

DTC Flux and Torque ripple minimization based on PSO-PI Controller

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ABSTRACT: This paper presents a new direct torque control (DTC) strategy for induction motor based on particle swarm optimization (PSO). In conventional direct torque controlled (DTC) induction motor drive, there is usually undesired torque and flux ripple. So Tuning PI parameters (K_p , K_i) are essential to DTC system to improve the performance of the system. In this work, particle swarm optimization (PSO) is proposed to adjust the parameters (K_p , K_i) of the speed controller in order to improve the performance of the system (Torque and Flux ripple minimization), and run the machine at reference speed.

KEYWORDS: Direct torque control, PI controller, Particle swarm optimization.

I.INTRODUCTION

AC induction motors are the most common motors used in industrial motion control systems, as well as in domestic applications. Simple and rugged design, low-cost, low maintenance and direct connection to an AC power source are the main advantages of AC induction motors. Controlling the speed of an induction motor is far more difficult than controlling the speed of a DC motor since there is no linear relationship between the motor current and the resulting torque in the case of a DC motor. There are several methods to vary the speed of an induction motor over a wide range. The most modern technique is direct torque control method (DTC). The DTC offers many advantages like fast torque response, no need of coordinate transformation and less dependence on the rotor parameters. The conventional PI (proportional, integral) control method is widely used in motor control system due to the simple control structure and easiness of design. However tuning the parameters of PI controller is a difficult task. To enhance the capabilities of traditional PI parameter tuning techniques, several intelligent approaches have been suggested such as genetic algorithms (GA) and the particle swarm optimization (PSO).

Particle Swarm Optimization (PSO) is one of the modern algorithms used to solve global optimization problems. Thus, to solve an optimization problem, PSO applies a simplified social model. Compared to other methods, application of the PSO is simple to implement, it can quickly find a number of high quality solutions, and has stable convergence characteristics. The PSO method is an excellent optimization methodology and a promising approach for solving the optimal PI controller parameters problem.

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Vol. 6, Issue 11, November 2017

II. MATHEMATICAL MODELING OF INDUCTION MOTOR

Mathematical modelling of the induction motor been done based on the equations (1) – (5).

$$V_{qs} = R_s i_{qs} + \frac{d}{dt} \phi_{qs} \quad (1)$$

$$V_{ds} = R_s i_{ds} + \frac{d}{dt} \phi_{ds} \quad (2)$$

$$0 = R_r i_{qr} + \frac{d}{dt} \phi_{qr} - \omega_r \phi_{dr} \quad (3)$$

$$0 = R_r i_{dr} + \frac{d}{dt} \phi_{dr} + \omega_r \phi_{qr} \quad (4)$$

$$T_e = \frac{3}{2} \left(\frac{p}{2} \right) (\phi_{ds} i_{qs} - \phi_{qs} i_{ds}) \quad (5)$$

III. CONVENTIONAL DIRECT TORQUE CONTROL

A. DTC STRATEGY:

Field Oriented method decouples stator current vector into d-q components. FOC duplicate the DC motor dynamics. Unlike FOC, DTC does not duplicate the DC motor dynamics, but DTC method chooses the voltage vectors according to the demanded flux and torque in order to keep them within hysteresis bands.

The torque developed by the induction motor is given by

$$T_e = \frac{3}{2} \frac{p}{2} \frac{L_m}{\sigma L_s L_r} |\overline{\lambda}_s| |\overline{\lambda}_r| \sin\theta \quad (6)$$

From the above equation we can say that the torque produced by the induction motor depends upon the stator flux, rotor flux and phase angle between them.

The induction motor stator voltage equation is given by

$$\overline{V}_s = \frac{d\overline{\lambda}_s}{dt} - \overline{I}_s r_s \quad (7)$$

Change in flux can be expressed as

$$\Delta \overline{\lambda}_s = \overline{V}_s \Delta t \quad (8)$$

This means that the voltage vector changes the flux vector. It is well know that two level inverter is capable of producing eight voltage vectors. A switching table is generated which determines the voltage vector that has to be applied. The selection of the voltage vector depends on the position of the stator flux and torque. Voltage vector selection table can be expanded to include more number of voltage vectors by three level inverter. The use of PI controllers to command a high performance DTC of induction motor drive is often characterized by an overshoot during start up. This is mainly caused by the fact that the high value of the PI generates a positive high torque error. This will let the DTC scheme take control of the motor speed driving it to a value corresponding to the reference stator flux. At start up, the PI controller acts only on the error torque value by driving it to the zero borders. When this border is crossed, the PI controller takes control of the motor speed and drives it to the reference value. Another main problem of the Conventional PI controller is the correct choice of the PI gains . Traditional PI controller using fixed gains may not provide the required control performance for the reason that the induction motor parameters are changing on different operating conditions. To tune the PI controller, lots of strategies have been proposed. The most famous, which is frequently used in industrial applications, is the Ziegler-Nichols method which does not require a system model and control parameters are designed from the plant step response. Tuning using this method is characterized by a good

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disturbance rejection but on the other hand, the step response has a large percentage overshoot in addition to a high control signal that is required for the adequate performance of the system. Another technique uses frequency response methods to design and tune PI controller gains based on specified phase and gain margins as well as crossover frequency. Furthermore, root locus and pole assignment design techniques are also proposed in addition to transient response specifications. All these methods are considered as model based strategies and then the efficiency of the tuning law depends on the accuracy of the proposed model as well as the assumed conditions with respect to actual operating conditions. All these techniques takes a more time for tuning the PI controller. To overcome the stated problems, an adaptive PI controller has been proposed to replace the classical PI controller where the proportional and integrator gains are tuned by the Particle Swarm Optimization (PSO).

