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Direct Torque Control of Induction Motor by Using Particle Swarm Optimization Technique

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ABSTRACT

This paper is based on an efficient and reliable evolutionary approach of particle swarm optimization (PSO) using direct torque control (DTC) of induction motor. In order to resolve the problem of parameter variation the PI controllers are generally used in industrial plants because it is uncomplicated and robust. However, there is a problem in changing PI parameters. So, the engineers are looking for automatic tuning procedures. In traditional direct torque-controlled induction motor drive, there is generally undesired torque and ripple in form of flux. So Tuning PI parameters (Kp, Ki) are critical to DTC system to improve the performance of the system. In this paper, particle swarm optimization (PSO) is planned to correct the parameters (Kp, Ki) of the speed controller in order to get improved performance of the system and also responsible to run the machine at base speed.

Keywords : Direct Torque Control, Particle Swarm Optimization, PI Controller, Induction Motor.

I. INTRODUCTION

An induction motor or a synchronous motor is an AC based electrical motor in which the electric current in the rotor necessary to increase torque is obtained by electromagnetic induction from the magnetic field of the stator winding. Induction motors are the general motors' used in industrial motion control systems, as well as for domestic purposes. Simple and rugged design, cheap in cost, less maintenance and direct connection to an AC power supply are the main advantages of AC induction motors. To calculate the speed of an induction motor is more difficult than calculating 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 a small number of methods to calculate the speed of an induction motor over a wide range. Induction motors are broadly used in various industries as main work-horses to generate rotational motions and forces. In general, variable-speed drives for induction motors require both broad operating range of speed and fast torque response, apart from of load variations. Conventional control makes use of the mathematical model for the controlling of the system. When there are system parametric variations or environmental disturbance, behaviour of system is not appropriate and deviates from the desired performance.

The DTC offers a variety of 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 generally used in motor control system due to the easy control structure and acceptance of design. However tuning the parameters of PI controller is a complicated task. To enhance the capabilities of traditional PI parameter tuning techniques, some intelligent approaches have been recommended 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 any optimization problem PSO applies a simplified social model. On comparing to additional methods, application of the PSO is easy to implement and it can quickly locate a number of high quality solutions and has secure convergence characteristics. The PSO method is a remarkable optimization methodology. It is basically one of the most promising approaches for solving the optimal PI controller parameters problem. There are a number of significant control methods available for induction motors including scalar control, vector or field-oriented control, direct torque and flux control, sliding mode control, and the adaptive control. Scalar control is aimed at controlling the induction machine to operate at the steady state, by varying the amplitude and frequency of the fundamental supply voltage. A method to use of an improved V/f control for high voltage induction motors and its stability was proposed in. The scalar controlled drive, in contrast to vector or field-oriented controlled one, is easy to implement, but provides somewhat inferior performance. This control method provides limited speed accuracy especially in the low speed range and poor dynamic torque response.

The Particle Swarm Optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart (Kennedy and Eberhart, 1995). Some of the attractive features of the PSO, include the ease of implementation and the fact that no gradient information is required. It can be used to solve a wide array of different optimization problems, including most of the problems that can be solved using Genetic Algorithms; some example applications include neural network training and nonlinear optimization problems with continuous variables and it is easily expanded to treat problems with discrete variables. In this paper, a sincere attempt is made to reduce the settling time of the responses and make the speed of response very fast by designing an efficient controller using PSO-PI control strategy. Here, we have control strategy for the speed control of IM, which has yielded excellent results compared to the others mentioned in the literature survey above. The results of our work have showed a very low transient response and a non-oscillating steady state response with excellent stabilization.

MATHEMATICAL MODELING OF INDUCTION MOTOR

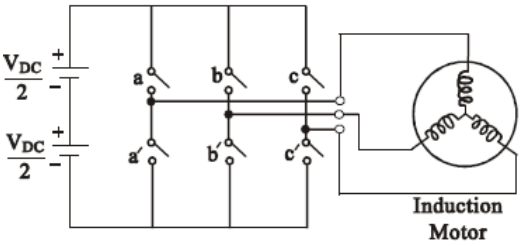
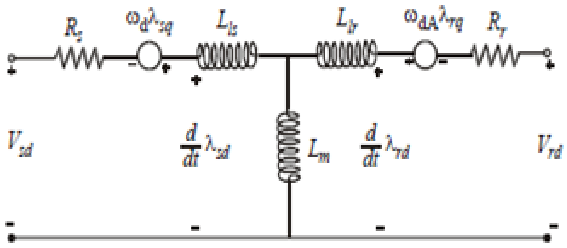
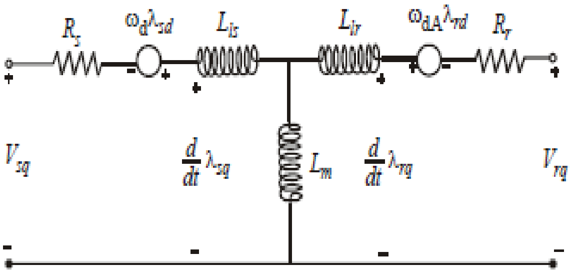


