pi-\theta) & \sin\frac{4\pi}{3} & \sin\left(\frac{\pi}{3}-\theta\right) & \sin\frac{2\pi}{3} & \sin\left(\frac{5\pi}{3}-\theta\right) \\ 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 \end{bmatrix} \tag{9}$$

The electromechanical energy conversion takes place in (α, β) subsystem:

$$\begin{bmatrix} v_{\alpha s} \\ v_{\beta s} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s + sL_s & 0 & sM & 0 \\ 0 & R_s + sL_s & 0 & sM \\ sM & \omega_r M & R_r + sL_r & \omega_r L_r \\ -\omega_r M & sM & -\omega_r L_r & R_r + sL_r \end{bmatrix} \begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \\ i_{\alpha r} \\ i_{\beta r} \end{bmatrix} \tag{10}$$

With,

$L_s = L_{s1} + M$: is the stator inductance;
$L_r = L_{r1} + M$: is the rotor inductance.

IV. VECTOR CONTROL

The objective of vector control is to assimilate the operating mode of the induction machine at the one of a DC machine with separated excitation, by decoupling the torque and the flux control. In vector control of induction machine, the direct axis should be aligned with rotor flux vector ($\Phi_{dr} = \Phi_{dr}^{*}$), and then the quadrature component of rotor flux will be equal to zero ($\Phi_{qr} = 0$) [1]. Therefore,

$$\Phi_{qr} = L_r i_{qr} + L_m (i_{qs} + i_{qr}) = 0 \tag{11}$$

$$i_{qr} = \frac{L_m i_{qs}}{L_r + L_m} \tag{12}$$

And,

$$\Phi_{dr} = \Phi_r^{*}, \qquad \frac{d\Phi_{dr}}{dt} = 0 \tag{13}$$

By substituting (12) in (2), we obtain:

$$\omega_s - \omega_r = \frac{R_r i_{qs}}{(L_r + L_m) i_{ds}} \tag{14}$$

However, with using (12) and (4), the torque equation can be expressed as:

$$T_e = K \Phi_{dr} i_{qs} \tag{15}$$

Where K is torque constant. So, if the rotor flux is constant, the stator current i_{qs} can be control the torque and the rotor flux can be controlled with direct component of stator current [1, 18-19].

V. NEURAL FUZZY SPEED CONTROLLER

For the control speed we use a controller based on Artificial Neural Network (ANN) [20]. Fig. 3 shows the block diagram of the considered circuit.

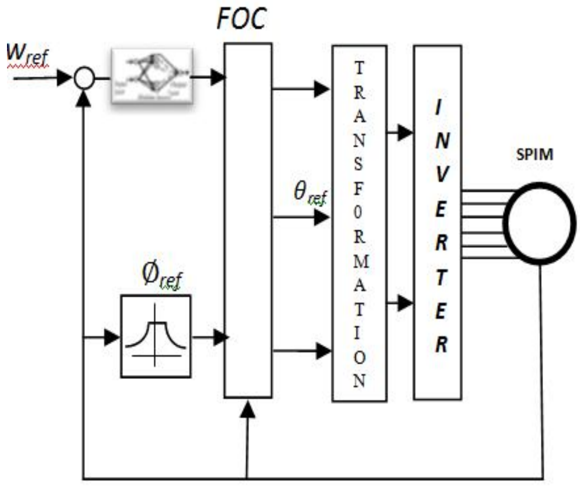

Fig. 3 Scheme of neural fuzzy-speed control

The multi-layer preceptor, the number of hidden layers and hidden neurons is not known a priori. Furthermore, there is no general rule for predicting the number of hidden neurons necessary to achieve a specified performance of the model.

One of the most popular programs is the back-propagation. So for the proposed application, an ANN with a single layer with activation function tansig type is used. In this step, the authors execute several tests and analyzing the performance of the system [20]. The neural network controller considered is shown in Fig. 4. Two neurons in input layer, 30 neurons in hidden layer and one neuron in output layer.