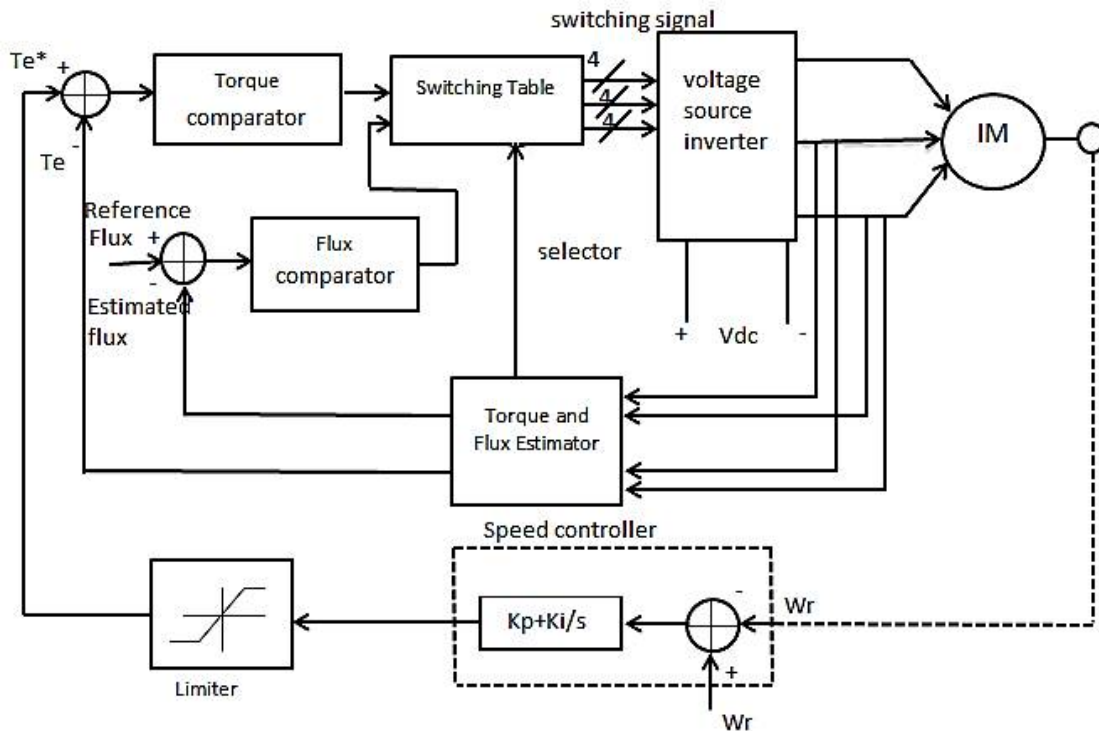


Fig 1. Conventional DTC of Induction motor.

IV. PSO ALGORITHM

A. Step.1 initialization

- i. Determine the particle size m and set the values of parameters $c1$ and $c2$. Initialize weight factor w .
- ii. Randomly generate the particles to be the candidate solutions to the optimization problem called Population vector.
The size of Population vector $(pv) = [k_p \ k_i] m \times 2$.
Where m = particle size.

Population vector (PV) is generated by using the formula

$$PV = k_p \min + (\text{rand}(m, 1) * (k_p \max - k_p \min)).$$

Substitute this data in objective function to obtain fitness vector.

Fitness vector = $[\] m \times 1$.

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Vol. 6, Issue 11, November 2017

B. Step.2 velocity vector calculation $v(t)$

In the original version of PSO, each component of velocity vector is kept within the range $[-V_{max}, V_{max}]$.

$$V_{max} = (k_p \cdot \max - k_p \cdot \min) / n;$$

Where n = number of iterations.

Order of velocity vector = $ps \times ncv$.

Where ps = particle size,

ncv = number of control variables.

C. Step.3 Calculation of $pbest$ and $gbest$

$Pbest_{population}$ = population vector (pv).

$pbest_{fitness}$ = fitness vector (fv).

$Gbest$ is the best position among all individual best positions achieved so far.

D. Step.4 Iteration process

Weight updating

$$W(t) = \alpha * w(t-1).$$

Where α = random number.

Velocity updating

$$V(t) = w(t) * v(t-1) + c1 * r1 * (pbest - xi) + c2 * r2 * (gbest - xi).$$

Where xi = current location.

