FIELD-ORIENTED CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR WITH OPTIMUM PROPORTIONAL-INTEGRATOR-DERIVATIVE CONTROLLER USING DYNAMIC PARTICLE SWARM OPTIMIZATION ALGORITHM

Amir Ahmadian[1], Mahmood Ghanbari[*2], Hasan Rastegar[3]
[1.] Department of Electrical Engineering, AliAbad Katoul Branch, Islamic Azad University, AliAbad Katoul, Iran.
[2.] Young Researchers and Elite Club, AliAbad Katoul Branch, Islamic Azad University, AliAbad Katoul, Iran.
[3.] Department of Electrical Engineering, Amirkabir University of Technology, P.O. Box: 15875-4413, Tehran, Iran.
[*]**Corresponding author**: Mahmood Ghanbari, Email: mmm_gh_53@yahoo.com, Fax: +98 1732158891

Abstract: *In this paper, optimum design of PID controller for speed control of permanent magnet synchronous motor is presented using dynamic particle swarm optimization algorithm. Controller design is achieved through a model of motor with the aid of field-oriented control with linear system. Dynamic particle swarm optimization algorithm can optimally tune the PID factors and provide an optimum controller. As a result, performance characteristics of system step response such as overshoot, rise time and settling time will reduce in PMSM and this performance improvement is investigated in MATLAB. The obtained results show optimum behavior of the proposed method comparing with Genetic Algorithm optimization of PID factors tuning for field-oriented control of PMSM.*

Keywords: Permanent magnet synchronous motor (PMSM), Proportional-Integrator-Derivative (PID) Controller, Optimization, Dynamic Particle Swarm Optimization (DPSO) Algorithm

1. INTRODUCTION

Permanent magnet synchronous motors (PMSMs) as variable speed drives have been replacing induction motors in industrial applications due to good features like low volume, low weight, high efficiency, high standalone torque density and ease of control. PMSMs are now widely used as high performance starter such as industrial robots and machining tools (Gupta and Gupta. p, 2012). Therefore, speed control of such motors is of great importance. In the recent decades, meaningful progress is achieved for speed control techniques. Control methods such as adaptive control, fuzzy control and neural networks are presented. However, PID controllers are widely used that are based on the proportional, integrator and derivative variables.

Unfortunately, these techniques have no effective method for optimum tuning of PID parameters because the motor model is a set of non-linear and coupled elements. In this context, Genetic Algorithm has gained a lot of attention but some researches have shown the drawbacks of this method (HU et al., 2012). Particle Swarm Optimization (DPSO) Algorithm was first introduced by Kennedy and Eberhart in 1995 for better optimization of such parameters which is an improved heuristic algorithm. PSO has features such as simple concept, easy execution and efficient calculations (Nasri et al., 2007). This is an efficient method for non-linear constrained systems (HU et al., 2012). In this paper, an optimization method based on DPSO is presented for design of PID controller in order to control the speed of PMSM. In the proposed method of this paper, PSO with dynamic weights technique is used

2. Dynamic model of permanent magnet synchronous motor

There are different methods for speed control of permanent magnet synchronous motor that some of them are used in (Balda and Pillay, 1990; Ayyar et al., 2012). In this paper, equations of ref (Krishan, 2010) are used as reference for speed control of PMSM as follow:

The equation of q-axis voltage when d-axis current is zero (for maximum torque) is as follow:

$$V_{qs}^{r} = \left(R_s + L_q p\right) i_{qs}^{r} + \omega_r \lambda_{af} \quad (1)$$

Electromechanical equation of PMSM is as (2):

$$\frac{P}{2}\left(T_e - T_l\right) = J_p \omega_r + B_1 \omega_r \quad (2)$$

Electromagnetic torque equation is:

$$\frac{P}{2}\left(T_e - T_l\right) = J_p \omega_r + B_1 \omega_r \quad (3)$$

And if the applied load is with friction:

$$\frac{P}{2}\left(T_e - T_l\right) = J_p \omega_r + B_1 \omega_r \quad (4)$$

Replacing equations (3) and (4) in (2) gives (5):

$$\left(J_p + B_t\right)\omega_r = \left\{\frac{3}{2}\left(\frac{P}{2}\right)^2 . \lambda_{af}\right\} i_{qs}^{r} = k_t + i_{qs}^{r} \quad (5)$$

And

$$B_t = \frac{P}{2} B_l + B_l \quad (6)$$

And

$$K_t = \frac{3}{2}\left(\frac{P}{2}\right)^2 \cdot \lambda_{af} \quad (7)$$

Figure (1) shows block diagram of equations (1) and (5) when it is combined with current transfer function and speed control feedback loops.

