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A New Approach to Direct Torque Control of Induction Motor with Teaching Learning Based Optimization

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ABSTRACT*:* The undesired torque and flux ripple 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 thisTeaching Learning Based Optimization(TLBO) 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 TLBO based PI controller has resulted is maintaining a constant speed of the motor irrespective of the load torque fluctuations.

KEYWORDS*:* Teaching Learning Based Optimization, 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. 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.

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

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II. MATHEMATICAL MODELING OF INDUCTION MOTOR

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

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

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

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

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

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

III. CONVENTIONAL DIRECT TORQUE CONTROL

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

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

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

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

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

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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

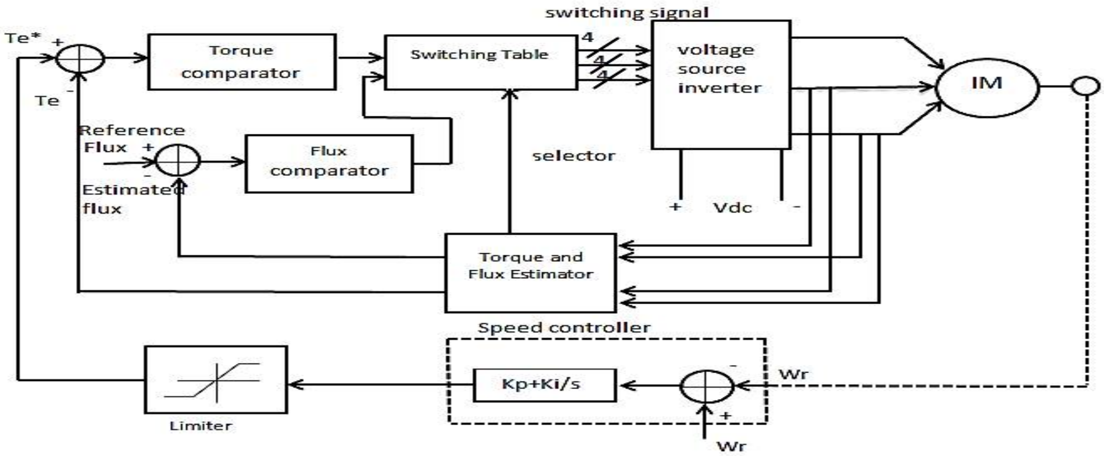

Fig 1.Conventional DTC of Induction motor.

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.TEACHING LEARNING BASED OPTIMIZATION

TLBO is also a population based method that uses a population of solutions to proceed to the global solution. For TLBO, the population is considered as a group of learners or a class of learners. In optimization algorithms, the population consists of different design variables. In TLBO, different design variables will be analogous to different subjects offered to learners and the learners' result is analogous to the 'fitness', as in other population-based optimization techniques. The teacher is considered as the best solution obtained so far. The process of TLBO is divided into two parts. The first part consists of the 'Teacher Phase' and the second part consists of the 'Learner Phase'. The 'Teacher Phase' means learning from the teacher and the 'Learner Phase' means learning through the interaction between learners.

