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Optimal Tuning of PI Control for DTC of Induction Motor using Flower Pollination Algorithm

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ABSTRACT: This paper presents the optimal tuning of PI controller for DTC control scheme of an induction motor. The load and speed variation are considered during optimization, then provides appropriate gains to the speed controller to obtain good performance of the motor. In DTC control scheme of an induction motor, the torque and flux responses controlled directly. But, there may be undesired ripples. These can be reduced by optimal tuning of PI controller gain values (Kp and Ki). The PI controller tuned by many intelligence algorithms for the optimum gain values of Kp and Ki. This work proposed a Flower Pollination Algorithm (FPA) technique to determine the optimal proportional-integral controller parameters. By this FPA technique, the DTC of induction motor runs with better speed performance. This DTC system simulated under several loading conditions by using MAT LAB/SIMULINK.

KEY WORDS: Direct Torque Control, PI Controller, Flower Pollination Algorithm

I. INTRODUCTION

Induction motors are the most widely used machines in AC drives because of their rugged construction, simple design and low cost. To control [1] the torque and flux of the induction motor different strategies are available. Direct torque control [2] is one of the methodwhich is used in variable frequency drives for the control of the induction motor. In DTC of induction motor the output is controlled directly, by controlling the torque and flux values. The PI controller in DTC system gives the controlled output and it is considered as reference torque value. The PI controller gain values tuning is essential to get optimum output. Optimized DTC can improve the system performance [3] by continuously tuning the Kp& Ki values.Optimization techniques [4]set many limitations while developing the mathematical and operational research models. Model solutions in traditional optimization algorithms are mostly dependent on the type of objective and constraint functionsto enhance the capabilities of PI controller. Flower pollination algorithm technique selected for best optimal tuning for DTC system.

Flower Pollination Algorithm is proposed to adjust the parameters of the PI controller in order to minimize torque ripple, flux ripple and improve the speed performance of an induction motor. Application of the FPA is simple to implement, it can quickly find solutions and has stable convergence characteristics. FPA has been successfully applied to solve a wide range of numerical optimization problems and also responsible for getting the optimum tuned gain values.

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II. MATHEMATICAL MODELING OF INDUCTION MOTOR

The following are the modeling equations [5] of an induction motor:

$$V_{qs}^{s} = R_s i_{qs}^{s} + \frac{d}{dt}\Psi_{qs}^{s} \qquad (1)$$

$$V_{ds}^{s} = R_s i_{ds}^{s} + \frac{d}{dt}\Psi_{ds}^{s} \qquad (2)$$

$$0 = R_r i_{qr}^{s} + \frac{d}{dt}\Psi_{qr}^{s} - \omega_r \Psi_{dr}^{s} \qquad (3)$$

$$0 = R_r i_{dr}^{s} + \frac{d}{dt}\Psi_{dr}^{s} + \omega_r \Psi_{qr}^{s} \qquad (4)$$

$$T_e = \frac{3}{2}\frac{P}{2}\left(\Psi_{ds}^{s} i_{qs}^{s} - \Psi_{qs}^{s} i_{ds}^{s}\right) \qquad (5)$$

III. THREE PHASE VOLTAGE SOURCE INVERTER

The circuit topology for 3-ϕvoltage source inverter [6] using IGBT's is shown in Fig1. S1 to S6 are the six power switches that shape the output, which are controlled by the switches a, b and c.

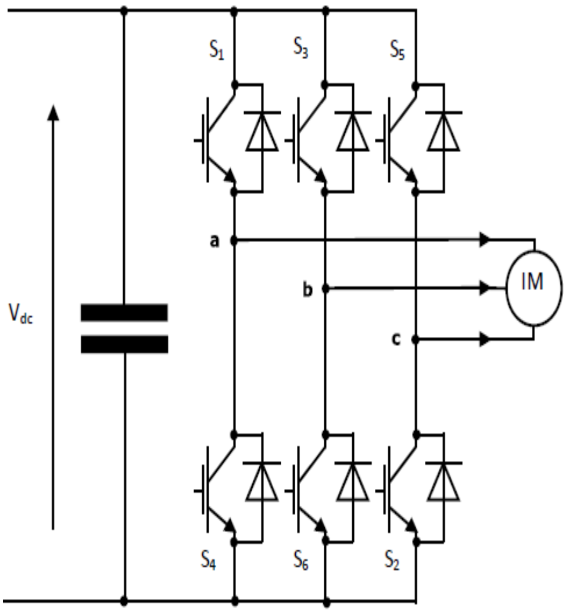

Fig1. Voltage source inverter using IGBTs

The inverter produce output when any one of the switch ON in every segment. If an upper switch ON, the corresponding lower switch is OFF in that segment. The state of the switch will determine the output voltage of inverter. The speed and electromagnetic torque of induction motor is controlled by the selection of optimal inverter switching modes.