Fig 1. Power circuit connection diagram for the IM



(a) d-axis



(b) q-axis

Fig 2. Equivalent circuit of induction motor in d-q frame

The stator and rotor voltage equations are given by,

$V_{sd}=R_sI_{sd}+ d/dt\ \lambda_{sd}-\omega_d \lambda_{sq}$ (1)

$V_{sq}=R_sI_{sq}+ d/dt\ \lambda_{sq}+\omega_d \lambda_{sd}$ (2)

$V_{rd}=R_rI_{rd}+ d/dt\ \lambda_{rq}-\omega_{d}A\ \lambda_{rq}$ (3)

$$V_{rq}=R_rI_{rq}+ d/dt\ \lambda_{rq}+\omega_d A\ \lambda_{rd} \qquad (4)$$

Where Vsd and Vsq, Vrd and Vrq are the direct axis and quadrature axis stator and rotor voltages. The squirrel-cage induction motor considered for the simulation study in this thesis, has the d and q-axis components of the rotor voltage zero. The flux linkages to the currents are related by the Equation (5) as,

$$\begin{bmatrix}\lambda_{sd}\\ \lambda_{sq}\\ \lambda_{rd}\\ \lambda_{rq}\end{bmatrix}=M\begin{bmatrix}i_{sd}\\ i_{sq}\\ i_{rd}\\ i_{rq}\end{bmatrix};M=\begin{bmatrix}L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix} \quad (5)$$

The electrical part of an induction motor can thus be described by a fourth-order state space model (4*4) which is given

In Equation (6), by combining equations (1-5) as

$$\begin{bmatrix}v_{qs}\\ v_{ds}\\ v_{qr}\\ v_{dr}\end{bmatrix}=\begin{bmatrix}R_s+sL_s & -\omega_e L_s & sL_m & -\omega_e Lm\\ -\omega_e L_s & R_s+sL_s & -\omega_e L_m & pL_m\\ sL_m & (\omega_e-\omega_r)L_m & R_r+sL_r & (\omega_e-\omega_r)L_r\\ -(\omega_e-\omega_r)L_m & sL_m & -(\omega_e-\omega_r)L_r & R_r+sL_r\end{bmatrix}\begin{bmatrix}i_{qs}\\ i_{ds}\\ i_{qr}\\ i_{dr}\end{bmatrix}.(6)$$

Where s is the laplacian operator. By superposition, i.e., adding the torques acting on the d-axis and the q-axis of the rotor windings, the instantaneous torque produced in the electromechanical interaction is given by

$$T_{em}=\frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_{rq}i_{rd}-\lambda_{rd}i_{rq}\right) \quad (7)$$

PARTICLE SWARM OPTIMIZATION

Natural creatures sometimes behave as a swarm. One of the main streams of artificial life researches is to examine how natural creatures behave as a swarm and reconFig the swarm models inside a computer. Swarm behavior can be modeled with a few simple rules. School of fishes and swarm of birds can be modeled with such simple models. According to the research results for a flock of birds, birds find food by flocking (not by each individual). The observation leads the assumption that all information is shared inside flocking. PSO is basically developed through simulation of bird flocking in two-dimension space). The position of each agent is represented by XY axis position and also the velocity is expressed by vx (the velocity of X axis) and vy (the velocity of Y axis). Modification of the agent position is realized by the position and velocity information. Bird flocking optimizes a certain objective function. Each agent knows its best value so far (pbest) and its XY position. This information represents the personal experiences o each agent. Moreover, each agent knows the best value so for in the group (gbest) among (pbests). Namely, each agent tries to modify its position using the following information: the current positions (x, y), the current velocities (vx, vy), the distance between the current position and pbest, the distance between the current position and gbest. This modification can be represented by the concept of velocity.

