DIRECT TORQUE CONTROL FOR MATRIX CONVERTER-FED THREE PHASE INDUCTION MOTOR WITH HYBRID PSO

[1,2]**RUZLAINI GHONI,** [2]**AHMED N. ABDALLA, ZAHIM SUJOD**[2]

[1]Faculty of Electrical Automation Engineering Technology, TATiUC, Terengganu, Malaysia-24000

[2]Faculty of Electrical and Electronic Engineering, UMP, Kuantan, Malaysia -26300

E-mail: hleni@yahoo.com, ahmed@ump.edu.my

ABSTRACT

Direct Torque Control (DTC) for Induction Motors using Matrix Converters is a high performance motor control scheme with fast torque and flux responses. This paper presents a new control scheme based on hybrid particle swarm optimization (HPSO). The main advantages of the matrix converter are combines with those of the DTC technique, generating the required voltage vectors under 0.9 input power factor operations. The results demonstrate the good quality and robustness in the system dynamic response and reduction in the steady-state and transient motor ripple torque.

Keywords: *Hybrid Particle Swarm Optimization (HPSO), DTC-Matrix Converter, Induction Motor*

1. INTRODUCTION

Matrix converters as induction motor drivers have received considerable attention in recent years because of its good alternative to voltage-source inverter pulse width modulation (VSI-PWM) converters. In reality, the matrix converter provides important benefits such as bidirectional power flow, sinusoidal input current with adjustable displacement angle (i.e. controllable input power factor), and a great potential for size reduction due to the lack of dc-link capacitors for energy storage [1-4].

Direct torque control (DTC) method has becomes one of the high performance control strategies for induction motor to provide a very fast torque and flux control [5]. It is the direct control of torque and flux of an electrical motor by the selection through a look-up table, of the power converter voltage space vectors. The main advantage of DTC is its structure simplicity, since no coordinate transformations, current controllers and PWM are needed. Moreover the controller does not depend on motor parameters. DTC is considered to be a simple and robust control scheme which achieves quick and precise torque control response. For such advanced reasons, the combination of the advantages of the matrix converter with those of the DTC method is effectively possible [6]. However, some research is still being done to reduce the electromagnetic torque ripple, which is its main drawback that leads to the raising stator current distortion noise [1]. The following methods are applied to improve the effects of the ripple on the torque output: fuzzy logic controller, multilevel inverter, the modulation methods of the SVM [7-9] and so on. Using the above methods always increases the complication of the system structure and burdens the workload of the DSP because of complicated calculations such as square root and trigonometric functions algorithm are involved. It is crucial to keep the short sampling period time in order to maintain the electromagnetic torque ripple within an acceptable hysteresis band [10]. It is difficult to implement DTC using common IC hardware. The DTC algorithm is usually implemented by serial calculations on a DSP board. However, as a predictive control scheme, the DTC has a steady-state control error produced by the time delay of the lengthy computations, which depends largely on the control algorithm and hardware performance. A typical DSP (TMS32010) execution time of the DTC algorithm for a VSI-fed induction motor is more than 250µs [11]. ANN has faster parallel calculation and more simple circuit structure, so it is superior to a DSP board in execution time and hardware structure. The execution time of neural devices is less than 0.5µs (analogue) or 0.8µs (digital) per neuron [12]. So, DTC of VSI fed induction motor based on ANN had been pointed out [13, 14]. Moreover, the designers must possess plentiful experiences on related theories.

In this paper, a new DTC control for matrix converter with hybrid PSO (HPSO) is proposed which allows under the constraint of unity input power factor, the generation of the voltage vectors required to implement the DTC of three phase induction motor. Depending on the induction motor operating point such vectors might be applied and consequently the electromagnetic torque ripple is reduced. Experimental results demonstrate the effectiveness of the proposed control scheme was presented. Both, steady-state and transient behaviour have been investigated.

2. DTC BASED HPSO INDUCTION MOTOR CONTROLLER ANN PARAMETERS

The DTC using a multilevel inverter can produce more sets of space vector to control torque and flux of a motor and gain more smooth electromagnetic torque of the motor. However, the multilevel inverters need more power switch elements and cause more cost and complication to the whole system [15]. Due to the property of a matrix converter, there are more sets of space vectors can be applied to DTC. As a result, the drive systems fed by the matrix converter that need not any additional power switch element can attain the same performance as the multilevel inverter.

