

Full Length Research Paper

DTC torque ripple minimization based on PSO-PID controller

Hassan Farhan Rashag¹, S. P. Koh¹, Ahmed N. Abdalla^{2*}, Nadia M. L. Tan³, K. H. Chong¹ and S. K. Tiong¹

¹Department of Electronics and Communication Engineering, Universiti Tenaga Nasional, Selangor 43000, Malaysia.

²Faculty of Electrical and Electronic Engineering, University Malaysia Pahang, Pekan 26600, Malaysia.

³Department of Electrical Power Engineering, Universiti Tenaga Nasional, Selangor 43000, Malaysia.

Accepted 11 March, 2012

In conventional direct torque controlled (DTC) induction motor drive, there is usually undesired torque and flux ripple. The given torque is the speed output regulator; therefore, it necessarily continues tuning for adjusting parameters K_p , K_i . In conventional proportional- integral (PI) speed controller, the performance of motor may differ over time that may cause unexpected torque disturbances, causing sluggishness of a control system. Tuning PID parameters are essential to DTC system to improve the performance of the system at a low speeds. In this paper particle swarm optimization (PSO) proposed to correct the parameters (K_p , K_i) of a speed controller in order to minimize torque ripple, flux ripple, and stator current distortion. Firstly, introduce brief description for conventional DTC design and PSO. Secondly, close loop speed controller in DTC for induction motor using PSO technique to provide high performance of accuracy. Finally, simulation results demonstrate that a reduction of torque and flux ripples is achieved in a whole speed range.

Key words: Particle swarm optimization, PID controller, direct torque control.

INTRODUCTION

Today, besides the growth in technology and the immediate improvement in power devices, perfect and reliable parameters are significant for the drawing and development of the high-performance induction motor drive system. However, the practice demands precise parameters of PI- speed controller in direct torque control to reach exceptional performance with high-quality correctness and widespread reasonableness.

Various researchers have done a lot of investigate on optimization parameters of PID controller. PSO has been practical productively in different optimization problems. One of the earliest applications of PSO was in the preparation of feed-forward neural networks (FFNN) (Eberhart and Kennedy, 1995; Zhao et al., 2005).

However, a few researches are still being completed to diminish the electromagnetic torque ripple, and this main problem leads to the increment of the stator current distortion noise (Hong-Hee Lee et al., 2007). Artificial neural networks (ANN) can be used to design mathematical controllers in order to keep on high dynamic performances and toughness and low speeds even when detuning occurs (Sung-Hoe Huh et al., 2005). However, this method is not ideal in on line real time performance. DTC also presents some drawbacks, including large torque ripple, variable switching frequency, and acoustic noises, among others (Buja et al., 2004). It is possible to directly control the stator flux and the electromagnetic torque by the selection of optimal inverter switching modes (Casadei et al., 2002) but this technique encounter problem like variable switching frequency at high sample time. The active vector is obtained from the conventional switching table,

*Corresponding author. E-mail: dramaide@yahoo.com.

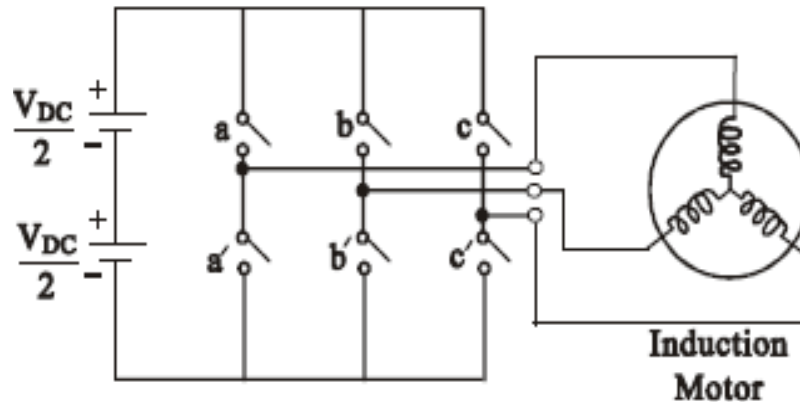


Figure 1. Circuit diagram of induction motor connected to an inverter.

and the duty ratio is determined according to various principles, including torque-ripple minimization (Morales and Pacas, 2008; Abad et al., 2008; Shyu et al., 2010) fuzzy-logic adaptation (Romeral et al., 2005), equalizing the mean torque with the reference value over one cycle (Pacas and Weber, 2005; Kang and Sul, 1999). These methods are complicated and require lots of motor parameters. Several methods are employed to decrease the harmonics on the level of the torque and flux. Fuzzy logic strategy has been planned for speed control in vector control induction motor drives and shared with neural networks; a hybrid adaptive neurofuzzy controller has also been presented for speed control (Jia-Qiang and Jin Huang, 2005) and genetic algorithm optimal voltage space vector is achieved using genetic algorithm (GA) based neural network (Veena et al., 2009). Nevertheless, all have some disadvantages such as GA needs a big computational complexity. Fuzzy system requires many parameters for optimization, structure and parameters of neural network do not have a common standard to confirm. Douiri et al. (2010) proposed the performance of the sensorless speed control of induction motor using a speed proportional integral (PI) neural networks controller.

