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New Improved PSO Based Parameter Estimation for Energy Efficient Control of Induction Motor Drive

J. G. Yadav[1] & S. P. Srivastava[2]
[1] *Deptt. of EEE, Raj Kumar Goel Institute of Tech. Ghaziabad, UP, India,*
[2] *Deptt. of Electrical Engg Indian Institute of Technology, Roorkee, India*
(E-mail: jg_yadav@rediffmail.com, satyafee@iitr.ernet.in)

Abstract: Induction motor is most frequently used electric machine in various applications due to its well known advantages. The method of vector control help achieve high performance from an induction motor but performance deteriorates due to variation of its parameters. In this paper improved version of Particle Swarm Optimization i.e. Systematic Mutation based Particle Swarm Optimization, SMPSO is used for parameter estimation and efficiency determination so that parameter variation effect is taken into account. Performance of SMPSO algorithm for parameter estimation and efficiency determination is compared using the conventional equivalent circuit and modified equivalent circuit of induction motor. It is observed that better performance is obtained with modified equivalent circuit.

Keywords: Efficiency, Induction Motor, Parameter Variation, Parameter Estimaion, SMPSO, Particle Swarm Optimization.

1. INTRODUCTION

Three-Phase induction motors are the most frequently used machines in various electrical drives. About 70% of all industrial loads on a utility are represented by induction motors it, therefore, becomes imperative that major attention be paid to the efficiency of induction motors. Induction motor is a high efficiency electrical machine when working close to its rated torque and speed. However, at light loads, iron losses increases dramatically, reducing considerably the efficiency. In an effort to improve the efficiency of motor drive, there have been improvements in the materials [1], design [2] and construction techniques [3]-[4]. However, motor loss is still greatly dependent on control strategies, especially when the motor operate at light load [5].

In recent decades many investigation have been done by researchers to control ac motors similar to that of separately excited dc machines that lead them to vector control theory. Vector control made the ac drive equivalent to dc drives in the independent control of flux and torque. The method of vector control helps achieve high performance from an induction motor [6]. The major disadvantage of the vector control scheme is that it is machine parameter dependent, since the model of the machine is used for flux estimation. The machine parameters are affected by variations of the temperature and saturation levels of the machine. Any mismatch between the parameters in the motor and that instrumented in the vector controller will result in the deterioration of performance in terms of steady state error and transient oscillations of rotor flux and torque [7].

Also the rotor field component and the torque producing current in vector control are decoupled, the torque sensitivity remains maximum in both transient and steady-state operation. In the field oriented vector control method for induction motor drives, the slip relation is employed to obtain the correct subdivision of the stator current into the torque & flux components. The slip calculation depends on the rotor time constant (value of Lr and Rr). Therefore, the parameter values used in controller need to be accurate for good static and dynamic performance of the induction motor drive. These parameters vary with variation in temperature, frequency and with variation in load. In-correct parameter values in the controller result in a detuning of the controller due to the loss of correct field orientation [8]. The detuning causes incorrect calculation of rotor filed angle and stator current components. The effects of detuning are the following: (1) The flux level is not properly maintained (2) The resulting steady state torque is not the command value (3) The torque response is not instantaneous (4) More stator current is drawn for the same load. Tracking and adapting the rotor resistance within the controller in real time can solve this problem [8]- [9].

The equations relating the required motor parameters to the given data are often nonlinear. Optimization techniques like Newton-Raphson have been applied to this type of problem with some success, although with the inherent problem of convergence to a local minimum instead of a global minimum. This problem has been minimized using evolutionary algorithms like GA [10]. The performance of GA and GP can be affected by numerical values of constant needed in implementation like population size and mutation rate. It is well known fact that the rotor resistance and the stator resistance may vary upto 100% and 50% of their nominal values respectively during operation of the IM due to rotor heating. Standard methods of estimation of parameters are the blocked rotor tests, no load test and the standard frequency response test. But these methods can not be used online during the normal operation of machine, [11] presents an adaptive variable structure identifier that provides finite time convergent estimate of the induction motor rotor resistance under feasible persistence of excitation condition. In [8], [9] interesting algorithms for IM parameter estimation are proposed using least square technique but more sophisticated filters are required when PWM inverters are used. Moreover, online variation of the IM parameters are not investigated. Remarkable results have been obtained by the authors of [12] in deriving rotor resistance and load torque estimates suitable for online rotor speed and flux adoptive control. The main drawback of this approach is that the rotor resistance estimator is based on a simplified model of IM which requires the rotor speed to vary slowly.