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IV.DIRECT TORQUE CONTROL OF INDUCTION MOTOR

The block diagram of DTC of induction motor [7] is shown in Fig2.

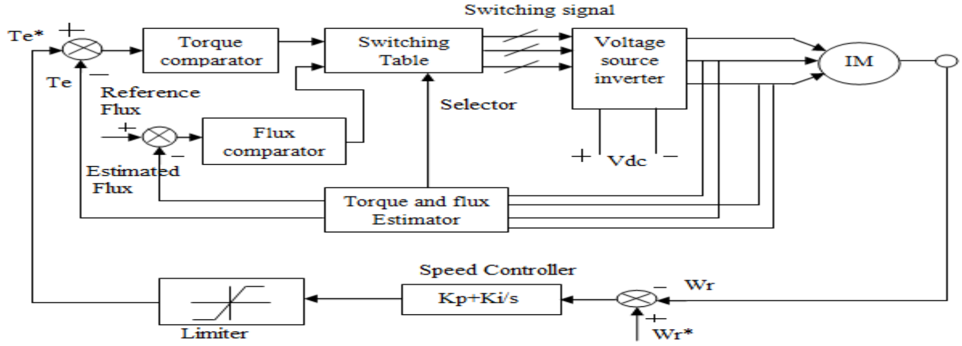

Fig2. DTC of induction motor

The electromagnetic torque developed by the induction motor is given by

$$T_e = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_s L_r \sigma}\Psi_s \Psi_r \sin\theta \qquad (6)$$

Where Ψ_r and Ψ_s are the rotor and stator flux linkages and θ is the angle between the fluxes and σ is the leakage coefficient.

Induction motor fed by three phase voltage source inverter consisting of six IGBT switches. 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. Six non-zero vectors (V_1-V_6) shape the axis of a hexagonal as shown in Fig3 and Table 1 shows voltage vector selection according to stator flux and torque errors.

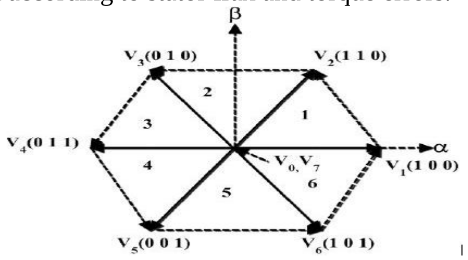

Fig3.Voltage vectors (V_1-V_6)

Table1: Voltage vectors selection table

$d\Psi$	dT_e	S_1	S_2	S_3	S_4	S_5	S_6
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

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In general, V_2 and V_3 vectors can be selected to increase the torque and V_5, V_6 and V_0 vectors will decrease the torque. The PI controller in DTC system controls the output by optimal tuning. Optimization considers the load and speed variations, and provides appropriate gains to the speed controller [8] to obtain good dynamic performance [9] of the motor. There are many optimal techniques for tune the gain values of PI controller. Examples particle swarm optimization, GA and etc. In this paper an adaptive PI controller has been proposed where the proportional and integrator gains are tuned by the Flower Pollination Algorithm.

V.FLOWER POLLINATION ALGORITHM

The main purpose of a flower is ultimately reproduction via pollination. FPA was developed by Xin-She Yang in 2012[10-12], inspired by the flow pollination process of flowering plants. Flower pollination is typically associated with the transfer of pollen, and such transfer is often linked with pollinators such as insects, birds, bats and other animals. FPA has been extended to multi-objective optimization. For simplicity, the following four rules are used.

1. Biotic and cross-pollination can be considered processes of global pollination, and pollen-carrying pollinators move in a way that obeys Levy flights (Rule 1).
2. For local pollination, a biotic pollination and self-pollination are used (Rule 2).
3. Pollinators such as insects can develop flower constancy, which is equivalent to a reproduction probability that is proportional to the similarity of two flowers involved (Rule 3).
4. The interaction or switching of local pollination and global pollination can be controlled by a switch probability p ∈ [0, 1], slightly biased toward local pollination (Rule 4).