The artificial neural network then replaces the switching table of the conventional while the rotation speed is estimated by the MRAS method. Brahim et al. (2011) used two fuzzy logic regulators have been used to replace the classical PI regulators fuzzy (space vector modulation direct torque control) strategy for induction machine based on indirect matrix converters. Zheng Li and Ruan Y, (2010) suggested a novel control method with wavelet neural networks (WNN) is applied to direct torque and flux control over the induction motor drives. The WNN controller with the structure of NARMA is utilized as a speed controller to control the torque.

This paper proposes a high performance for direct torque control using particle swarm optimization for optimization of PID parameters. The induction motor

used in this proposed scheme is a 2.2 kw, 4 pole, 420 V. Finally; the simulation results demonstrate the validity of proposed method by minimizing torque error and stator flux with torque free of ripple at a low speed.

THEORETICAL BACKGROUND

Modeling of induction motor

The power circuit of the three-phase induction motor is shown in the Figure 1. The stator voltage equation in the d-q reference frame can be described as (Ashok et al., 2009).

$$V_{sd} = R_s i_{sd} + \frac{d}{dt} \lambda_{sd} - \omega_d \lambda_{sq} \quad (1)$$

$$V_{sq} = R_s i_{sq} + \frac{d}{dt} \lambda_{sq} - \omega_d \lambda_{sd} \quad (2)$$

The equations of rotor voltage in the direct and quadrature reference frame are shown.

$$V_{rd} = R_r i_{rd} + \frac{d}{dt} \lambda_{rd} - \omega_{dA} \lambda_{sq} \quad (3)$$

$$V_{rq} = R_r i_{rq} + \frac{d}{dt} \lambda_{rq} - \omega_{dA} \lambda_{sd} \quad (4)$$

The electromagnetic torque of induction motor is given by Equation (5).

$$T_{em} = \frac{3P}{2} L_m (i_{sq} i_{rd} - i_{sd} i_{rq}) \quad (5)$$

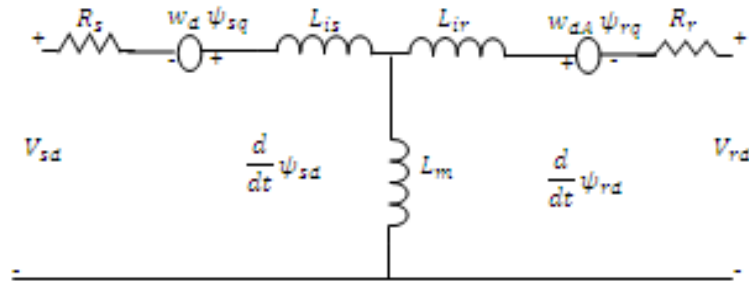


Figure 2. Equivalent circuit of induction motor in d- frame.

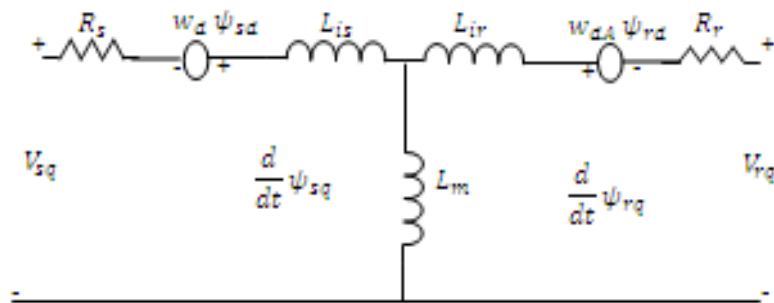


Figure 3. Equivalent circuit of induction motor in q-frame.

Where the flux linkage variables are defined in the equations as follows:

$$\lambda_{sd} = L_s i_{sd} + L_m i_{rd} \tag{6}$$

$$\lambda_{sq} = L_s i_{sq} + L_m i_{rq} \tag{7}$$

$$\lambda_{rd} = L_m i_{sd} + L_r i_{rd} \tag{8}$$

$$\lambda_{rq} = L_m i_{sq} + L_r i_{rq} \tag{9}$$

Where:

R_s, R_r are stator and rotor resistances; L_s, L_r, L_m are stator, rotor and mutual inductances; $\lambda_{sd}, \lambda_{sq}$ are stator flux in d-q frame; $\lambda_{rd}, \lambda_{rq}$ are rotor flux in d-q frame; $i_{sd}, i_{sq}, i_{rd}, i_{rq}$ are stator and rotor currents in d-q frame and P is number of poles.

The equivalent circuits of induction motor in the direct and quadrature reference frame are shown in Figures 2 and 3 respectively.