Inverter is modeled like a gain with delayed time which its transfer function is given in equation (8).

$$G_r(s) = \frac{k_{in}}{1+T_{in}} \quad (8)$$

where :

$$\begin{cases} k_{in=0.265\frac{V_{dc}}{V_{cm}}} \\ T_{in=\frac{1}{2fc}} \end{cases} \quad (9)$$

V_{dc}: input dc voltage for inverter
V_{cm}: maximum control voltage
f_c: switching frequency of inverter

Block diagram of current loop and speed control is shown in Figures (2) and (3), respectively.

$$\frac{i_{qs}^{r}}{i_{qs^*(s)}^{r}} = \frac{K_{in} k_a (1+sT_m)}{H_C K_a k_{in}(1+sT_m) + (1+sT_{in}) \{K_a K_b + (1+sT_a)(1+sT_m)\}} \quad (10)$$

$$k_a = \frac{1}{R_s}; T_a = \frac{L_q}{R_s}; k_m = \frac{1}{B_t}; T_m \frac{J}{B_t}; k_b = k_t k_m \lambda_{af} \quad (11)$$

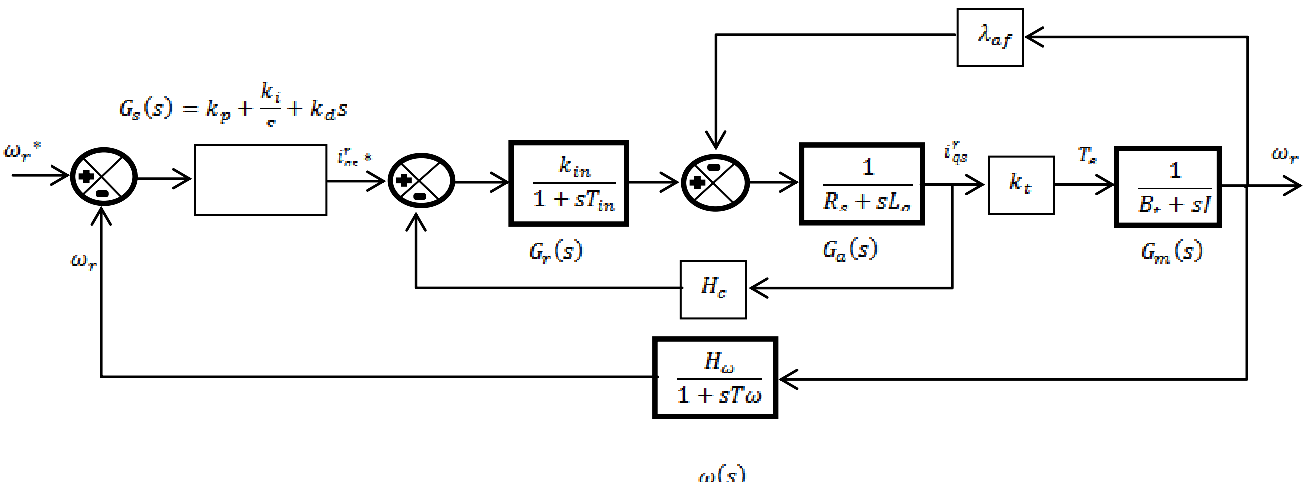

Figure (1) Block diagram of speed contol of PMSM (Ayyar et al., 2012)

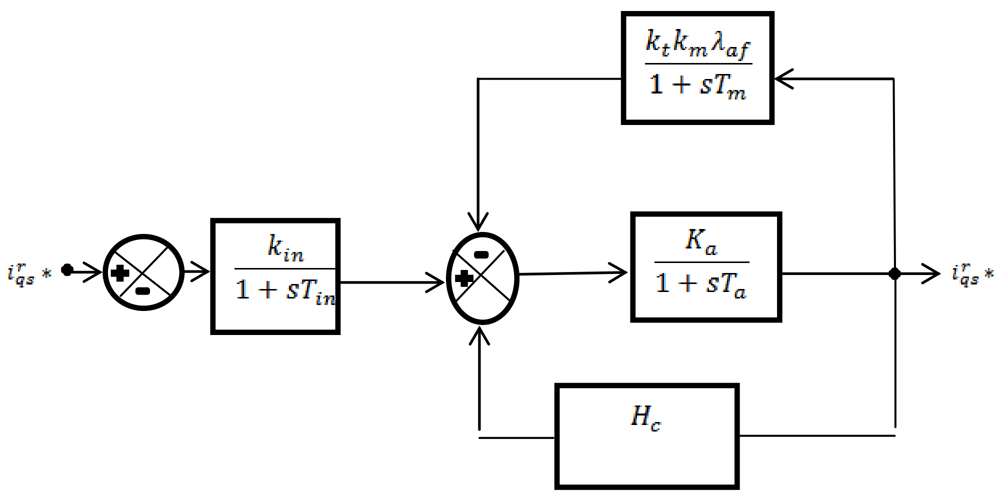

Figure (2) Block diagram of current loop control of PMSM (Ayyar et al., 2012)

3 Dynamic particle swarm optimization algorithm

PSO is an evolutionary method with individual improvement mechanism, group cooperation and competition. In these decades, this method is being paid attention which is based on simplified bio social models and it is widely used in continuous unconstrained optimization problems. PSO has memory and the data of proper solutions are kept in mind but in GA when the population variations occur, the previous obtained data is lost (Ghanbari et al., 2013).