Figure 1 shows the general control scheme proposed for the DTC-based HPSO induction motor matrix converter. In this scheme the two comparators with hysteresis used in the standard DTC configuration to control flux and torque were replaced by HPSO working as equivalent of PI controllers whose output were fed to space vector modulator (SVM). The HPSO stator flux controller loop provided the input V_x and the HPSO torque controller loop provided the input V_y to the SVM. The SVM combined V_x and V_y inputs with the estimated stator flux position and the converter input voltage to modulate the required output voltage vector in the matrix converter.

The proposed system took into account the DTC operating principle and the overall induction motor behaviour and used an AI controller that directly performed the motor control functions.

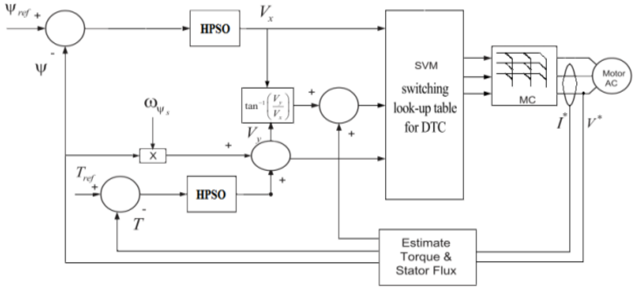
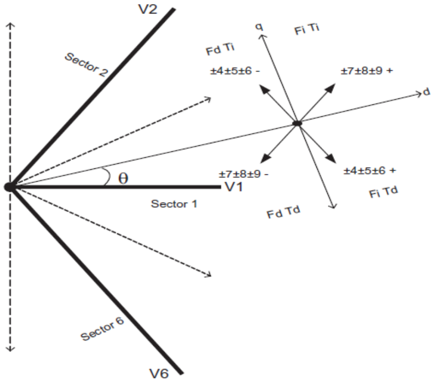
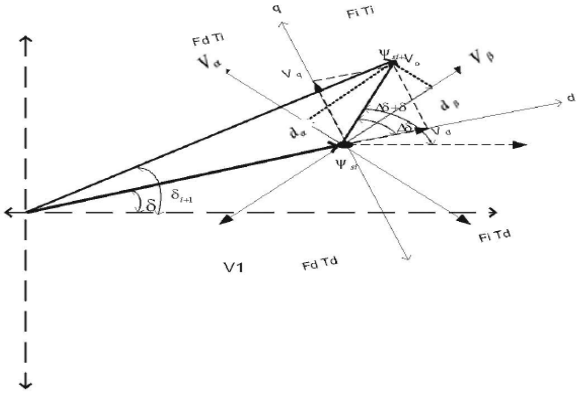


Figure 1: DTC-based Hybrid PSO

Figure 2(a) shows the situation presented when the flux space vector is in sector 1, presenting the effect that each stator voltage vector, if applied in this situation, would have on the torque and flux. Figure 2(b) shows in detail the effect that the selection of a particular voltage vector, voltage vector 2 in this case, would have, taking into account the present stator flux space vector. In this situation the quadrature component of space voltage vector 2 will increase the torque, while its direct component will increase stator flux. The linkage between stator flux space vector position and the actual effect produced by the stator voltage vector are the reasons why it is necessary to decouple the torque and stator flux feedback loops, in such a way that the selection of the next space voltage vector to be applied to the machine is influenced in the quadrature component by the torque error and in the direct component by the flux error.



(a)



(b)

Figure 2: (a) Standard DTC control scheme basic vector diagram (b) Vector diagram showing the stator voltage V2 d-q components

The physical relationship between the variables to be considered can be found working from the induction motor stator circuit equation in the stator frame of reference;

$$\vec{V_S} = R_S \,.\, i_S + \frac{d}{dt}\vec{\varphi_S} + j\omega_{\varphi S} \,.\varphi_S \qquad (1)$$

If flux orientation is such that $\vec{\varphi_S} = \varphi_S$ then the flux dynamic amplitude will be given by the real part of equation (1) as follows:

$$\frac{d}{dt}\varphi_S = V_{Sd} - R_S i_{Sd} \qquad (2)$$

Hence the direct component of the stator voltage vector V_{Sd} directly controls the stator flux. In this conditions torque is a function of the stator current quadrature component:

$$T_e = 1.5\, p \,.\varphi_S i_{Sq} \qquad (3)$$

From equation (1) and (3):

$$T_e = 1.5p \,.\, \varphi_S \left(\frac{V_{Sq} - w_{\varphi S} \,.\varphi S}{R_S}\right) \qquad (4)$$

Hence the stator vector quadrature component can be used for torque control, with an adequate decoupling between the flux and torque control functions. It is necessary then to use the flux and torque errors as inputs to the HPSO controllers that will determine the direct and quadrature components of the new stator voltage vector. To increase the system information level, the flux space vector rotational speed is calculated as the time derivative of the flux space vector position. This can be used to give an element of acceleration to the calculation of quadrature voltage vector component, increasing the torque controller robustness.