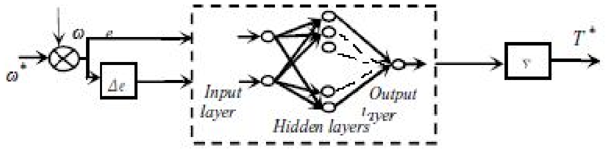

Fig. 4 Scheme of speed control using ANN.

VI. SIMULATION RESULTS

In order to examine the effects of rotor resistance variation of the machine, we have been simulated in following conditions: the rotor resistance cycle is show in Fig .5.

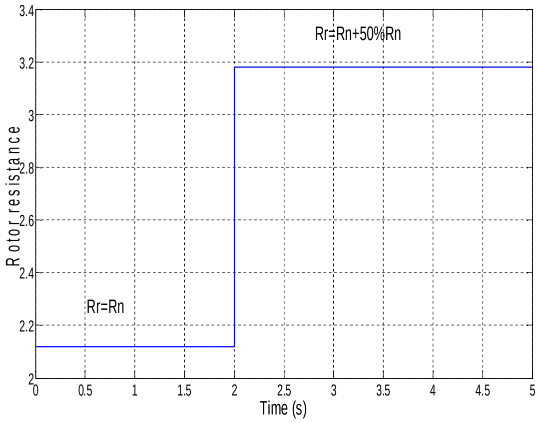

Fig. 5 Variation of rotor resistance

The simulation tests consist for the study of performances of the considered controller taking the parameters variations of the rotor resistance which is basically variable during the functioning. For this purpose, we have considered that the rotor resistance was increases by 50%, starting from the instant 2s and we applied a speed reference of 200rd/s, 300rd/s and -300rd/S. Fig. 6a, 6b, 6c and Fig. 6d shows respectively , the superposition of the speeds, torques, the direct and squaring flux component.

We note that the speed precisely follows the reference value and remains insensitive to the variation of the load when the controller is type NN. In addition, the response time is significantly better for the NN compared to the PI controller. The torque has better performance when the NN is used Fig. 6b. Fig. 6c and Fig. 6d show respectively the direct and squaring components of flux (Φ_{dr}, Φ_{qr}). We note that the decoupling between the torque and flux is remains assured. In fact, the change the load charge does not have any influence on flux magnitude but for a PI controller, the decoupling is lost. Indeed, the two components move away from their reference when the load torques increase.