Many nonlinear programming techniques like Newton-Raphson, cyclic method, Hook, Jeeves and Rosenbrock methods have been applied to parameter estimation and hence efficiency determination of induction motors. The optimum determined by the Newton-Raphson technique depend heavily on initial guess of the parameters, with the possibility of a slightly different initial value, causing the algorithm to converge to an entirely different solution (Nangsue *et.al* 1999). Also this algorithm needs derivative during the optimization process, which may be difficult to calculate. Bounkhela, Zaim and Rezzong (2005) proved that the Rosenbrock method is better than the Scatter Search and Hook and Jeeves method in terms of fast and efficient search. Apart from conventional methods, some of the evolutionary techniques like Genetic Algorithm (GA) (Pillay *et.al* 1998) and Genetic Programming (GP) (Nangsue, Pillay and Chonry 1999), Partickle Swarm Optimization (PSO) (Benaidja and Khenfer 2006), Differential Evolution (DE) (Ursem and Vadstrup 2004) have been successfully applied to induction motor parameter(electrical and mechanical) estimation.

In this work an improved version of Particle Swarm Optimization, SMPSO is proposed for estimation of parameters of IM and its online implementation for efficiency calculation which eliminates the drawbacks of available methods.

2. EFFECT OF PARMETER VARIATION ON THE PERFORMANCE OF THE DRIVE

The slip gain K_s in indirect vector control is a function of machine parameters [13]. It is desirable that these parameters match the actual parameters of the machine at all operating conditions to achieve decoupling control of machine. The slip gain detuning problem is the serious disadvantage of indirect vector control.We know that

$$K_s = L_m R_r / L_r \varphi_m$$

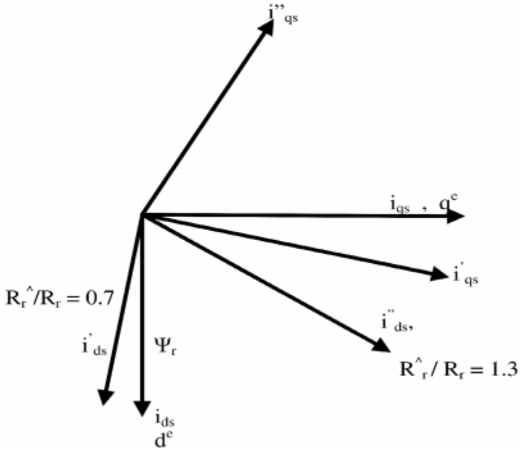

Figure 1: Vector Control Detuning Due to Rotor Resistance Mismatch

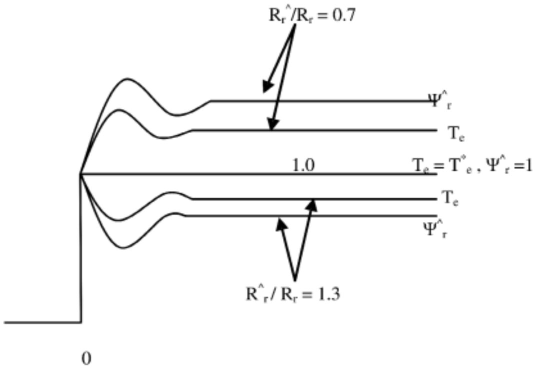

Figure 2: Effect of Detuning

With closed loop control the estimated value of φ_m is known, therefore the variation of three parameters (L_m, L_r, and R_r) is of concern. The saturation effect of magnetizing inductance L_m almost cancels the variation of L_m / L_r, thus leaving the dominant effect of rotor resistance variation on K_s.

With open loop flux control at steady state condition, $\varphi_m = i_{ds} L_m$, therefore K_s becomes a function of rotor time constant.

The effect of rotor resistance detuning and the corresponding coupling effect are explained in Figure 1 above where R_r actual rotor resistance of machine and R'_r is estimated resistance used in K_s parameter. If R'_r is lower than R_r the slip frequency w^*_{sl} will be lower than the actual giving backward alignment of $i'_{ds} - i'_{qs}$ shown in Figure 1, with such a misalignment if torque is increased by a step of i'_{qs} a component of this current on the d^e axis will increase the flux i.e. overfluxing. The resulting torque and flux responses in both the transient and steady state conditions are shown in Figure 2. On the other hand the effect of higher than the actual resistance ($R'_r/R_r = 1.3$) will cause underfluxing and the corresponding performance is indicated in Figure 2.

