

INDIRECT FIELD ORIENTED SPEED CONTROL OF AN INDUCTION MOTOR DRIVE BY USING PSO ALGORITHM

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Abstract - The field oriented control of induction machine is widely used in high – performance applications. The primary advantages of this approach are the decoupling of torque and flux characteristics and easy implementation. Detuning caused by parameter disturbances still limits the performance of these drives. In order to accomplish variable-speed operation, a conventional controller is used. The conventional controllers provided limited good performance over a wide range of operation, even under ideal field-oriented conditions. In order to overcome this problem of parameter variation the PI controllers are widely used in industrial plants because it is simple and robust. However there is a problem in tuning PI parameters. So the control engineers are on look for automatic tuning procedures. In recent years, many intelligence algorithms are proposed to tuning the PI parameters. Tuning PI parameters using different optimal algorithms such as the simulated annealing, genetic algorithm, and particle swarm optimization algorithm. In this paper a scheduling PI tuning parameters using particle swarm optimization strategy for an induction motor speed control is proposed. The results of our work have showed a very low transient response and a non-oscillating steady state response with excellent stabilization. The simulation results presented in this paper show the effectiveness of the proposed method, with satisfied response for PSO-PI controller.

Keywords - Induction machine; Variable speed drives; Field-Oriented Control; Fuzzy logic; Speed Control; IFOC; Induction Motor Drive; Particle Swarm Optimization
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I. INTRODUCTION

Nowadays, AC motors, in particular squirrel cage induction type, are widely used in industry due to their simple and rugged structure. Moreover, they are economical and immune to heavy overloads. However the use of induction motors also has its disadvantages, mainly the controllability, due to its complex mathematical model and its nonlinear behavior during saturation effect. Induction motor (IM) require complex control algorithms, because there is no linear relationship between the stator current and either the torque or the flux. This means that it is difficult to control the speed or the torque. So the development of high performance motor drives to control such motor is very important in industrial applications, high performance control and estimation

techniques for induction motor drives are very fascinating and challenging subjects and recently many techniques have been developed for induction motor drives and hence very good control performances have been achieved. Generally, a high performance drive system must have good dynamic speed command tracking and load regulating responses, and the performances are insensitive to the drive and load parameter variations.[4]. Among the existing techniques, the most commonly used is the proportional-integral (PI) controller. The conventional PI controller is one of the most common approaches for speed control in industrial electrical drives. The fixed gain controllers may be insufficient to deal with systems subjected to severe perturbations. In this case, the controller gains must be continuously tuned according to the current trend of the system. The conventional controllers cannot show good performance for marginally stable systems. The conventional controllers fail to provide a satisfactory performance for system with large overshoot. Apart from this the conventional controllers needs mathematical modeling of the system. The main drawbacks of conventional controllers are load rejection, robustness to inertia increasing, rotor resistance variations. However, the desired drive specifications still cannot be perfectly satisfied by these methods. In many motor control applications, direct control of torque is highly desirable as a system with a fast response to changes in torque is very beneficial. The field oriented control (FOC) or vector control theory is the base of a IFOC is a special control method for induction motor drives. With this control method, induction motors can successfully used in industrial application. But it's difficult to obtain modeling for industrial drives. replace expensive dc motors. The invention of vector or field-oriented control, and the demonstration that ac motor can be controlled like a separately excited dc motor, brought renaissance in the high performance control of induction motor drives. In fact, with vector control, induction motor drive outperforms the dc drive because of higher transient current capability, increased speed range and lower rotor inertia. The most important aspect of the field-oriented control of induction motor is the transformation of the stator currents into a torque producing component (the quadrature q) and a flux-producing component (the direct path d). The indirect field oriented control is used in high performance industrial drive application. The primary advantage of this method is decoupling of torque and flux characteristics. This method is easy for implementation. This control technique is very sophisticated in implementation