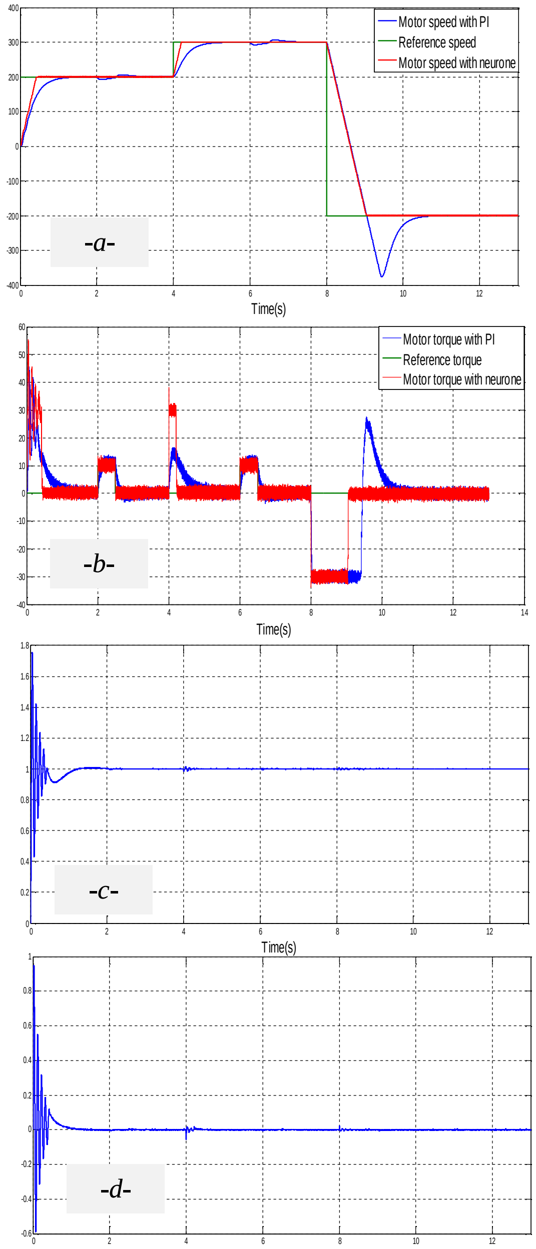

Fig. 6 Characteristics without changes in parameters

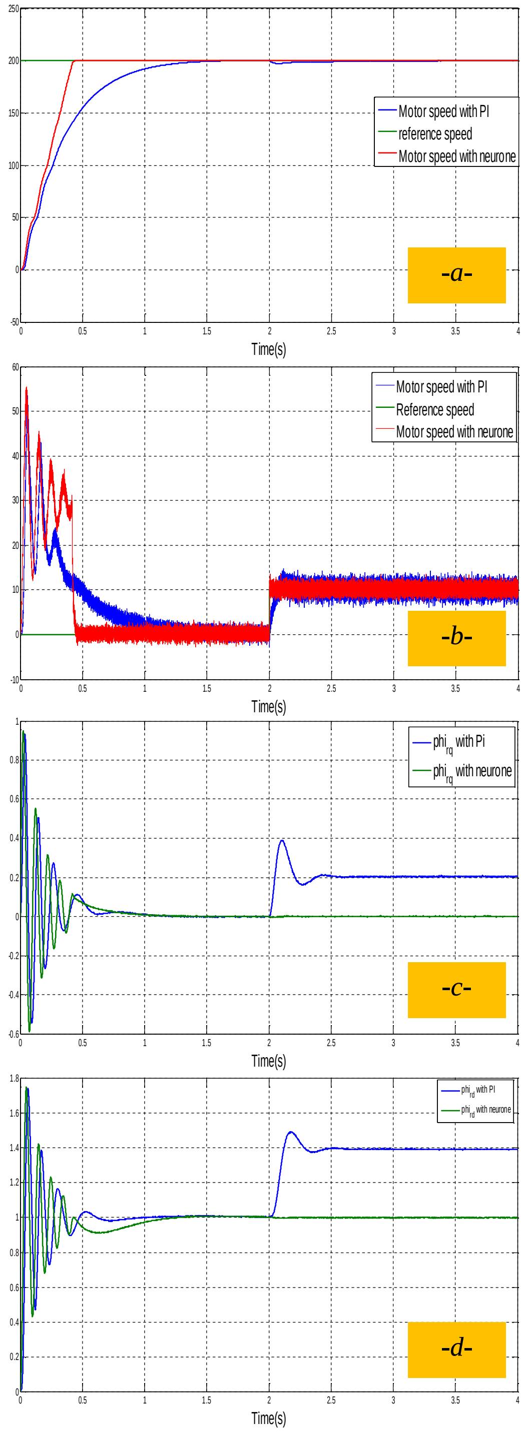

Fig. 7 Characteristics with changes in parameters

VII. CONCLUSION

In this paper, fuzzy vector control of a six phase induction machine has been shown to be able to assure the high performances despite parametric variation. The control is insensitive to rotor resistance variation .This returns to the fact that the fuzzy logic controller regulator synthesis is realized without taking into account the machine model.

REFERENCES

[1] F. Blaschke, “The Principe of Field-Orientation as Applied to the new Transvector Closed-Loop Control System Rotating Field Machines,” Simems Review, vol. 34, pp. 217-220, May 1972.

[2] K. Hasse, “About the dynamics of adjustable-speed drives with converterfed squirrel-cage induction motors,” (in German), Ph.D. Dissertation, Darmstadt Technische Hochschule, 1969.

[3] A. Chaari, M. Soltani, M. Gossa, “Comparative study between the conventional regulators and fuzzy logic controller: application on the induction machine,” International Journal of Sciences and Techniques of Automatic control & computer engineering IJ-STA, Volume 1, n° 2, pp. 196−212, December 2007.