Position updating

$$Xi^{k+1} = v(t) + xi^k$$

Where Xi^{k+1} = new position.

Xi^k = previous location.

E. Step.5 Stopping criteria

The objective function (fitness) value is calculated for each agent according to above steps, that is E_{pbest} . Compare particle's fitness evaluation (E_{pbest}) with its $Gbest$. If current value is better than $Gbest$ then set $Gbest$ equal to the current value and that position equal to the current location xi in D-dimensional space.

F. Step.6 Exit condition

If

$$E_{pbest} < \text{erro}$$

r , (or)

The number of iterations reaches the maximum allowable number.

If one of the above conditions is satisfied then stop. Else go to step 4.

The optimal values of k_p and k_i are substituted in the conventional DTC and the results have obtained.

V. RESULTS AND DISCUSSIONS

From PSO Program we obtained the optimized values, that values substitute in the DTC system and finally observed results of DE based DTC system at different load torques. The applied load torques and the motor speed wave forms of PSO based DTC with Conventional DTC shown in the 4(a), 5(a), 6(a), 7(a) and 4(b), 5(b), 6(b), 7(b) respectively.

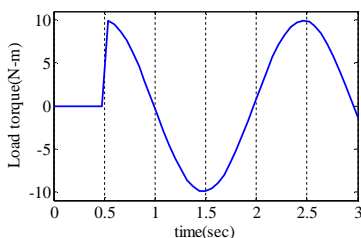


Fig.4(a) Applied load torque

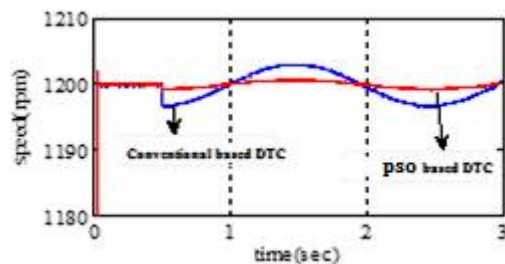


Fig.4(b).Speed wave forms of conventional and PSO based DTC

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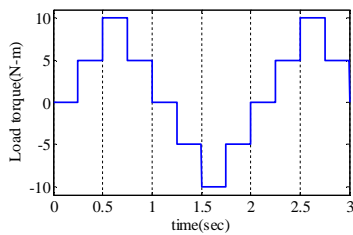


Fig.5(a) Applied load torque

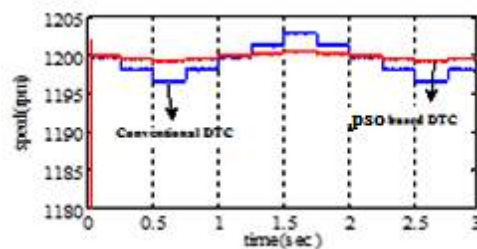


Fig.5(b).Speed wave forms of conventional and PSO based DTC

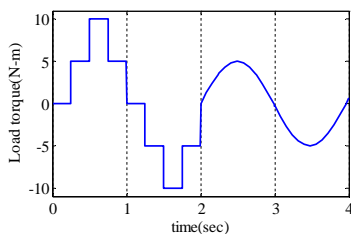


Fig.6(a) Applied load torque

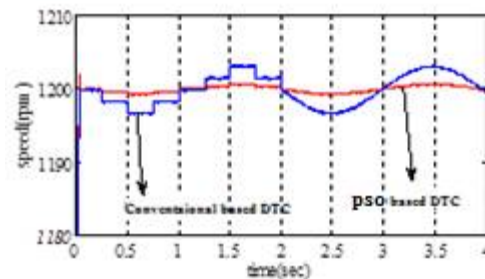


Fig.6(b).Speed wave forms of conventional and PSO based DTC

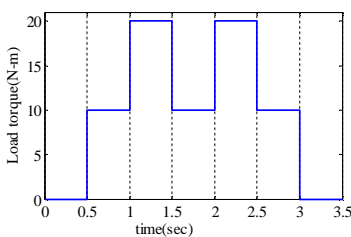


Fig.7(a) Applied load torque

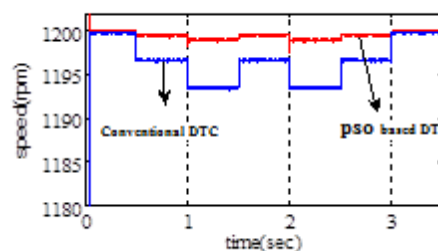


Fig.7(b).Speed wave forms of conventional and PSO based DTC

VI. CONCLUSION

Based on the DTC induction motor, PSO tuned PI controller is proposed in this paper. PSO tuned PI controller also improves the speed adjustment capability of the DTC system. From the simulation results of PSO based DTC it has been observed that an improved torque and flux response was achieved. The command flux optimization scheme has reduced the torque ripple. It can be concluded that PSO based DTC is better compared to the conventional DTC system.

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