# Solution to Direct Torque Control of Induction Motor with Artificial Bee Colony Algorithm

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***Abstract:*** The undesired flux ripple and torque may occur in conventional direct torque control (DTC) induction motor drive. DTC can improve the system performance at low speeds by continuously tuning the regulator by adjusting the Kp, Ki values. In this Artificial Bee Colony Algorithm (ABC) is proposed to adjust the parameters (Kp, Ki) of the speed controller in order to minimize torque ripple, flux ripple, and stator current distortion.The ABC based PI controller has resulted is maintaining a constant speed of the motor irrespective of the load torque fluctuations.

***Keywords: Artificial Bee Colony Algorithm, Forager Bee, Scout Bee Direct Torque Control, PI controller.***

## I. INTRODUCTION

Induction motors are the most widely used machines in AC drives because of their rugged construction and cost. To control the torque and flux of the induction motor different strategies are available as per the literature. DTC was patented by Manfred Depen brock in the US and in Germany, the latter patent having been filed on October 20, 1984, both patents having been termed direct self-control (DSC). However, Isao Takahashi and Toshihiko Noguchi described a similar control technique termed DTC in an IEEJ paper presented in September 1984 and in an IEEE paper published in late 1986. The DTC innovation is thus usually credited to all three individuals. The only difference between DTC and DSC is the shape of the path along which the flux vector is controlled, the former path being quasi-circular whereas the latter is hexagonal such that the switching frequency of DTC is higher than DSC. DTC is accordingly aimed at low-to-mid power drives whereas DSC is usually used for higher power drives.

Direct torque control is one of the methods which is used in variable frequency drives for the control of the induction motor. Direct torque control has emerged over the last decade to become one possible alternative to the well-known Vector Control of Induction Machines. In DTC, the stator flux and the torque are directly controlled by selecting the appropriate inverter state. The output of the speed regulator (PI controller) results in generation of the reference torque. However the PI controller cannot result in perfect control if its parameters Kp, Ki are not properly chosen. The undesired torque and flux ripple may occur in conventional direct torque controlled induction motor drive. DTC can improve the system performance at low speeds by continuously tuning the regulator by adjusting the Kp, Ki values. Many artificial intelligence techniques and random search methods have been employed to improve the control parameters.

Artificial Bee Colony Algorithm (ABC) is proposed to adjust the parameters (Kp, Ki) of the speed controller in order to minimize torque ripple, flux ripple, and stator current distortion. ABC is generally considered as a reliable, accurate, robust and fast optimization technique. ABC has been successfully applied to solve a wide range of numerical optimization problems.

## II. MATHEMATICAL MODELING OF INDUCTION MOTOR

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

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

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

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

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

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

## III. CONVENTIONAL DIRECT TORQUE CONTROL

### 3.1. 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

$$T_e = \frac{3}{2}\frac{p}{2}\frac{L_m}{\sigma L_s L_r}\left|\overline{\lambda_s}\right|\left|\overline{\lambda_r}\right| \sin\theta \qquad (6)$$