3. OPTIMIZATION ALGORITHM USED FOR PARAMETER ESTIMATION

Particle Swarm Optimization (PSO) technique has become very popular since last decade to solve multi dimension non linear programming problems due to its less complexity, fast convergence, etc., than Genetic Algorithm and Evolutionary Programming [14]. Although the rate of convergence of PSO is good due to fast information flow among the solution vectors, its diversity decreases very quickly in the successive iterations resulting in a suboptimal solution. Aiming at this shortcoming of PSO algorithms, many PSO structures are proposed in the literature. For all these approaches the common shared feature is to avoid premature convergence. In reference [15] authors have suggested an approach to prevent the convergence to local optima by improving the swarm exploration and exploitation through two neighborhood structures: geometrical nearest neighbor and global random neighbor.

Many recent developments in science, economics and engineering demand numerical techniques for searching global optima to corresponding optimization problems [16]. PSO technique is a population based stochastic search technique first introduced by Kennedy and Eberhart.

PSO can be represented by the concept of velocity and position. The two basic equations which govern the working of PSO are that of velocity vector (v_{id}) and position vector (x_{id}) are given by [16]:

$$v_{id} = wv_{id} + c_1 r_1 (p_{id} - x_{id}) + c_2 r_2 (p_{gd} - x_{id}) \tag{1}$$

$$x_{id} = x_{id} + v_{id} \tag{2}$$

The first part of equation (1) represents the inertia of the previous velocity, the second part is the cognition part and it tells us about the personal thinking of the particle, the third part represents the co-operation among particles and is therefore named as the social component. Acceleration constants c_1, c_2 and inertia weight w are the predefined by the user and r_1, r_2 are the uniformly generated random numbers in the range of [0, 1].

In this work improved version of Particle Swarm Optimization i.e. Systematic Mutation based Particle Swarm Optimization, SMPSO algorithm is used. SMPSO is an extension of the SPSO algorithm by including an component of mutation in it[17]. The mutation operator defined in SMPSO algorithm uses quasi-random Sobol sequence and is called a systematic mutation(SM) operator. In the SMPSO algorithm the worste particle of the swarm is muted by the use of SM operator.

The SM operator is defined as

$$SM = R_1 + (R_2 / \ln R_1)$$

Where R_1 and R_2 are random numbers in Sobol sequence.

The idea behind applying the mutation to the worste particle is to push the swarm from the back. The quasi-random numbers used in the SM operator allows the worste particle to move forward systematically.

4. METHODS OF PARAMETER ESTIMATION AND EFFICIENCY DETERMINATION

The general block diagram of parameter estimation at different loading conditions of Induction Motor using optimization algorithm is shown in Figure 3. The stator line resistance is measured after shutting down the motor. The parameters: rotor and core loss resistances and stator and magnetizing inductances at different loading conditions are tabulated as look-up table and are used while simulating the motor with energy controller.

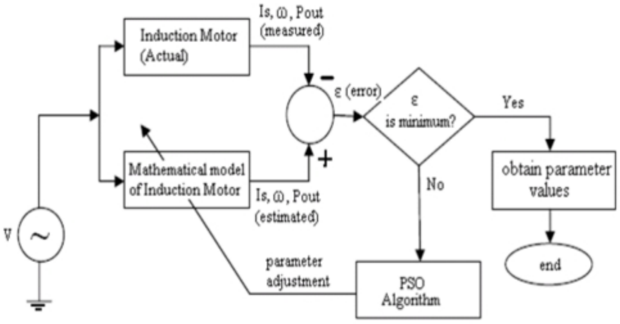

Figure 3: Block Diagram for Induction Motor Parameter Estimation and Efficiency Determination

First, the stator line resistance is measured after shutting down the motor. Summation of losses method is used for efficiency determination. The winding arrangement of a star connected motor is shown in Figure 4 and resistance per phase is calculated as bellow:

$$r1 = r1_{line} / 2$$

where $r1_{line}$ is stator line resistance and r_1 is stator phase resistance.

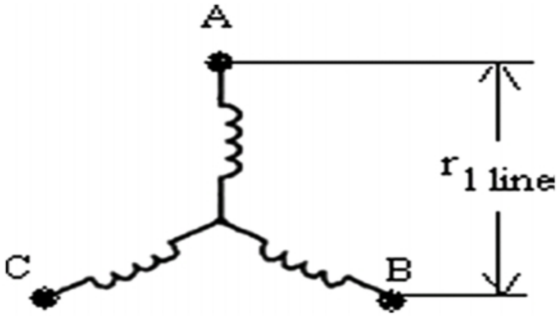

Figure 4 : Winding Arrangement of Star Connected Motor

Some measurements on the motor are required before running the optimization algorithm to estimate the motor parameters, these measurements are stator line to line voltage V_1, stator current I_1, input power P_{in}, and rotor speed at different load points. The pf can be calculated as:

$$Pf = P_{in} /(3)^{1/2} V_1 I_1$$

Two variation are made in the conventional exact equivalent circuit of induction motor for comparison: (1) inclusion of stray load loss resistance r_{str} as shown in Figure (5) and (2) parallel connection of x_m, r_m is transformed into series connection as x'_m, r'_m as shown in Figure (6).