Direct torque control

DTC consists of two independent hysteresis comparators as shown in Figure 4 which is producing the error signal

of stator flux and electric torque. It does not need complicated coordination transformations and decoupling calculation. It became the mainly accepted controller for controlling induction motors. Its main distinctiveness is the high-quality performance compared to the conventional vector control, and it has some advantages based on its simpler structure and control diagram. It is one of the potential ways of controlling the induction motor. It is achievable to control directly the stator flux and the torques by selecting the suitable inverter state. This method still requires further research in order to improve the motor's performance, as well as achieve a better behavior environmental compatibility (Electro Magnetic Interference and Energy), that is preferred for all manufacturing applications (Yattana et al., 2008)

PID controller

The PID controller is the most common form of feedback control. It is used within the process industries, and it consists of proportional, integral, derivatives (K_p, K_i, K_d). The proportional gain minimizes settling time and steady-state error. The integral gain increases both overshoot and settling time but it eliminates steady state error. In contrast, the derivative gain decreases both overshoot and settling time. It still has a large range of applications

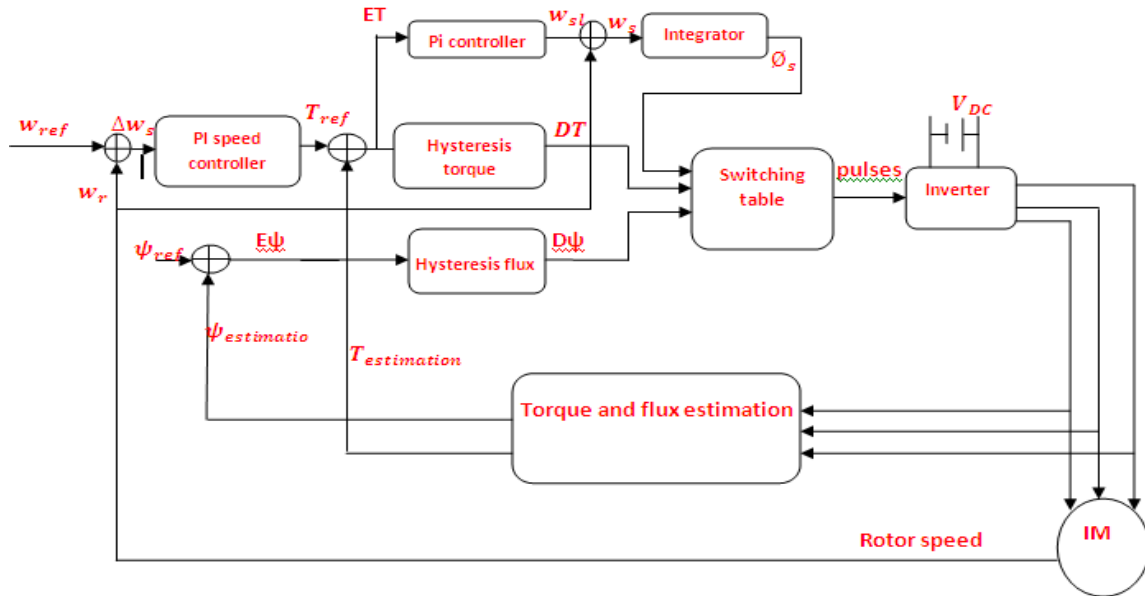


Figure 4. Block diagram of direct torque control.

in engineering control. Virtually, all PID controllers made today are based on microprocessors. This has given opportunities to deliver supplementary features like automatic tuning, gain scheduling, and continuous adaptation.

PSO algorithm

Partical swarm optimization (PSO) was first proposed by Russell Eberhart and James Kennedy (1995). PSO is an evolutionary computation technique motivated by the simulation of social behaviors .Among particles "flying" through a multidimensional search space, each particle representing a single intersection of all search dimensions (Kennedy and Eberhart, 2002).

PSO has two primary operators; velocity and position update. The advantage of the PSO over many of the other optimization algorithms is its relative simplicity and stable convergence characteristic with good computational efficiency. The new velocity value for each particle during each iteration is computed based on its current velocity, the distance from previous best position and from global best position. Therefore, the new velocity is used to calculate the next position of the particle in the search space. This process is iterated until the minimum error is achieved.

The algorithm of PSO in D-dimensional space can be illustrate as follows. Let $X = (x_{1i}, x_{2i}, \dots, x_{Di})$ is the "particle" current position and $V_i = (v_{1i}, v_{2i}, \dots, v_{Di})$ its velocity. The local best location is denoted as $P_{best,i} = (p_{1i}, p_{2i}, \dots, p_{Di})$. Let $P_{gbest} = (p_{g1}, p_{g2}, \dots, p_{gd})$ represent the global best position

of the particles. The velocity can be determined by the following equations:

$$v_{id}^{(k+1)} = h^{(k)} v_{id}^{(k)} + c_1 r_1 (P_{id}^{(k)} - X_{id}^k) + c_2 r_2 (P_{gd}^{(k)} - X_{id}^k) \quad (10)$$

$$X_{id}^{(k+1)} = X_{id}^{(k)} + v_{id}^{(k)} \quad (11)$$

where, $i=1,2,\dots,n$, $d=1,2,\dots,D$; and D is the dimensions number for each particle, c_1, c_2 is constant of acceleration, k is the times of iterative, r_1, r_2 are the two random number with the range of [0,1], h is the inertia weighting factor. the inertia weight is given by Equation (12).

$$h = h_{max} - [(h_{max} - h_{min}) / k_{max}] \times k \quad (12)$$

where h_{max}, h_{min} are the maximum and minimum numbers of iteration respectively and (k) is the present number of iterations.