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FLOWCHART OF TLBO ALGORITHM

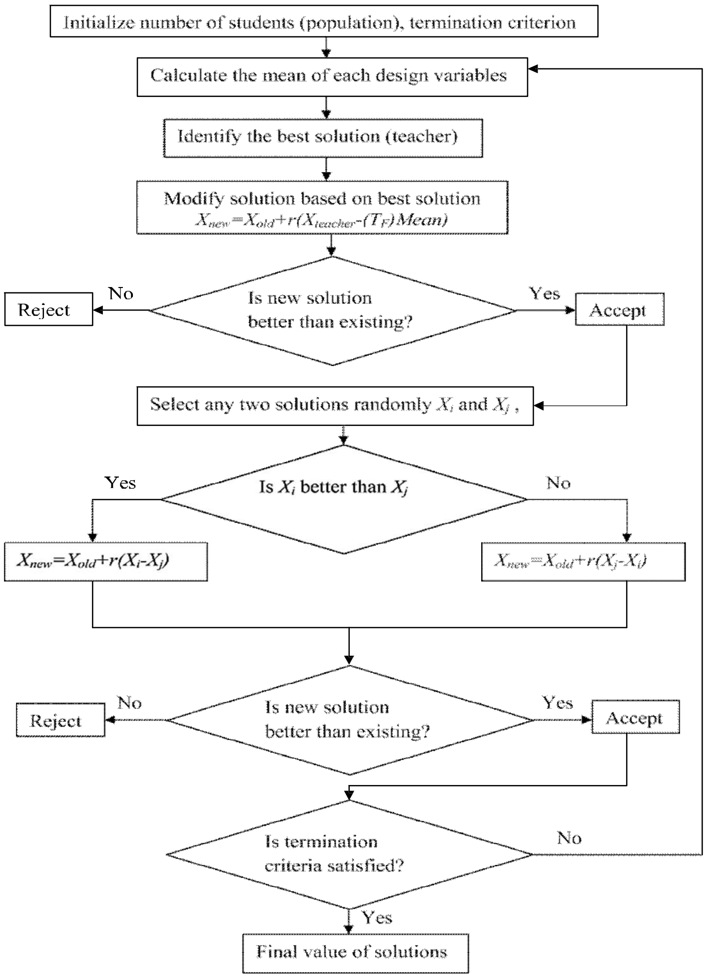

Fig. Flow chart of TLBO algorithm

STEPS IN TEACHING AND LEARNING BASED OPTIMIZATION ALGORITHM

The main steps involved in TLBO algorithm are as follows:

A. INITIALIZATION

(i) Initialization of TLBO parameters:

The parameters like initial population size, number of design variables, Limits of control variables and maximum generation limit are initialized.

(ii) Initialize the population

Generate a random population according to the population size and number of design variables. For TLBO, the population size indicates the number of learners and the design variables indicate the subjects (i.e. courses) offered. This population is expressed as

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$$\text{Population} = \begin{bmatrix} x_{1,1} & x_{1,2} & \cdots & x_{1,D} \\ x_{2,1} & x_{2,2} & \cdots & x_{2,D} \\ \vdots & \vdots & \vdots & \vdots \\ x_{P_n,1} & x_{P_n,2} & \cdots & x_{P_n,D} \end{bmatrix} \quad (4.1)$$

Where p = population size
D = no. of variables

B. TEACHER PHASE

Calculate the mean of the population column-wise, which will give the mean for the particular subject as

$$M_{,D} = [m_1, m_2, \ldots m_D] \quad (4.2)$$

The best solution will act as teacher for that phase

$$X_{Teacher} = X_{f(x)=min} \quad (4.3)$$

The teacher will try to shift the mean from $M_{,D}$ towards $X_{Teacher}$, which will act as a new mean for the iteration. So,

$$M\_new_{,D} = X_{teacher,D} \quad (4.4)$$

The difference between two means is expressed as

$$Difference_{,D} = r(M\_new_{,D} - T_F M_{,D}) \quad (4.5)$$

The value of TF is selected as 1 or 2. The obtained difference is added to the current solution to update its values using

$$X_{new,D} = X_{old,D} + Difference_{,D} \quad (4.6)$$

Accept X_{new} if it gives better function value

C. LEARNER PHASE

As explained above, learners increase their knowledge with the help of their mutual interaction. The mathematical expression is

For $i = P_n$

Randomly select two learners X_i and X_j where $i \neq j$

if $f(X_i) < f(X_j)$

$X_{new,i} = X_{old,i} + r_i (X_i - X_j)$

Else

$X_{new,i} = X_{old,i} + r_i (X_j - X_i)$

End If

End For

Accept X_{new} if it gives a better function value.

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D. SELECTION

By sorting the profits, the nests with the best profit values are selected and memorize the best solution and go to step 2.

E.STOPPING CRITERIA

Step 3 is repeated until the minimum or maximum (depends on minimization or maximization) is achieved or maximum iteration count is reached.

In the current work, when the number of generations reaches the given maximum number of generations is used as stopping criteria. Best nests are copied to next generations until stopping criteria is satisfied.