PSO is initialized by a set of random particles and then they find the best solution using iteration. The technique follows two particles for updating, one particle which is optimal is named final local best (P_{best}) and the other optimal particles are named final global best (G_{best}) (YU and Li-meng, 2008).

The stages for PSO are defined now:

Location and velocity of i_{th} particle in the search space d at time t is:

$$X_i = [x_{i,1}, x_{i,2}, \dots, x_{i,d}]^t \quad (12)$$

$$V_i = [v_{i,1}, v_{i,2}, \dots, v_{i,d}]^t \quad (13)$$

The best location of each particle is equal to the best value of objective function at time t:

$$P_i = [p_{i,1}, p_{i,2}, \dots, p_{i,d}]^t \quad (14)$$

The location of best global particle is equal to the best value of objective function of all population at time t:

$$P_g(t) = [p_{g,1}(t), \dots, p_{g,d}(t)]^t \quad (15)$$

The new velocity of each particle in time t+1 is:

$$P_g(t) = [p_{g,1}(t), \dots, p_{g,d}(t)]^t \quad (16)$$

where c_1 and c_2 are velocity constants, ω inertia coefficient, r_1 and r_2 are considered at final as two unexpected numbers.

$$v_{i,j}(t+1) = wv_{i,j}(t) + c_1 r_1 \left(p_{i,j} - x_{i,j(t)}\right) + c_2 r_2 \left(p_{g,j} - x_{i,j}(t)\right), j = 1,2, \dots, \alpha$$

3.1. Dynamic weights

In PSO the new location of particles can be varied by weights of these parameters. Location of particles in iterative executions is varied based on best local experience, best global experience and a random velocity. Weights are categorized into static and dynamic groups.

Static weights are defined by iterative executions of algorithm and are set before the program execution. But dynamic weights vary in each iteration and provide the possibility of utilizing a proper factor to find the optimal solution. The factors of each control variable are calculated separately and lead to optimal values of different particles. Dynamic weights are utilized considering the proper values of particles and best provided locations in each iteration. Dynamic weights show better, quicker and more stable results with higher convergence (Altaf et al., 2012).

A good proposition is to select the inertia coefficient high in the first step and then decrease it gradually to reach the optimal solution as the following relation:

$$\omega_{(k)} = \omega_{max} - \frac{K}{K_{MAX}}(\omega_{max} - \omega_{min}) \qquad (18)$$

Stages of DPSO are expressed as follow (Ghanbari et al., 2013):

Stage (1): production of the first population

Stage (2): determination of the best individual and overall memories.

Stage (3): updating the location and velocity (17)

Stage (4): updating the inertia coefficient

Stage (5): if the stop criteria are not met, returning to Stage (2)

Stage (6): otherwise, finish

4. SIMULATION AND RESULTS

In this paper, simulation is performed for proposed method on PMSM of ref (Ayyar et al., 2012) based on Table (1) and the transfer function of system is based on the specifications of Table (1).

$$G(S) = \frac{1657.078S+2763.2}{0.00000576S^4+0024S^3+4.2s^2+27.778s+34.63} \qquad (19)$$

which the transfer function (19) is reduced to the following relation with the method that Portone has noted in (Portone, 1997) :

$$G_r(s) = \frac{394.4s+336.56}{s^2+5.796s+4.22} \qquad (20)$$

Figure (4) shows the response diagram to the unit step input and the reduced system. As shown, the response of the two systems is identical.

In order to adjust the initial condition of DPSO, the number of selected particles are considered 50 in range [0,1] and 200 iteration and error convergence is selected based on Figure (5) which shows very good convergence. Then, PID factors by optimizing the objective function are given in Table (2). Firstly, the obtained results are compared with the results of GA (Ayyar et al., 2012).