MATERIALS AND METHODS

A parameter optimization procedure of PID controller becomes more important, especially for speed control in DTC .In this case ,it is impossible to get high performance for speed control in DTC drive without optimizing the $K_p, K_i,$ and K_d parameters by using intelligent techniques .It can be noted there is a difference between the conventional parameters and optimized parameters of direct torque control which will find the exact PID parameters that minimizing the error between estimation torque and reference torque. Speed and flux used as a reference signals in the optimization which contains two processes PID controller and PSO.

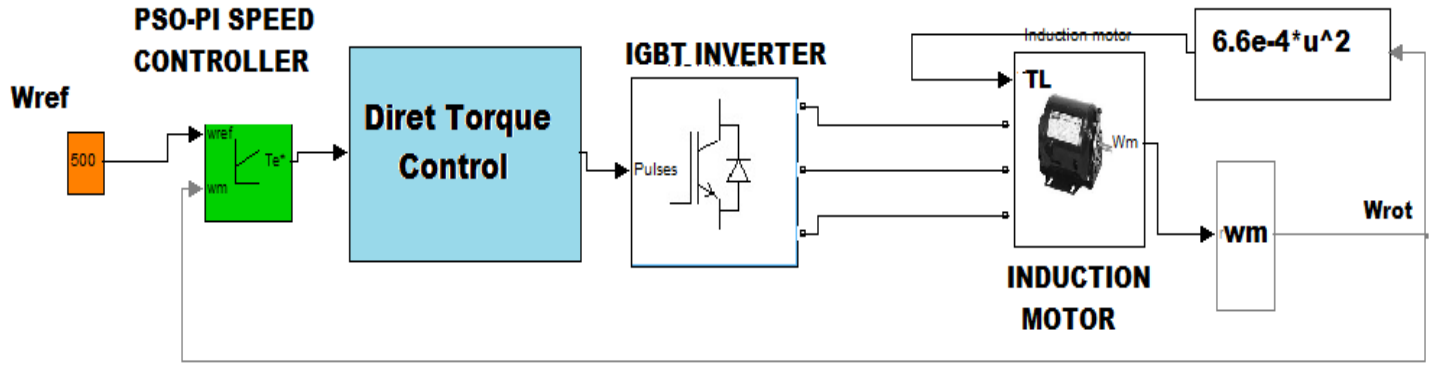


Figure 5. DTC control based on PSO-PID controller.

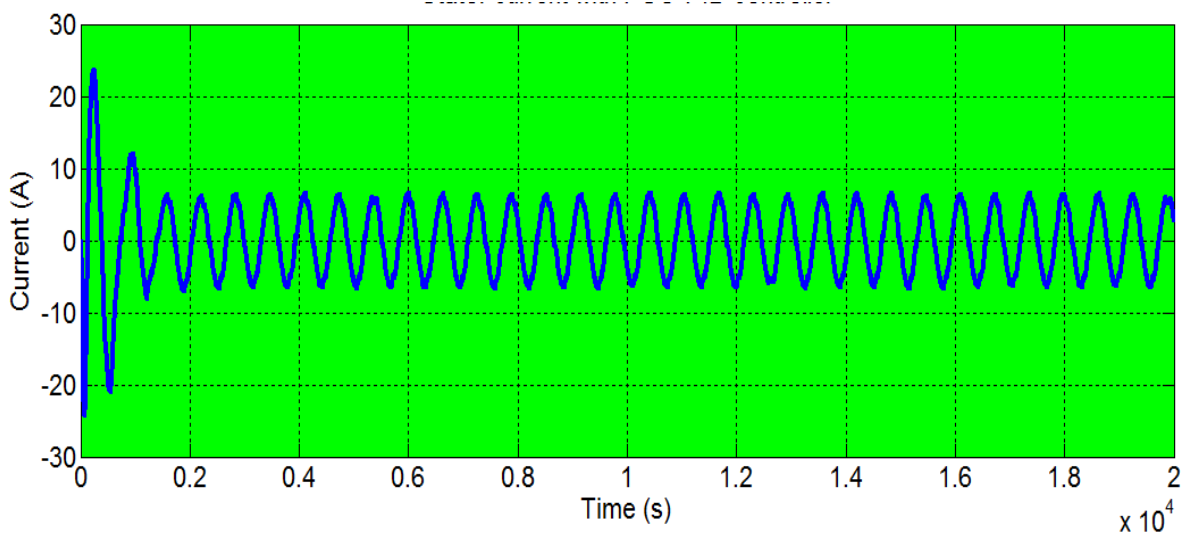


Figure 6. Stator current with PSO-PID controller in DTC.

The procedure used to execute this proposed method can be summarized as follows:

1. Initialize velocity, position, number of iterations, groups of particle, inertia weight and constants.
2. Calculate the fitness function of each particle to measure the system performance.
3. Set the parameters K_p, K_i in speed control of DTC randomly.
4. Compare the fitness value during each iteration for each particle with its location position .if it is better, and then replace it as a current position.
5. Compare the fitness value for each particle in each generation with global position.
6. Update velocity and positions for each particle, which can be calculated by equations.
7. If the number of iteration is not achieved, then return to step 2.
8. The best location by groups to get parameters of PID controller based on particle swarm optimization.