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

$$V_s = \frac{d\overline{\lambda_s}}{dt} - \overline{I_s} r_s \qquad (7)$$

Change in flux can be expressed as

$$\Delta\overline{\lambda_s} = \overline{V_s}\,\Delta t \qquad (8)$$

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

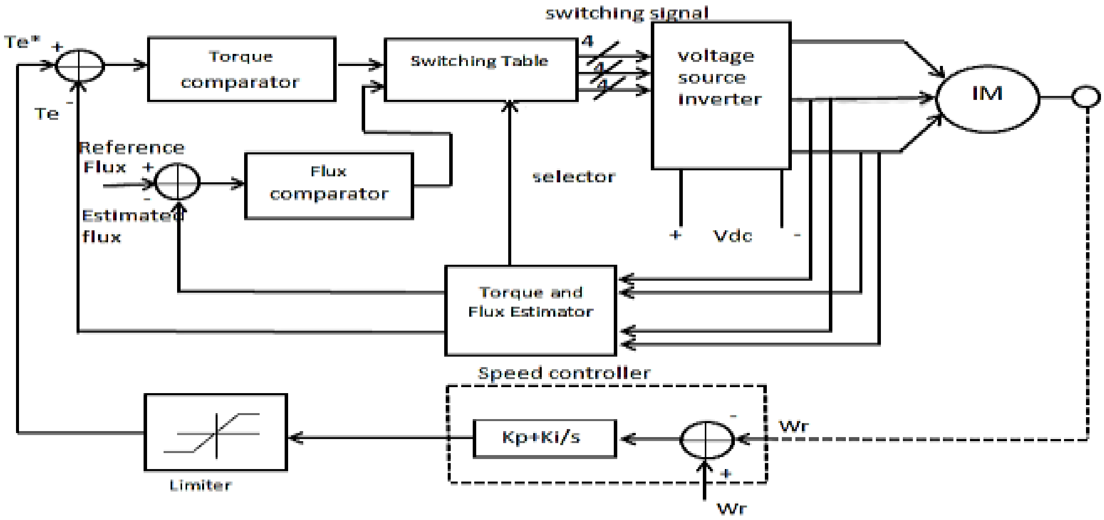


Fig.1.1.Conventional DTC of Induction motor.

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 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 fortuning 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 Differential Evolution algorithm.

## IV. ARTIFICIAL BEE COLONY ALGORITHM

The Artificial Bee Colony algorithm proposed by Dervis Karaboga in 2005 for real-parameter optimization is a recently introduced optimization algorithm which simulates the foraging behaviour of bee colony. In the ABC algorithm, the foraging artificial bees are divided into three groups: employed bees, unemployed bees and scout bees. One half of the colony size of the ABC algorithm represents the number of employed bees, and the second half stands for the number of unemployed bees. The employed bees are responsible for exploiting the explored food sources and passing their food information to onlooker bees. The onlooker bees will make a move to choose a food source on this information, and then further exploit the foods around the chosen food source. The employed bee change to a scout bee when it abandons a food source and search the environment surrounding the nest (up to a 14 km radius) for the new food sources. The details of the algorithm are as follows.

**4.1 Food source sites initialization**

In the initialization of the algorithm, a set of food source sites ( $eb$ ) are created randomly. Let's consider $u^{th}$ food source in the population as

$$d_u = d_{u,1}, d_{u,2}, d_{u,3}, \ldots\ldots, d_{u,n} \tag{9}$$

And each food source site is created as per the Eq. (10)

$$d_{uv} = d^{min} + rand(0,1)(d^{max} - d^{min}) \tag{10}$$

Where u signifies the size of food source sites, u=1, 2, 3... eb , v signifies the parameters to be optimized,
v =1, 2, 3,…, ncv $d_u$ *max* & $d_u$ *min* are the upper and lower bounds for the dimension u. After initialization of the food source sites $fit_u$ amounts are calculated.

**4.2. Employed bee forager**

A new candidate food sources is created by modification of $d_u$ of its current position and then calculate nectar or fit u amount. The position of the new food source is defined as

$$w_{u,v} = d_{u,v} + \xi_{u,v}(d_{u,v} - d_{q,v}) \tag{11}$$

Where $q$ = 1, 2,3, ..., $eb$ is a randomly chosen index that has to be different from $u$, □$_{u,v}$ is a uniformly distributed real random number in the range [-1, 1].

$$fit_u = \begin{cases} \frac{1}{1+obj_u}, & if\ obj_u \geq 0 \\ 1 + abs(obj_u), & if\ obj_u < 0 \end{cases} \tag{12}$$

Where $obj_u$ is the cost value or objective value of the solution $w_u$ . If the $fit_u$ of $w_u$ is equal or better than that of $d_u$ it will be replaced by the new candidate food source position $w_u$ otherwise the previous position is kept in memory.