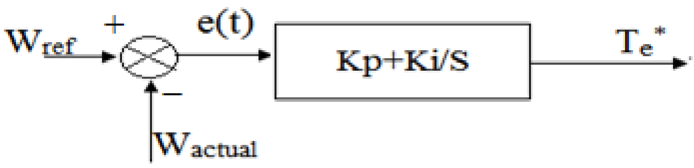

Fig4. PI controller

$$e(t) = W_{ref} - W_{actual} \tag{7}$$

$$e(t) = \frac{T_e^*}{Kp + Ki/s} \tag{8}$$

Where

e(t) = Speed error value
T_e^* = Reference torque
Kp = Proportional constant of PI Controller
Ki = Integral constant of PI Controller

Steps for FPA algorithm:

Step 1:
Initialize ‘N’ no of flower as population, find the objective function value for each flower and select global flower from the population.

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Step 2:

For each flower generate a random number, If random number less than switching probability then draw a (d-dimensional) step vector L which obeys a Levy distribution Global pollination .

Global population = $X_i^{t+1} = X_i^t + L(g_* - X_i^t)$ (9)

Where "X_i^t" is the pollen i or solution vector xi at iteration t, "L" is the strength of the pollination and "g_*" is the current bestsolution found among all solutions at the current generation/iteration.

$$L \sim \frac{\lambda I'(\lambda)\sin(\pi\lambda/2)}{\pi}\frac{1}{S^{1+\lambda}} \quad (S >> S_0 > 0) \quad (10)$$

Here "$I'(\lambda)$" is the standard gamma function, and this distribution is valid for large steps S> 0.

Step 3:

If random value greater than switching probability, Draw ϵ from a uniform distribution randomly choose j and k among all the solutions do local pollination.

Local population = $X_i^{t+1} = X_i^t + \in (X_j^t - X_k^t)$ (11)

Step 4:

Find the solutions for all 'N' flowers w.r.t new solutions, if new solution is better then update it in population. Repeat steps for all population and find best current solution g_*.

VI. RESULTS AND DISCUSSION

In this section, the conventional DTC was initially simulated with chosen Kp& Ki values.Later the Flower pollination algorithm was applied to controller of conventional DTC of induction motor. The input parameters of Flower pollination algorithm are given in Table2.The optimal parameters for Flower pollination algorithm Kp & Ki are 120 & 1.3539 respectively. The optimized parameters for both conventional DTC and FPA based DTC are shown in Table3 & the Induction motor parameters are shown in Table4.

Table2: Algorithm parameters

Parameters	values
No of iteration	100
Population size	10
No of variables	2
Kp limits	0 to 120
Ki limits	0 to 10

Table3: Optimal parameters

Conventional DTC		FPA based DTC	
Kp	Ki	Kp	Ki
30	0.4	120	1.3539

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Table4. Induction Motor Parameters

Parameters	Values
Rating of IM	3-ph,4kw,50Hz
Rs	1.57Ω
Rr	1.21Ω
Ls=Lr	0.17H
Lm	0.165H
P	4 poles
J	0.089 kg-m^2

The plots are taken for the both conventional DTC and FPA based DTC when appling and removing of a load torque at 0.4sec and 0.6 sec respectively. The plots are shown in Fig5 and Fig6 respectively. In the both the cases the speed deviation occurred at 0.4 sec to 0.6sec. The speed deviation was less in FPA based DTC over conventional DTC. It is clearly given that the FPA based DTC improve the speed performance when comparing with conventional DTC and are shown in Fig7.The optimal values of FPA based DTC improves the speed performance by minimizing the speed error.