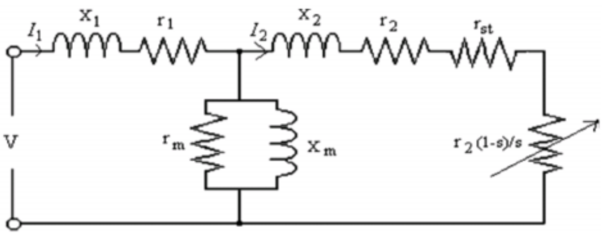

Figure 5: Equivalent Circuit of Induction Motor with Stray Loss Resistance

The values of x'_m and r'_m can be calculated as below:

$$r'_m = r_m x^2_m /(r^2_m + x^2_m);\ x'_m = r^2_m x_m / (r^2_m + x^2_m)$$

where x_m mutual inductance and r_m is core loss component of resistance.

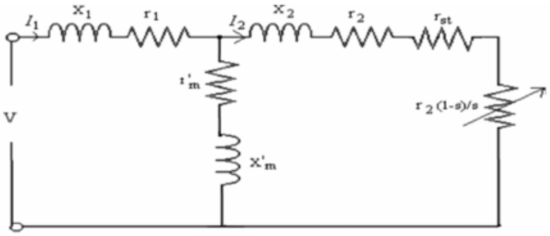

Figure 6: Modified Equivalent Circuit of Induction Motor

The goal of optimization algorithm is to minimize the error between the measured and calculated parameters. For this purpose the objective function used is

$$\text{Max } ff1 = 1 / (f_1^2 + f_2^2)$$

Where $f_1 = (I_{1est} - I_1)\ 100 / I_1$ and $f_2 = (P_{inest} - P_{in}) 100 / P_{in}$

5. SIMULATION RESULTS AND DISCUSSION

The simulation results corresponding to Figure (5) are:

Efficiency : 85.5178

I_1 = 7.50089

P_inp_est = 3728.26

Pf_est = 0.79765

P_out_est = 3188.33 and that for Figure (6) are:

Efficiency = 85.9009

I_1 = 7.95734

P_inp_est = 3779.65

Pf_est = 0.750808

P_out_est = 3246.75

The decision variables of the objective function are x_1, r_2, x_m and r_m. The optimization algorithm SMPSO is used to determine the above unknown variables. The assigned parameters of the given motor are K_a = 225, K_c = 234.5, r_1 =1.635 ohm.

The comparison of result of algorithm corresponding to Figure (5) and Figure (6) shows that the Figure (6) in which series connection of x'_m and r'_m is considered to give better result in terms of efficiency determination. Hence, the parameters, namely current, input power, speed and output power are sufficient to estimate motor parameters accurately, quickly determine efficiency and obtaining good transient and steady state performance.

6. CASE STUDY

In order to illustrate the importance of SMPSO controller for estimating the parameters and efficiency calculation of the IM, practical load (mine hoist) [18] diagram is considered in this paper and is shown in Figure (7). T is assumed with respect to duty time of the load in the mine hoist.

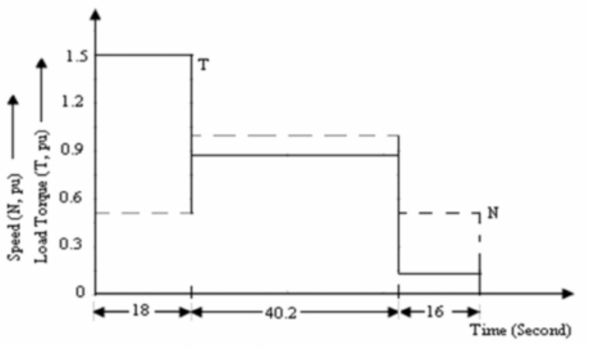

Figure 7: Mine Hoist Load

7. CONCLUSION

In this work we implemented improved version of PSO namely SMPSO for parameter estimation and efficiency calculation of an induction motor. Modified equivalent circuit is used along with conventional equivalent circuit for the estimation of parameters and calculation of the efficiency of induction motor. These results are compared and it is observed that modified equivalent circuit helps in obtaining better results in terms of parameter estimation and efficiency determination.

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