using the conventional controllers.[4]. Fuzzy control has emerged over the years to become one of the most active and fruitful areas of research in the application of fuzzy set theory. In recent years, fuzzy logic has been successfully applied in many control applications including the control of ac induction motors. Furthermore, fuzzy logic controller has been shown to be insensitive to external disturbance and small unknown or erroneous information. A conventional PI controller requires accurate sensor inputs and appropriate values of the PI constants to produce high performance drive. Therefore the unexpected change in load conditions or environmental factors would deteriorate the drive performance. In contrast, fuzzy logic controllers use heuristic input-output relations to deal with vague and complex situations. One of the main advantages of using fuzzy logic (FL) is to overcome the need for a precise mathematical model of the controlled system. [5]. Fuzzy controllers are nonlinear controllers. FL can control nonlinear systems .that would be difficult or impossible to model mathematically. This opens doors for control systems that would normally be deemed unfeasible for automation. Fuzzy logic has been widely applied in power electronics and systems. Applications include, speed control of dc and ac drives, feedback control of converter, off line PI and PID tuning, non-linearity compensation, on-line and off-line diagnostics, modeling, parameter estimation, performance optimization of drive systems based on on-line search, estimation for distorted waves, and many other variety of applications.

II. IFOC

In IFOC the controlled stator currents are represented as the vector. This control is based on the projection which transforms the three phase time and speed dependent system into a two co-ordinate (d and q co-ordinates) time invariant system. The IFOC machines need two constants as input references. They are, the torque component (aligned with q co-ordinate). The flux component (aligned with d co-ordinate). [3]. As IFOC is simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth model. The main advantage of IFOC is decoupling of torque and flux characteristics. Under ideal IFOC conditions, the rotor flux linkage is oriented along the d-axis of the motor. In the synchronously rotating reference frame it follows

$$\lambda_{dr} = \lambda_{r*} = L_m i_{ds*} \tag{1}$$

$$\lambda_{qr} = d\lambda_{qr*} / dt = 0 \tag{2}$$

The rotor slip speed is determined as

$$\omega_{sl} = \omega_{sl*} = i_{qs*} / T_r i_{ds} \tag{3}$$

The electromagnetic torque T can be expressed as

$$T = 3PL_m^2 / 2 L_r (i_{ds} i_{qs}) \tag{4}$$

The IFOC achieves ideal torque and flux decoupling by means of coordinate transformations and two proportional integral (PI) current regulators. The regulator outputs are applied to the inverse of park transformation, the outputs of which are the stator voltages in the orthogonal reference

frame. The outputs of the SVPWM are the signals that drive the inverter. The current model generates the rotor flux position and is heavily dependent on Tr. The speed of error is processed by the FLC to generate the torque component current command i_{qs*} . See (Fig.1) The switching signal from the SVPWM is given to the 3 phase inverter. The 3 phase inverter converts the DC into AC. The three phase stator currents are measured. The measurements provide values i_a, i_b and i_c . The 3 phase currents are converted to the two axis system. The conversion provides current in the d, q rotating reference frame. This conversion is done by using the park transformation. The i_{ds} and i_{qs} components are compared to the references i_{dsref} (the flux reference) and are i_{qsref} (total reference). At this point, this control structure shows an interesting advantage it can be used to control either synchronous and induction machines simply changing the flux reference and obtaining flux position. The output of the PI controller is v_{qs} and v_{ds} . This voltage is given to the inverse park transformation. . The output of the inverse park transformation is v_{as}, v_{bs}, v_{cs} voltages. These voltages are given to the SVPWM. The outputs of the SVPWM are the signals that drive the inverter. The feedback signal is given to the controller until the rated speed is obtained.