The voltage vector components were combined to produce a vector with a magnitude V_{Si} and an angle $\Delta\delta$ measured from the flux vector position. The HPSO controller was able to directly set a limit to the direct and quadrature stator vector components, but the output angle must be referred to the stator reference frame.

In order to do this the calculated phase angle $\Delta\delta$ must be added to the estimated flux space vector angle in the SVM modulator block. Stator resistance was used in flux and torque estimations. The stator voltage vector control law is given by:

$$V_{Sd} = HPSO\,(k_{p\varphi} . e_{\varphi S} + \int k_{i\varphi} \,. e_{\varphi S} d_t) \qquad (5)$$

$$V_{Sq} = HPSO\left(k_{pT_e} . e_{\varphi S} + \int k_{iT_e} \,. e_{\varphi S} d_t\right) + w_{\varphi S} \,.\varphi_S \qquad (6)$$

$$\vec{V_S} = V_{Sd} + jV_{Sq} \qquad (7)$$

Where the term HPSO in each equation denotes the value of each HPSO output, the estimated torque was subtracted from the torque reference and the result was the input to the HPSO controller, whose output wass defined both by the error history and by the last converter output state.

PSO and GA have been used to perform a wide range of optimization problems [11]. Each particle in the swarm represents a multicast tree. The population of permutation-based chromosomes $\{c_p = [c_p^1, \ldots\ldots, c_p^N], p = 1, \ldots., P\}$ was initialized by employing a hybrid of random and deterministic approaches, where *P* is known as the population size. In order to produce the deterministic solution, the DTC algorithm was tested first and the corresponding flux and torque errors subsequently added to the HPSO stator flux and torque controller, which serves as the deterministic population for the proposed HPSO approach.

3. RESULT AND DISCUSSION

In order to certify both, steady state and transient behavior of the proposed algorithm some simulation has been carried out. The three phase induction motor has the following parameters:

V=240V, f=50Hz, R_s=1.4576Ω, R_r= 0.9023Ω, L_s= 151.2 mH, L_r=163.76 mH, Lm=124.98mH, P=4

A. *Steady State*

The steady state of stator flux and Electromagnetic Torque in Figure 3 and Figure 4 shown the proper control which was kept with the reference value (1000rpm and 6.5Nm).

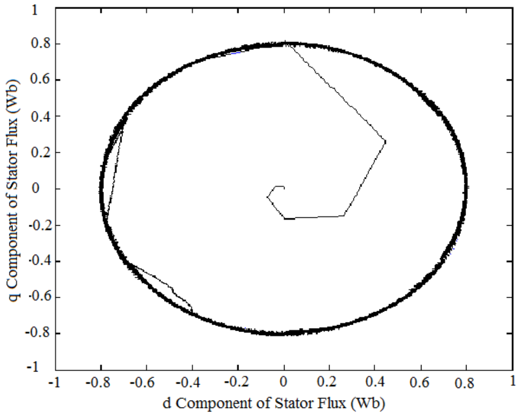


Figure 3: Stator flux trajectory at 1000 rpm and 6.5Nm

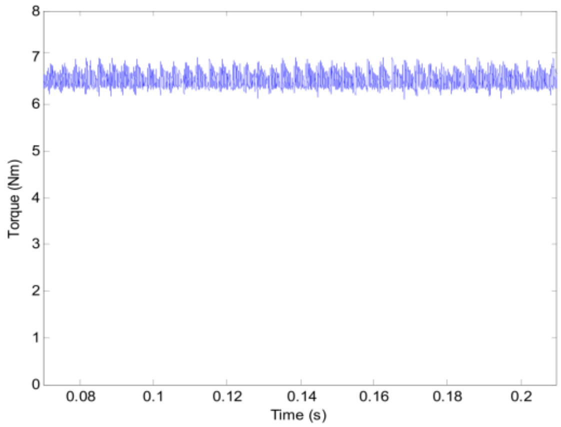


Figure 4: Electromagnetic Torque

A. *Dynamic behavior*

Fig.5 the dynamic behavior has been tested under the speed change.