The proposed PSO-PID controller in DTC is shown in Figure 5. The particle swarm optimization adjusting the parameters of PID

controller to minimizing the error between the reference and actual speed to get the reference torque as shown in Equations (13) and (14).

$$e(t) = (W_{ref} - W_{rot}) \tag{13}$$

$$Te^* = PSO \left[\left(K_p e(t) + \frac{1}{T_i} \int e(t) dt \right) \right] \tag{14}$$

Where $e(t)$ is the error speed. W_{ref}, W_{rot} are the reference and rotor speed respectively and Te^* is reference torque.

RESULTS

Figures 6 to 11 show the simulation result of the proposed methods which compared with classical direct torque control.

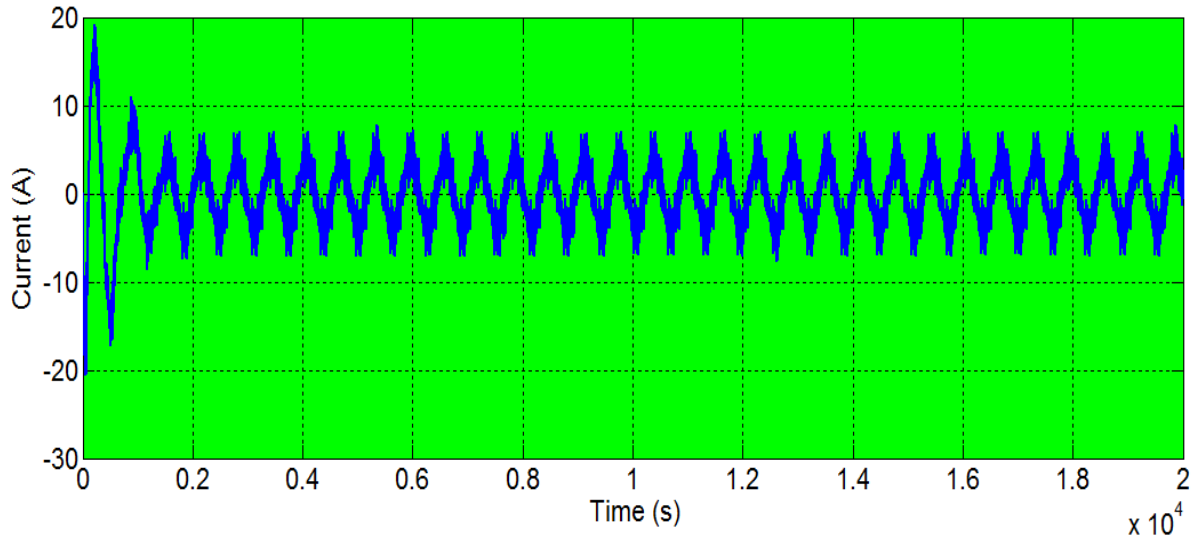


Figure 7. Stator current in DTC without PSO-PID controller.

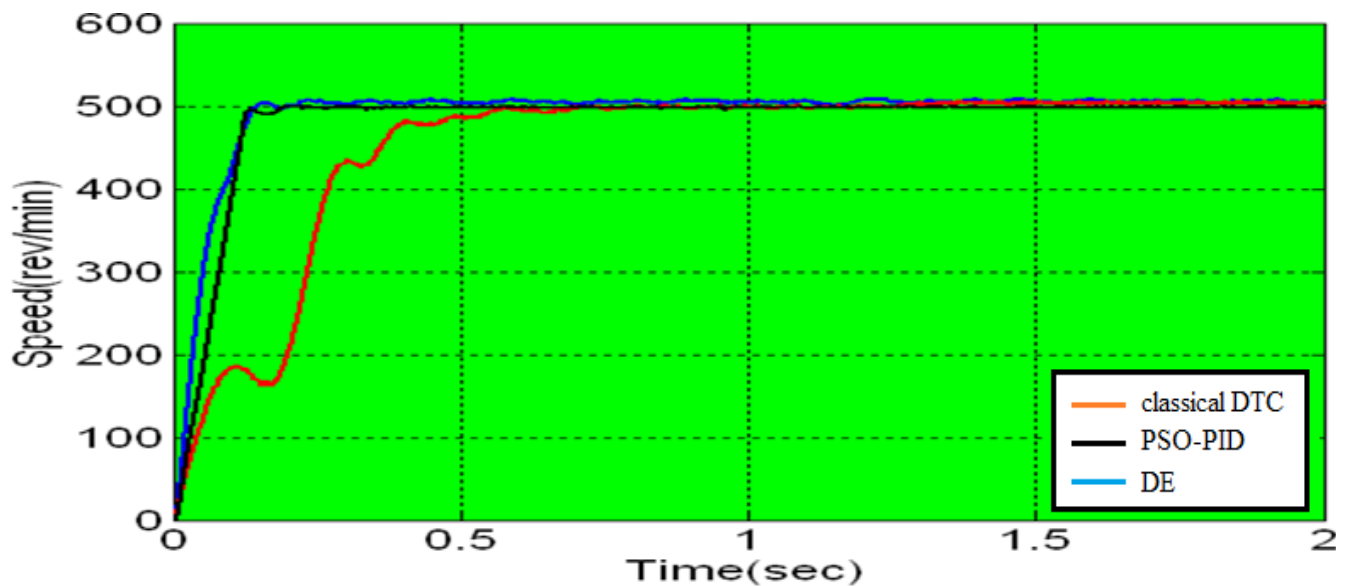


Figure 8. Comparison Speed of induction motor.