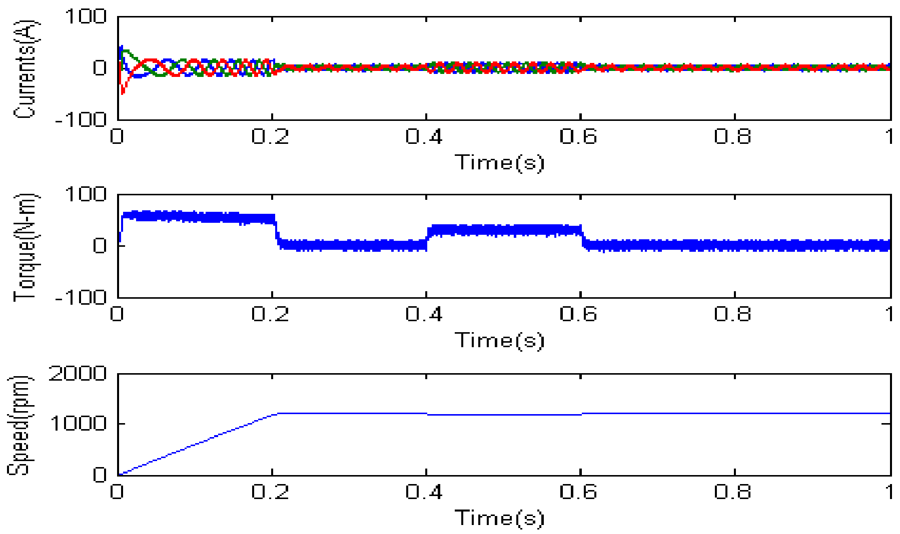

Fig5. Conventional DTC

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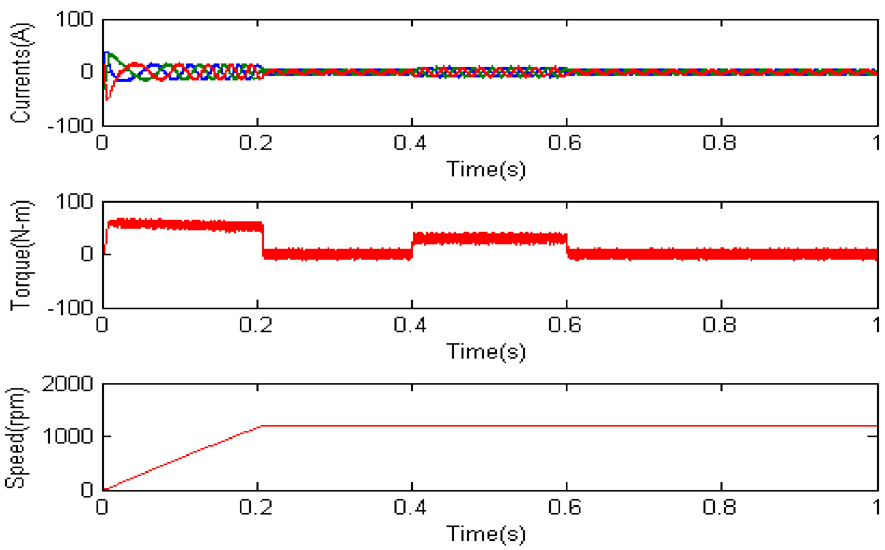

Fig6. FPA based DTC

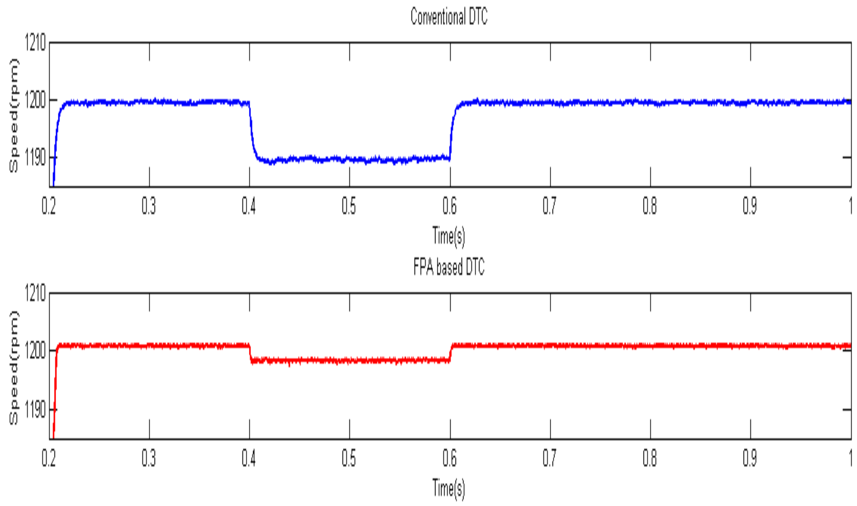

Fig7.Results comparison

VII. CONCLUSION

The behaviorof FPA based DTC adjusting the parameters of speed control (Kp, Ki) in order to overcome the drawbacks of DTC and to improve the performance of the whole system by tuning of PI controller is proposed in this paper. The tuned PI controller optimizes the speed controller by minimizing the speed error between the reference of rotor speed and actual speed. The simulation results of FPA based DTC develop the performance of three-phase induction motor by minimizing torque and flux ripples and also noted that the speed performance from on-load to no-load is improved by comparing with conventional DTC. Optimal FPA based DTC tuned by PI controller has improves the speed adjustment capability of the DTC system and also an improved torque and flux response was achieved.

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