**4.3 Onlooker probabilities**

After all employed bees complete the search process, each onlooker bee chooses a food source. The probability that a food source will be chosen by the onlooker bee is calculated.

$$prob_u = \frac{fit_u}{\sum_{u=1}^{eb} fit_u} \tag{13}$$

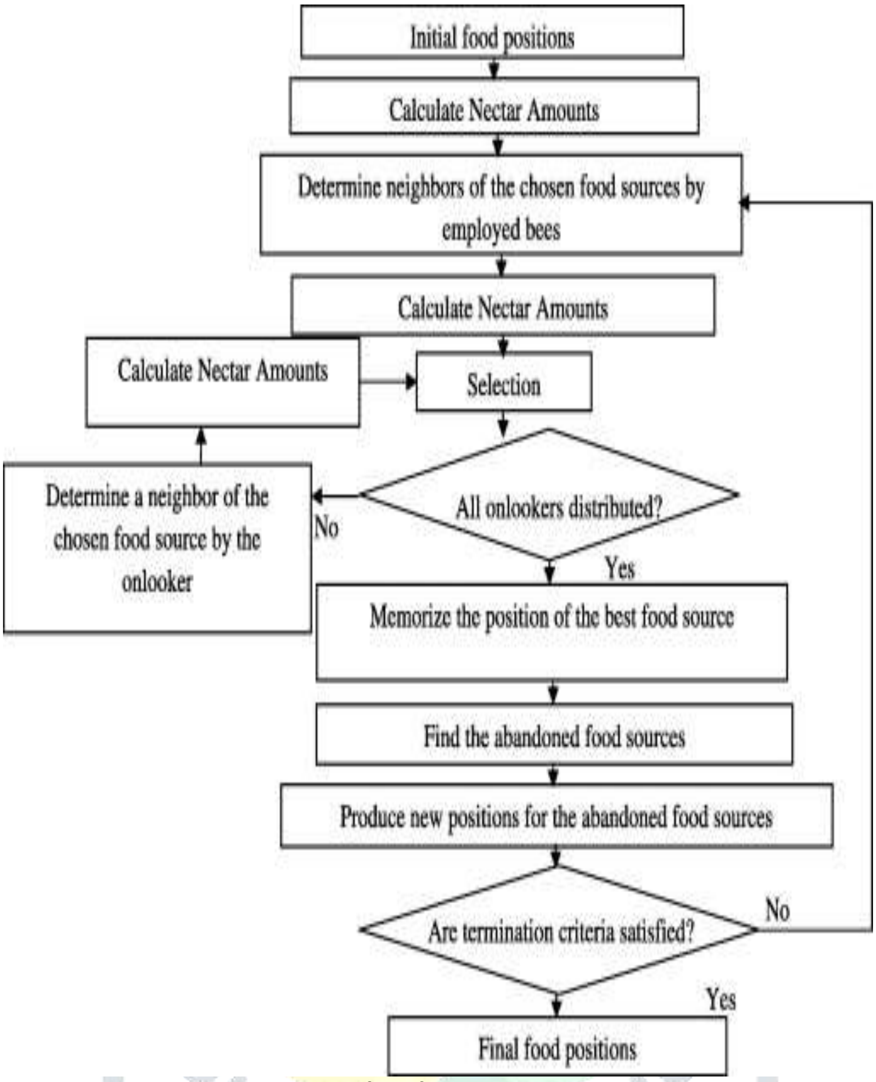


Fig.2 Flow Chart of Artificial Bee Colony Algorithm

### 4.4 Onlooker bee forager

This is also similar to employed bee forager step. Here, candidate food source is created of its current position as per Eq. (14) and calculate $fit_u$ value . If the new candidate food source has equal or better $fit_u$ value than the old source, it is replaced with the old one in the memory. Otherwise, the old one is retained in the memory. This process is repeated until all onlookers are distributed onto food source sites.

### 4.5 Scout bee forage

If the $fit_u$ value of the employed bees does not improved by a continuous predetermined number of iterations, those food sources are abandoned. The food source abandoned by its bee is replaced with a new food source discovered by the scout as per Eq. (10)

## V. RESULTS AND DISCUSSIONS

The optimized values can be obtained by using ABC Program, that values substitute in the DTC system and finally observed results of ABC based DTC system at different load torques. The applied load torques and the motor speed wave forms of ABC based DTC with Conventional DTC shown in the 3(a),4(a), 5(a), 6(a) and 3(b), 4(b), 5(b), 6(b) respectively.