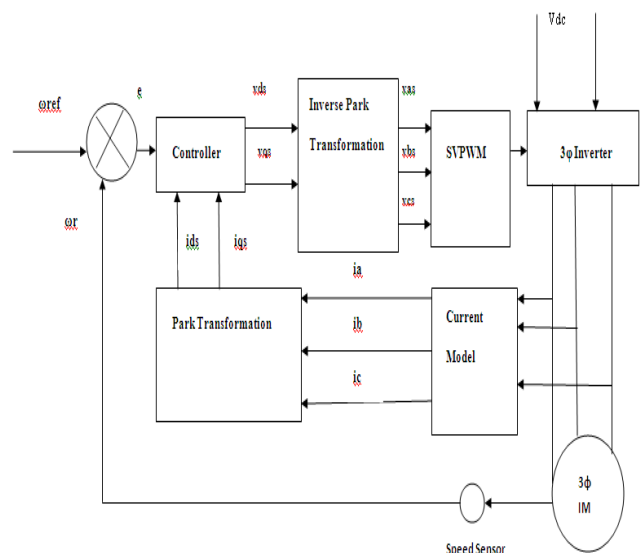


Fig 1. Block diagram of IFOC

III. TAKAGI – SUGENO FUZZY LOGIC CONTROLLER

A TSFLC can be developed by applying a tuning algorithm to directly adjust the following 1) the rules; 2) the MFs; 3) the scaling gains. The real time tuning of the scaling gains is necessary in order to maintain the desired performance of the drive. In this controller, the rotor speed ω_r is compared with the reference model output ω_r^* to generate the speed tracking error error e_{ω} . This error is evaluated in the evaluation block. If e_{ω} is within plus or minus 2 r/min, the self-tuning mechanism is not operational. If the magnitude of e_{ω} exceeds the predefined range, the evaluations block generates the tuning error e_{ω} to be injected into the TS-FLC block. This block generates weighting factors ω_e, ω_{ce} , and ω_u that adjust the gains n_e, n_{ce} , and n_u , respectively. The

tuning is performed such that the closed loop system behaves like a reference model $H_m(s)$. The tuning error and its rate of change are fuzzified by five symmetrical MFs, i.e., each updating gain is derived from a 5x5 TS-FLC lookup table with 25 fuzzy rules. TS-FLC operates in the following rule IF $\{\omega$ is ZE and $c\omega$ is ZE $\}$,

THEN $\{\omega_e$ is ZE, ω_{ce} is ZE, and ω_u is ZE $\}$ (5)

The term ZE corresponds rated value. As a result TS-FLC does not need to know the initial gains. The input output function of the proposed controller is described as follows:

$$U = \xi_{i,j}[(\mu_{Ei}(ne.e1) \cap \mu_{Ej}(nce.e2)).Un(I,j)(nu.u)] / \xi_{i,j}(\mu_{Ei}(ne.e1) \cap \mu_{Ej}(nce.e2)) \quad (6)$$

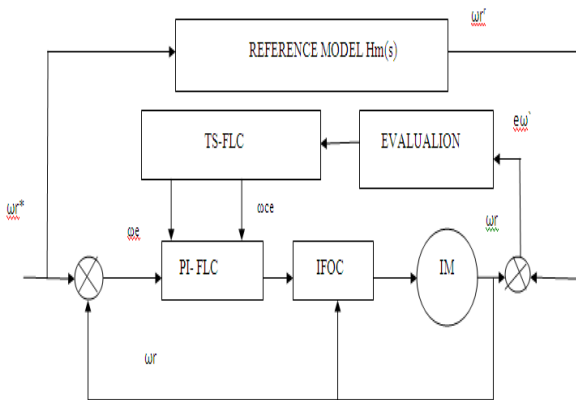


Fig 2- Structure of Ts-FLC

The difference here is that unlike the Mamdani method, the output MFs are only constants or have linear relations with the inputs. With a constant output MF (singleton), it is defined as the Zero- order Sugeno method, whereas with a linear relation, it is known as the first order sugeno method. Higher order sugeno methods are also possible, but are not of much practical use. The Sugeno method is widely used in adaptive neuro fuzzy interface systems. [10].

IV. PARTICLE SWARM OPTIMIZATION

A. Background of 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 reconfigure 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 each agent. Moreover, each agent knows the best value so far 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. Velocity of each agent can be modified by the following equation (7,8)

$$v_i^{k+1} = w v_i^k + c_1 r_1 \times (pbest_i - s_i^k) + c_2 r_2 \times (gbest - s_i^k) \quad (7)$$