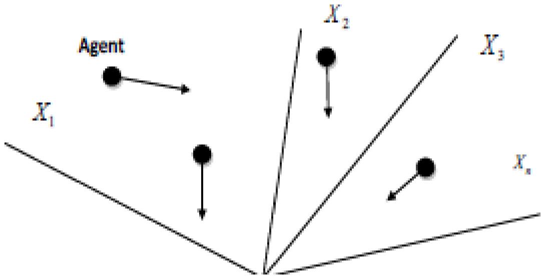


Fig 3. Searching concept with agents in a solution space by PSO

The general flow chart of PSO can be described as follows:

Step 1: Generation of initial condition of each agent Initial searching points (Si0) and velocities (Vi0) of each agent are usually generated randomly within the allowable range. The current searching point is set to pbest for each agent. The best-evaluated value of pbest is set to gbest and the agent number with the best value is stored.

Step 2: Evaluation of searching point of each agent

The objective function value is calculated for each agent. If the value is better than the current pbest of the agent, the pbest value is replaced by the current value. If the best value of pbest is better than the current gbest, gbest is replaced by the best value and the agent number with the best value is stored.

Step 3: Modification of each searching point

The current searching point of each agent is changed using (8)

Step 4: Checking the exit condition such as maximum number of iteration

The current iteration number reaches the predetermined maximum iteration number or any other stopping condition (desired accuracy) is reached, then exit. Otherwise, go to step 2.

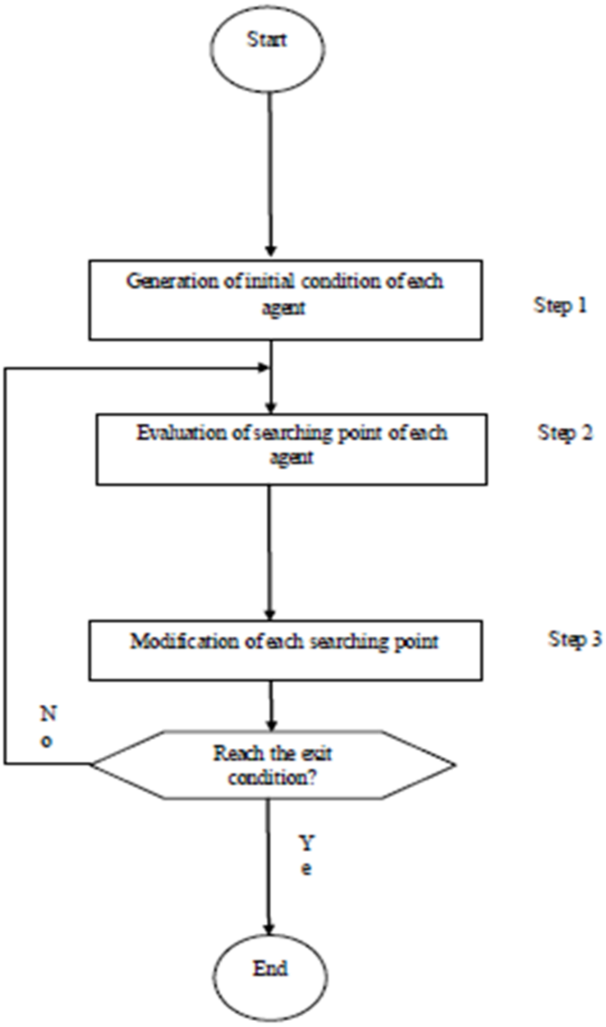


Fig 4. General flow chart of PSO

DIRECT TORQUE CONTROL OF INDUCTION MOTOR

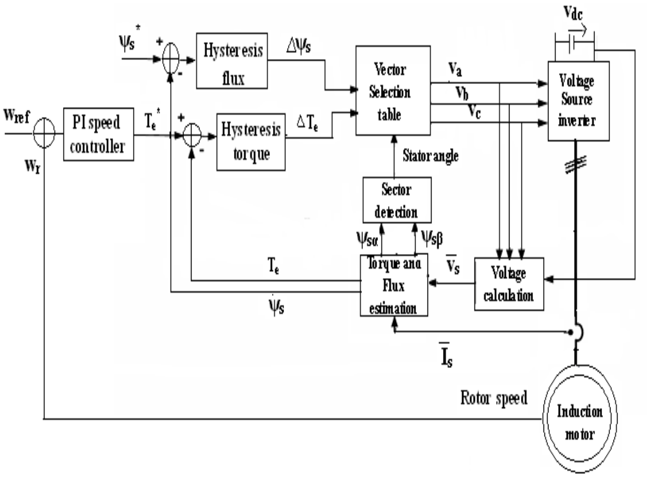


Fig 5. Block diagram of IM drive under DTC

Principle of DTC:

The fundamental control algorithm of DTC is consisted with two independent hysteresis comparators which are responsible to produce the error signal of stator flux and electrical torque. And these error signals are integrated with a switching table shown in table.1. The response signal for independent controllers appear from the stator current and voltage space vectors. The voltage space vectors are generate from inverter with the sensed dc link voltage and the inverter drive signals. Stochastic Algorithm can be applied to the tuning of PID controller gains to ensure optimal control performance at nominal operating conditions. PSO is employed to tune PID gains/parameters (Kp, Ki, Kd) in offline using the model in Eq.2. PSO firstly produces initial swarm of particles in search space represented by matrix. Each particle represents a candidate solution for PID parameters where their values are set in the range of 0 to 100. For this 3-dimentional problem, position and velocity are represented by matrices with dimension of 3xSwarm size. The swarm size is the number of particle where 40 are considered a lot enough.

II. RESULTS AND DISCUSSION

All To authenticate the performance of PSO based DTC we applied different load torques as shown in fig 5(a), 6(a), 7(a), and 8(a). The motor speed waveforms related to the PSO based DTC in comparison with conventional PI based DTC are as shown in fig 5(b), 6(b), 7(b), 8(b).

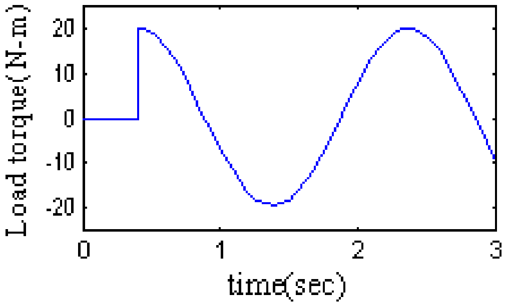


Fig.5 (a) External load torque disturbance

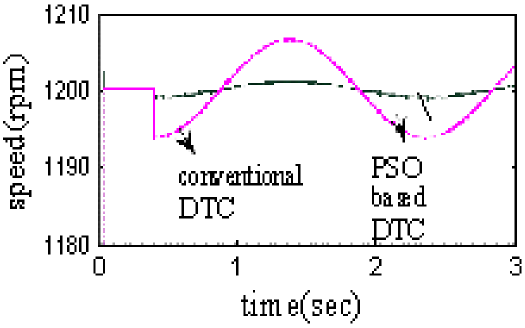


Fig.5 (b) Speed comparison with conventional and PSO based DTC

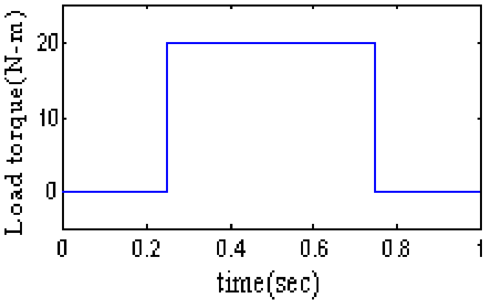


Fig.6 (a) External load torque disturbance

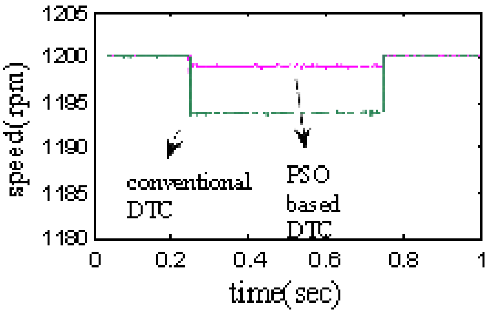


Fig.6 (b) Speed comparison with conventional and PSO based DTC

It has been observed that the speed performance of a PSO based DTC is better when compared with the conventional DTC.

III. CONCLUSION

In this paper, a sincere attempt is made to reduce the settling time of the responses and make the speed of response very fast by designing an efficient controller using PSO-PI control strategy. The simulation results of this method have improved the speed performance of the induction motor irrespective of the load torque fluctuations. The results of our work have showed a very low transient response and a non-oscillating steady state response with excellent stabilization. The proposed PSO method has optimized the parameters of PI controller by minimizing the speed error. It can be concluded that the PSO algorithm employed in DTC of induction motor has resulted in the optimal generation of kp, ki values. This proposed method has finally improved the dynamic speed behavior of the induction motor when compared with that of a Conventional PI controller based DTC of Induction motor.

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