DISCUSSION

In order to verify the accuracy and optimization of the parameters (K_p , K_i) for speed controller in DTC by using particle swarm optimization (PSO-PID controller). The proposed method is tested by the Matlab simulation tool. Beside of this, the reference speed is taken as 1500 rpm, reference flux 0.9 Wb with sampling time of 100 μ s. Simulation results demonstrated that the optimization algorithm using particle swarm to tuning PID parameters in the speed controller of DTC is much better than the

conventional method.

To validate the accuracy of proposed method, the stator current of DTC with PSO-PID controller is free of distortion comparing with classical DTC at a low speed (500 rpm) as shown in Figures 6 and 7 respectively.

In addition, it can be noted that the rotor speed in PSO-PID, DE-PID and classical DTC reached the steady-state value within 100, 125 and 600 ms respectively as shown in Figure 8. It was obvious that the torque ripple in the proposed method is almost neglected as shown in Figure 9 in contrast with torque of classical DTC in Figure 10. At

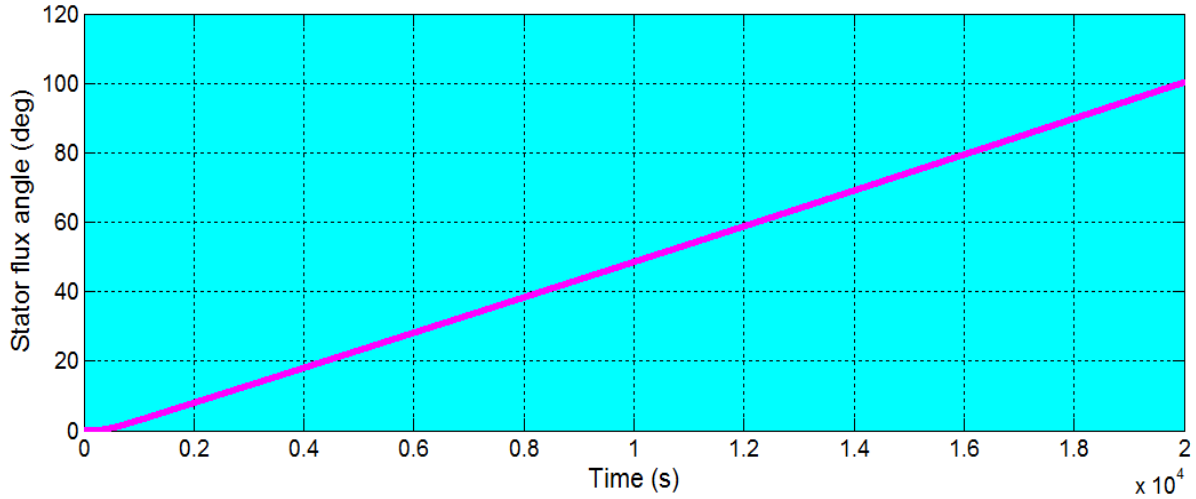


Figure 9. Stator flux angle in DTC with PSO.