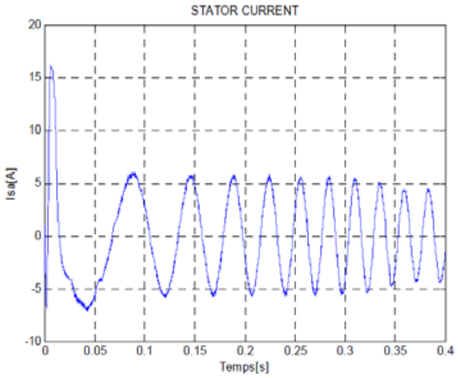


Figure 5: Stator current with speed changes 25% rpm with 3Nm

4. CONCLUSION

The proposed controller in this paper used the information provided by the torque and stator flux errors to modify the standard DTC voltage vector selection process. The voltage vector selected in the new HPSO scheme is the one producing the lowest possible start-up stator current and a reduced torque ripple hence improving the standard DTC scheme performance. Comparing with the DSP serial calculations of the DTC system for matrix converter induction motor, the control precision of DTC can be significantly improved by using the HPSO algorithm. Another hand, the HPSO induction motor model allows the estimation of important parameters of motor such as speed, stator flux, rotor flux and torque without using the sensors. The results obtained show a good torque response for 0.9 power factor operation.

REFERENCES:

[1] A. Alesina, M.G.B.V., "Analysis and Design of Optimum-Amplitude Nine – Switch Direct AC-AC Converters." *IEEE Trans. on Power. Electronic*, 4 (1989)

[2] D. Casadei, G.S., A. Tani, and L. Zari, "Matrix Converters Modulation Strategies: A New General Approach Based on Space-Vector Representation of the Switch State." *IEEE Trans. on Industrial Electronic*, 49(2) (2002)

[3] P. W. Wheeler, J.R., J. C. Claire, L. Empringham, A. Weinstein, "Matrix Converters : A Technology Review." *IEEE Trans. on Industrial Electronic*, 49(2) (2002)

[4] Ruzlaini Ghoni, Ahmed N.Abdalla, Zulkarnain Lubis, Mohd Nuhairi, Mohd Yusri "Performance Analysis of Difference Matrix

Converter Topologies on Three Phase Induction Motor Drives", *in 2nd International Conference On Engineering Technology*, 2009

[5] Hong-Hee Lee, H.M.N., Tae-Won Chun and Won-Ho Choi. "Implementation of Direct Torque Control Method Using Matrix Converter Fed Induction Motor." *In IEEE*, 2007

[6] Der-Fa Chen, C.-W.L., Kai-Chao Yao. "Direct Torque Control for a Matrix Converter Based on Induction Motor Drive Systems" *in IEEE* 2007

[7] Kazmierkowski, G.S.B. and .M.P., "Direct Torque Control of PWM Inverter-Fed AC Motors-A Survey". *IEEE Trans. on Industrial Electronics*, 51(4) (2004) pp 744-758

[8] Casadei, D.S., G. Tani, A., "Implementation of a Direct Torque Control Algorithm for Induction Motors Based on Discrete Space Vector Modulation." *IEEE Trans. on Power Electronics*, 15(4) (2000) pp 769-777

[9] Lascu, C.B., Blaabjerg F., "A Modified Direct Torque Control for Induction Motor Sensorless Drive." *IEEE Trans. on Industry Applications*, 36(1) (2000) pp 122-130

[10] Kazmierkowski, G.S.B.a.M.P., "Direct Torque Control of PWM Inverter-Fed AC Motors-A Survey." *IEEE Trans. on Industrial Electronics*, 51(4) (2004) pp 744-758

[11] T. G. Habetler, F.P., M. Pastorelli, L. M. Tolbert, "Direct Torque Control of Induction Machines Using Space Vector Modulation", *IEEE Trans. on Ind. Appl*., (20) (1992)

[12] M. E. Zaghloul, J.L.M., and R. W.Newcomb, ed. "Silicon Implementation of Pulse Coded Neural Networks." Kluwer Academic Publishers, 1994

[13] K. L. Shi, T.F.C., Y. K. Wong, "Direct Self Control of Induction Motor Based on Neural Network." *IEEE Trans. on Ind. Appl.*, 37(5) (2001)

[14] P.Q.Dung, H.T.N.T., "Direct Torque Control for Induction Motor using ANN", *in The 2004 International Symposium on Advanced Science and Engineering*. 2004, pp 60-63

[15] C. Martins, X.R., T. A. Maynard, and A. S. Caryalho, "Switching Frequency Imposition and Ripple Reduction in DTC Drives by Using a Multilevel Converter." *IEEE Transactions on Power Electronics*, (17) (2002) pp 286-297