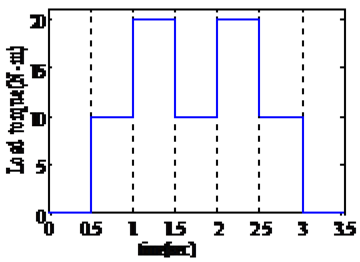

Fig.3 (a) Applied load torque

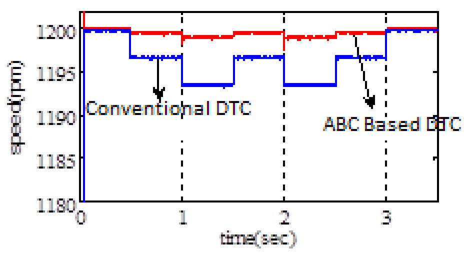


Fig.3 (b).Speed wave forms of conventional and ABC based DTC

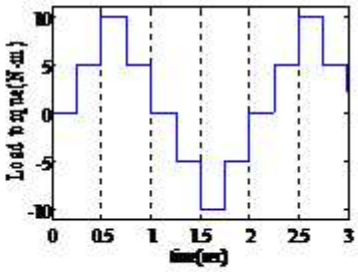

Fig.4 (a) Applied load torque

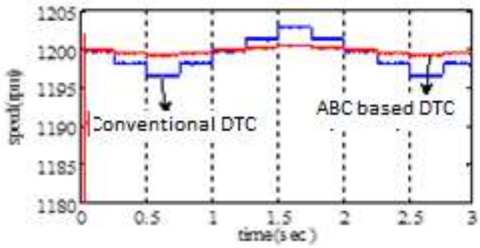


Fig.4 (b).Speed wave forms of conventional and ABC based DTC

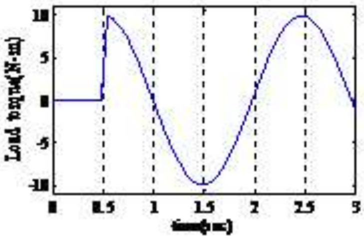

Fig.5 (a) Applied load torque

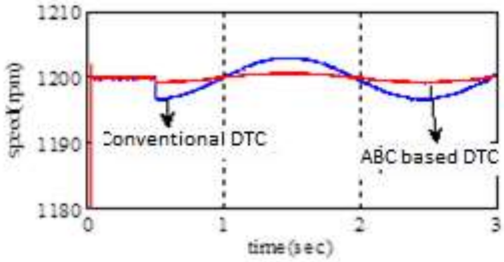


Fig.5 (b).Speed wave forms of conventional and ABC based DTC

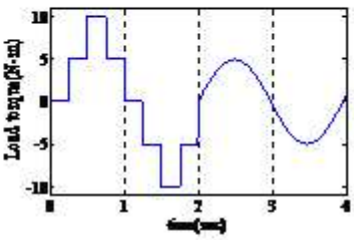

Fig.6 (a) Applied load torque

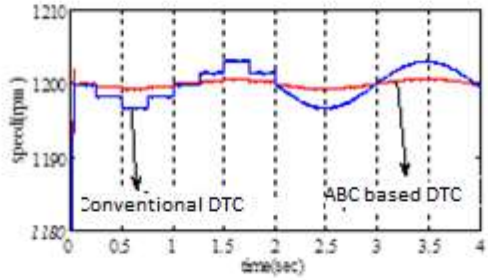


Fig.6 (b).Speed wave forms of conventional and ABC based DTC

## VI. CONCLUSION

Based on the DTC induction motor, ABC tuned PI controller is proposed in this paper. The speed adjustment capability of the DTC system improved by using ABC tuned PI controller. From the simulation results of ABC 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. By comparing the ABC based DTC method is better with the other conventional DTC system.

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