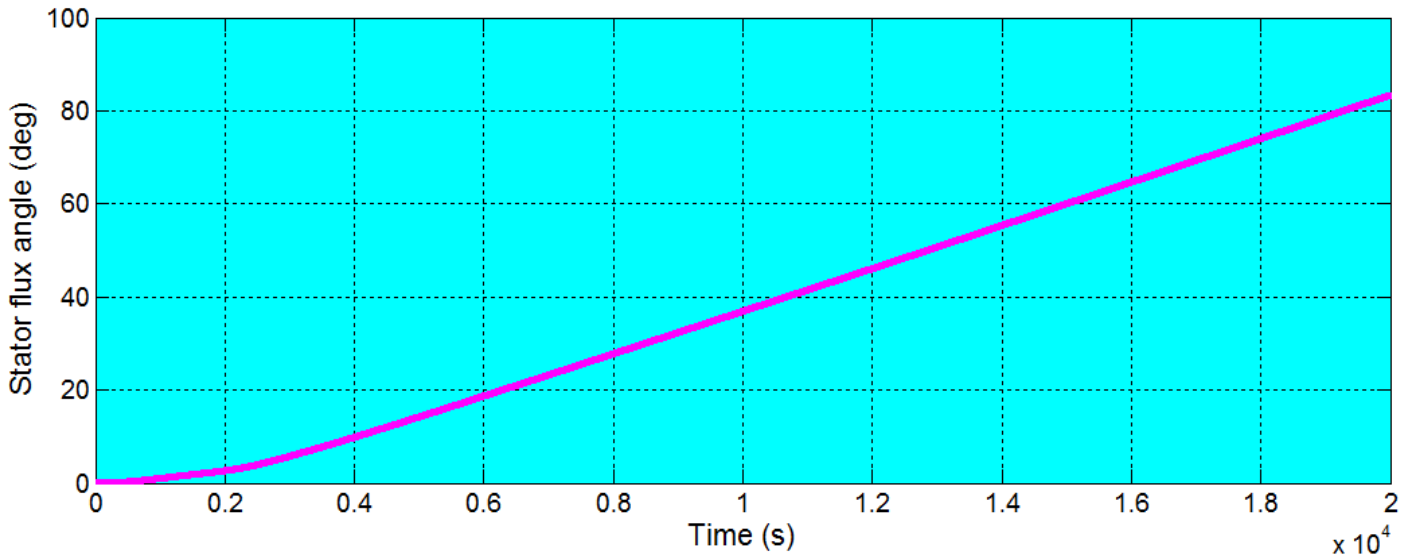


Figure 10. Stator flux angle in classical DTC.

the same time, the stator flux and stator flux angle as shown which described the performance of DTC based on PSO-PID and PID-DE controller have faster response, high accuracy compare to classical DTC and the performance of the whole system is improved as shown in Figure 11.

Conclusion

The proposed method describes behavior of direct torque control based on particle swarm optimization (PSO) by adjusting the parameters of speed control (K_p , K_i) in order

to overcome the drawbacks of DTC and to improve the performance of the whole system especially in low speed. The simulation results of this proposed method certainly can develop the performance of three-phase induction motor by minimizing torque and flux ripples and improve the response of speed with good stabilization. Therefore, PSO is proposed to optimize the parameters of PID controller in speed control of DTC. The total harmonic distortion of stator current is reduced by using PSO-PID controller to optimize the PI speed controller by minimizing the speed error between the reference of rotor speed and actual speed. Finally, the response of this proposed method congregate more