Results and Discussions

FromTLBO Program we obtained the optimized values, that values substitute in the DTC system and finally observed results of TLBO based DTC system at different load torques. The applied load torques and the motor speed wave forms of TLBO 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.

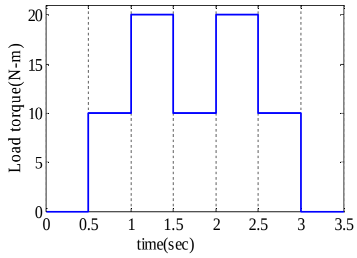

Fig.4(a) Applied load torque

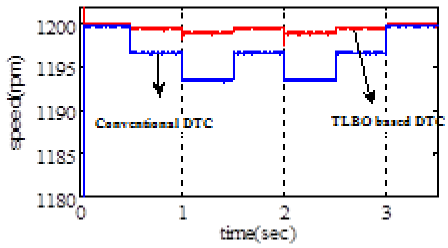

Fig.4(b).Speed wave forms of conventional and TLBO based DTC

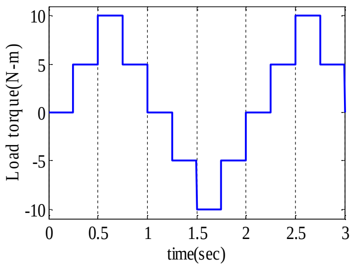

Fig.5(a).Applied load torque.

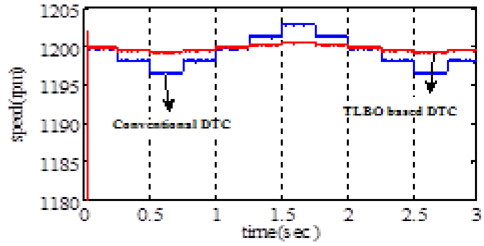

Fig.5(b).Speed waveforms of Conventional and TLBO based DTC .

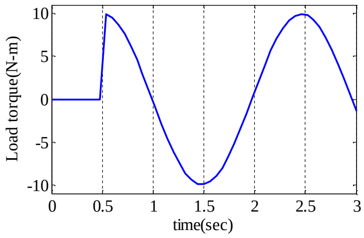

Fig.6(a).Applied load torque.

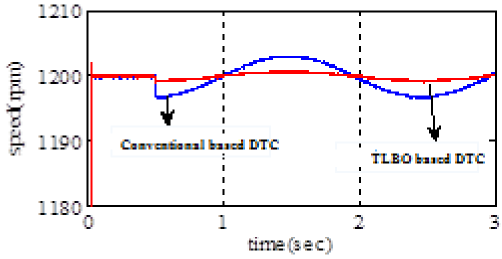

Fig.6(b).Speed waveforms of Conventional and TLBO based DTC .

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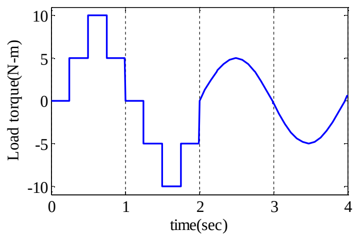

Fig.7(a).Applied load torque.

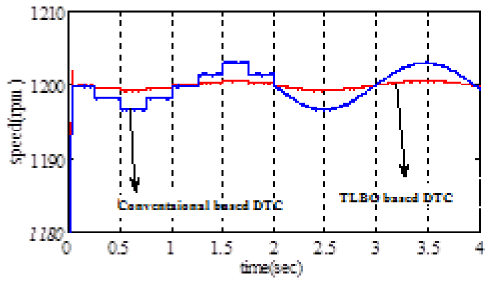

Fig.7(b).Speed waveforms of Conventional and TLBO based DTC.

VI. CONCLUSION

Based on the DTC induction motor, TLBO tuned PI controller is proposed in this paper.TLBO tuned PI controller also improves the speed adjustment capability of the DTC system. From the simulation results of TLBO 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 TLBO based DTC is better compared to the conventional DTC system.

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