Where, v_{ik} is current velocity of agent i at iteration k , $v_{i,k+1}$ modified velocity of agent i , r_1 and r_2 are random numbers, uniformly distributed in $[0,1]$, s_{ik} is current position of agent i at iteration k , $pbest$ is pbest of agent i , $gbest$ is gbest of agent i , w is weight function for velocity of agent i , c_1 and c_2 are positive constants, called cognitive and social parameter respectively. The following weighting function is usually utilized in (7)

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (8)$$

Where, w_{max} is initial weight, w_{min} is final weight, $iter_{max}$ is maximum iteration number, $iter$ is current iteration number. Using the above equation, a certain velocity that gradually gets close to (pbests) and (gbest) can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (9)$$

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

Step 1: Generation of initial condition of each agent Initial searching points (0_{is}) and velocities (0_{iv}) 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 (7)-(9)

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.

Features of the searching procedure of PSO can be summarized as follows:

(a) As shown in (7)-(9), PSO can essentially handle continuous optimization problem.

(b) PSO utilizes several searching points like genetic algorithm (GA) and the searching points gradually get close

to the optimal point using their (pbest) and the (gbest).

(c) The speed of each bird, Equation (8), has three components, namely, a momentum component trying to keep the same search direction, a component towards the birds self-best (cognitive term) and a component toward the global swarm best (social term).

(d) The above concept is explained using only XY-axis (two-dimension space). However, the method can be easily applied to n-dimension problem. Namely, PSO can handle continuous optimization problems with continuous state variables in an n-dimension solution space.

The PSO method appears to adhere to the five basic principles of swarm intelligence

1. Proximity, i.e., the swarm must be able to perform simple space and time computations;
2. Quality, i.e., the swarm should be able to respond to quality factors in the environment;
3. Diverse response, i.e., the swarm should not commit its activities along excessively narrow channels;
4. Stability, i.e., the swarm should not change its behavior every time the environment alters; and finally
5. Adaptability, i.e., the swarm must not be able to change its behavior, when the computational cost is not prohibitive.

Indeed, the swarm in PSO performs space calculations for several time steps. It responds to the quality factors implied by each particle's best position and the best position in the swarm, allocating the responses in away that ensures diversity. Moreover, the swarm alters its behavior only when the best particle in the swarm changes, thus, it is both adaptive and stable.

V. REALIZATION OF PSO-PI CONTROLLER TUNING OPTIMAL PARAMETERS

A. Proposed PSO-PI Controller

In this paper the particle swarm optimization algorithms (PSO) (each particle contains two members P and I) mean that the search space has two dimension and particles that must 'fly' in a two dimensional space, (PSO are applied to search globally optimal parameters of PI)[17]. PSO Algorithms are used to find the optimal parameters of IM speed control system. The conventional control system performance behaves poorly in characteristics and even it becomes unstable, when improper values of the controller tuning constants are used. The proposed PSO technique has the feature of tuning at every time, the particles are assumed new positions, they are ensured to update the best particle by comparing the costs corresponding to these positions with the previously selected best particle cost.

B. Fitness Function

In PI controller design methods, the most common performance criteria are integrated absolute error (IAE), the integrated of time weight square error (ITSE), integrated of squared error (ISE) and integrated of time weight absolute error (ITAE) that can be evaluated analytically in the frequency domain[18, 20]. These four integral performance criteria in the frequency domain have their own advantage and disadvantages. For example, disadvantage of the IAE and

ISE criteria is that its minimization can result in a response with relatively small overshoot but a long settling time because the ISE performance criterion weights all errors equally independent of time. Although the ITSE performance criterion can overcome the disadvantage of the ISE criterion, the derivation processes of the analytical formula are complex and time-consuming. In this paper a time domain criterion is used for evaluating the PI controller. A set of good control parameters P and I can yield a good response that will result in performance criteria minimization in the time domain. These performance criteria in the time domain include the overshoot, rise time, settling time, and steady-state error.

VI. CONCLUSION

In this thesis, the performance of IFOC based IM drive controlled approach is studied and presented using conventional controllers as well as with TS-FLC. This approach is very easy to implement. Since the conventional controller is a fixed gain controller it can be operated in a specified range. Then it is very much sensitive to load disturbances. Hence the proper response is not achieved. The results obtained with the conventional controller are not satisfactory So 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.

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