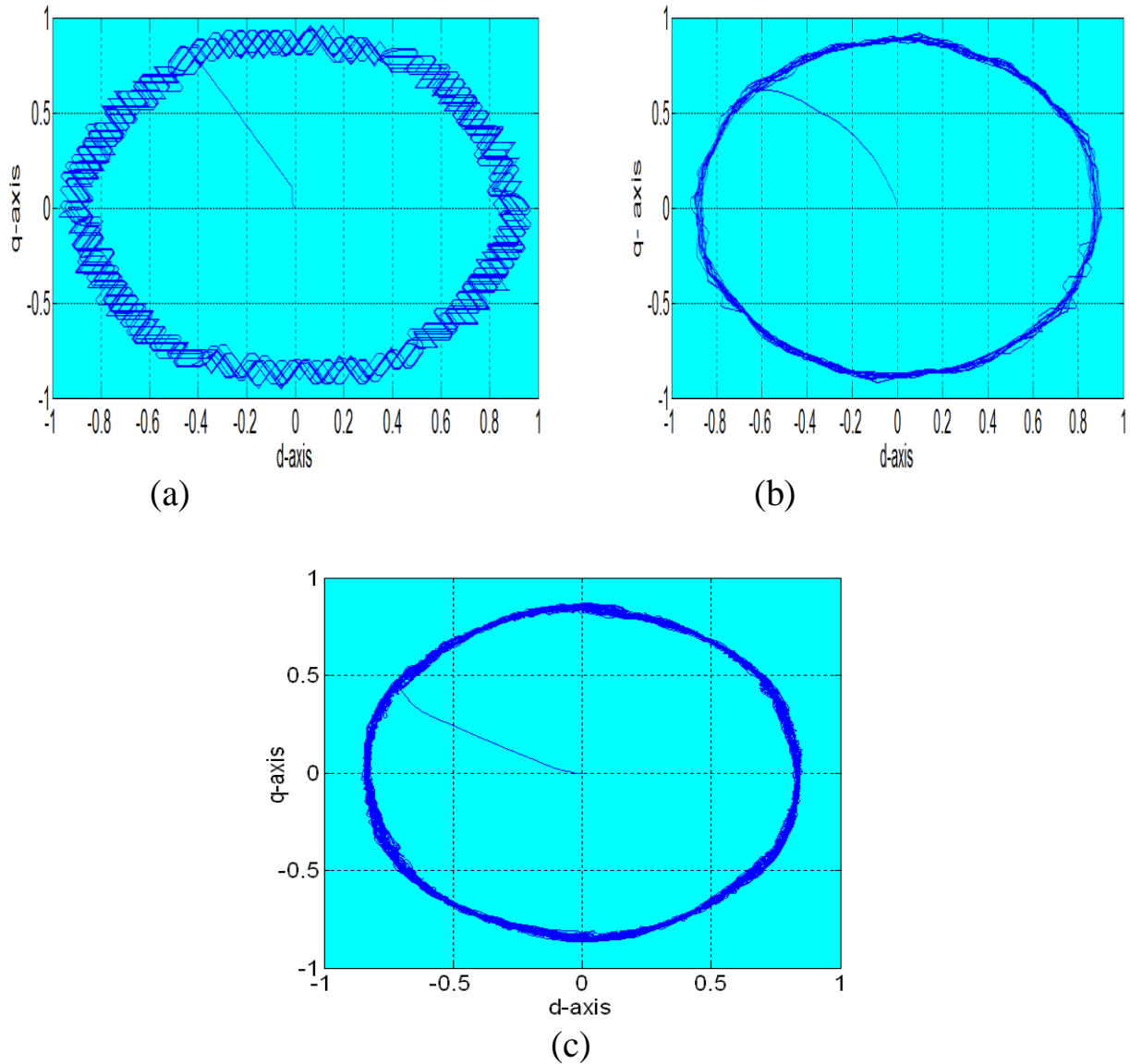


Figure 11. Stator flux in d-q plane (a) Classic DTC (b) PID-PSO (c) PID-DE.

quickly than traditional PID control system .In addition, the PSO-PID controller improves the dynamic response of the whole system.

REFERENCES

- Abad G, Rodriguez MA, Poza J (2008). 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 Trans. Power Electron.*, 23(3): 1050-1061.
- Ashok K, Kodad SF, Sankar RB (2009). Modelling of induction motor and control of speed using hybrid controller technology. *J. Theor. Appl. Inf. Technol.*, pp. 117-125.
- Brahim M, Farid T, Ahmed A, Nabil T, Toufik R (2011). A new fuzzy direct torque control strategy for induction machine based on indirect matrix converter. *Int. J. Res. Rev. Comput. Eng.*, 1(1): 18-22.
- Buja GS, Kazmierkowski MP (2004). Direct torque control of PWM inverter-fed AC motors- A survey. *IEEE Trans. Ind. Electron.*, 51: 744-757.
- Casadei D, Serra G (2002). Implementation of direct torque control algorithm for induction motors based on discrete space vector modulation. *IEEE Trans. Power Electron.*, 15(4): 769-777.
- Douiri R, Nesser T, Essadki A, Cherkaoui M (2010). Direct torque control of induction motor based on artificial neural network with estimation and regulation speed using the MRAS and neural PI controller. *J. Theor. Appl. Inf. Technol.*, pp. 15-21.
- Eberhart RC, Kennedy J (1995). A new optimizer using particle swarm theory. *Sixth Int. Symp. Micro mach. Hum. Sci.*, pp. 39-43.
- Hong-Hee Lee, HoangM, Tae-Won Chun, Won-Ho Choi (2007). Implementation of direct torque control method using matrix converter fed induction motor. *IEEE Int. Forum Strat. Technol.*, pp. 51-55.
- Jia-Qiang Y, Jin Huang (2005). Direct torque control system for induction motors with fuzzy Speed Pi regulator. *Fourth Int. Conf. Mach. Learn. Cybern.*, 2: 778-783.

- Kang JK, Sul SK (1999). New direct torque control of induction motor for minimum torque ripple and constant switching frequency. *IEEE Trans. Ind. Appl.*, 35(5): 1076-1082.
- Kennedy J, Eberhart R (2002). *Swarm intelligence*. Morgan Kaufmann Publishers, San Francisco, CA.
- Morales R, Pacas M (2008). Encoder less predictive direct torque control for synchronous reluctance machines at very low and zero speed. *IEEE Trans. Ind. Electron.*, 55(12): 4408-4416.
- Pacas M, Weber J (2005). Predictive direct torque control for the PM synchronous machine. *IEEE Trans. Ind. Electron.*, 52(5): 1350-1356.
- Romeral L, Arias A, Aldabas E, Jayne M (2005). Novel direct torque control (DTC) scheme with fuzzy adaptive torque-ripple reduction. *IEEE Trans. Ind. Electron.*, 50(3): 487-492.
- Shyu KK, Lin JK, Pham VT, Ming JY, Wang T (2010). Global minimum torque ripple design for direct torque control of induction motor drives. *IEEE Trans. Ind. Electron.*, 57(9): 3148-3156.
- Sung-Hoe Huh, Kyo -Beum Lee, Dong-Won Kim, Ick Choy, Gwi-Tae Park (2005). Sensor less speed control system using a neural network. *Int. J. Control, Autom. Syst.*, 3: 612-619.
- Veena P, Jeyabharath R, Rajaram M, Sivanandam SN (2009). Genetic neuro controller based direct torque control for switched reluctance motor drive. *Int. Conf. Man-Mach. Syst.*, pp. 2B51-2b56.
- Yattana K, Suttichai P, Hamid AT (2008). Modified direct torque control method for induction motor drives based on amplitude and angle control of stator flux. *Science Direct, Elect. Power Syst. Res.*, 78(10): 1712-1718.
- Zhao F, Ren Z, Yu D, Yan Y (2005). Application of an improved particle swarm optimization algorithm for neural network training. *IEEE Int. Conf. Neural network Brain*, pp. 1693-1698.
- Zheng H, Ruan Y (2009). A novel control method based on wavelet neural networks for direct torque control in induction motor drives. *IEEE Int. Conf. Elect. Mach. Syst.*, 9: 3967-3972.