[4] S. Sathiakumar, R. E. Betz, R. J. Evans, “Adaptive Field-Oriented Control of an IM using Predictive Control,” IEEE Trans. Aero. Elec. Syst, vol. 26, no. 2, March. 1990.

[5] R. Kianinezhad, B. Nahid, F. Betin, G.A. Capolino,"A novel Direct Torque Control (DTC) method for dual three phase induction motors", IEEE Xplore, 2006.

[6] D. Hadiouche, “Contribution to the Study of Dual Stator Induction Machines,” Modeling, Supplying and Structure Ph. D. dissertation (in French), GREEN, Faculty of Sci. and Tech. Univ. Henri Poincaré-Nancy I, France, Dec. 2001.

[7] E. Levi, “Recent developments in high performance variable-speed multiphase induction motor drives,” sixth international symposium nikola tesla, Belgrade, SASA, Serbia, October 18–20, 2006.

[8] D. Hadiouche, H. Razik, A. Rezzoug,"On the Modeling and Design of Dual Stator Windings to Minimize Circulating Harmonic Currents for VSI Fed AC Machines," IEEE Transactions On Industry Applications, vol.40, no.2, pp. 506-515, March ,April 2004.

[9] D. Psaltis, A Sideris, A. Yamamura . A Multilayered, ”Neural Network Controller,” IEEE Control System Magazine, vol.8, 1988.

[10] Y. Zhang, P. Sen, G. E. Hearn, “An On-line Trained Adaptive Neural Controller,” IEEE Control System Magazine, v.15, pp. 67-75, 1995.

[11] S. Weerasooriya and M. A. EI-Sharkawi Hearn, “Identification and Control of a DC Motor Using Back-propagation Neural Networks,” IEEE Transactions on Energy Conversion, v.6, pp. 663-669,1991.

[12] Hamidreza Pairodin Nabi, Pooya Dadashi, Abbas Shoulaie, “A novel structure for vector control of symmetrical six-phase induction machine with three current sensors,” Engineering, Technology & Applied Science Research, vol.1, no. 2, pp. 23-29, 2011.

[13] E. Levi, M. Jones, S.N. Vukosavic, “Even-phase multi-motor vector controlled drive with single inverter supply and series connection of stator windings,”Proc. IEE—Electric Power Applications, vol. 150, no. 5, pp. 580–590, 2003.

[14] A. Iqbal, “Modelling and control of series connected five phase and six phase two motor drives,” A thesis submitted in partial fulfillment of the requirements of Liverpool John Moores University for the degree of Doctor of Philosophy Study, August 2005.

[15] M. A. Fnaiech, F. Fnaiech, F. Betin and G. A. Capolino, “Comparison between fuzzy logic and sliding mode control applied to six phase induction machine positioning,” Int. Conf. on Elec. Machines. IEEE, pp. 1-6, 2008.

[16] B.M. Wilamowski and J. David Irwin, “Power electronics and motor drives,” by Taylor and Francis Group, LLC , CRC Press is an imprint of Taylor & Francis Group, an Informa business, 2011.

[17] B. Ghalem and A. Bendiabdellah, “Six-phase matrix converter fed double star induction motor," Acta Polytechnica Hungarica, vol. 7, no. 3, 2010.

[18] Nick R. N. I and Abdul H. M. Y, "Direct torque control of induction machines with constant switching frequency and reduced torque ripple," IEEE Tran. Ind. Electron, vol. 51, no.4, pp. 758-767, 2004.

[19] E. Hassankhan, Davood A. Khaburi, "DTCSVM scheme for IM fed with a three-level inverter," World Academy of Science, Engineering and Technology, vol. 44, pp. 168-172, 2008.

[20] F. Hamidia, A. Larabi and M.S. Boucherit, “ Comparative Study of the DTC-IM Speed Controller Based on Artificial Intelligence," Computer Technology and Application,vol. 3 ,pp .347-352, 2012 .