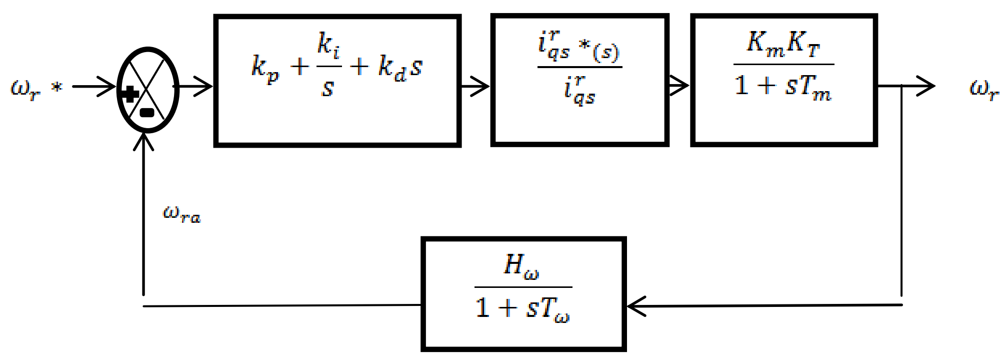

Figure (3) Speed-control loop (Ayyar et al., 2012)

Table (1): Specifications of PMSM (Ayyar et al., 2012)

$R_{S}=1.4$	P= 6
$L_d = 0.0056H$	$f_c = 2KHZ$
$L_q = 0.009H$	$V_{cm} = 10V$
$\lambda_{af} = 0.1546wb - turn$	$H_\omega = 0.05V/V$
$B_t = 0.01N.m/rad/s$	$H_C = 0.8V/A$
J=0.006	$V_{dc} = 285V$

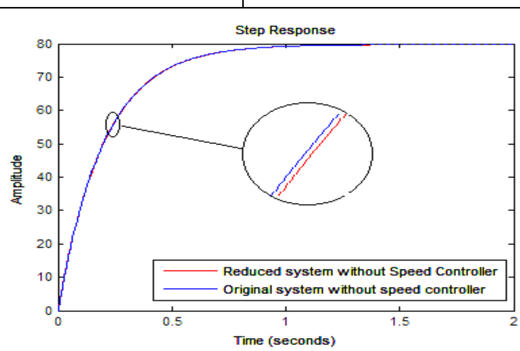

Figure (4) response diagram to the unit step input of original system and the reduced system (Ayyar et al., 2012)

After that, the values of maximum overshoot, settling time and stability index in an objective function to minimize it for PID controller are given in Table (3).

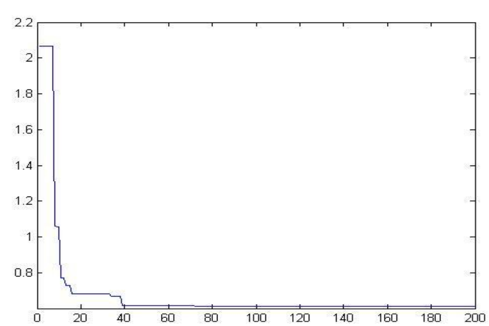

Figure (5) Error convergence

As shown in Figure (6), the proposed method has reached to a better response comparing to the main system and reduced system of (Ayyar et al., 2012) by applying the designed controller to the main system and without reducing the rank of main system. Tables (3) illustrate the details of this comparison.

The proposed method has provided much better step response condition

4.1. Objective function

$$MP+TS+SI \qquad (21)$$

MP: maximum overshoot

TS: settling time

SI: Stability index

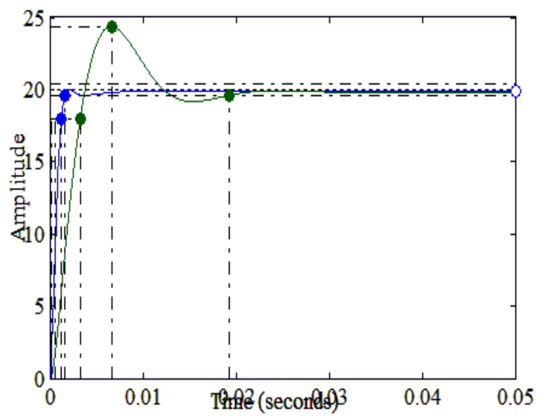

Figure (6) Comparing the motor output to the unit step input between DPSO controller and GA controller

Table (2) the obtained coefficients

	Kp	Ki	Kd
GA	17.70713	31.7933	0.00407
DPSO	18.2616	83.5732	0.0378

Table (3) the results of settling time, maximum overshoot and rise time

	Settling time	Rise time	Maximum overshoot
GA	0.0193s	0.00268	21.9
DPSO	0.00166s	0.00106	0

5. CONCLUSION

In this paper, an optimization method based on DPSO is presented to optimally design the PID controller for speed control of PMSM. As a result, this method gives better solution comparing to GA that leads to optimal factors for PID controller. The proposed method emphasized on reducing the complexity of controller design. The obtained results of the controller parameters are then combined with the main system and these closed-loop values are generated in an appropriate performance using unit step input.

REFERENCES

[1] Gupta .N.P, Gupta .P, " Performance Analysis of Direct Torque control of PMSM Drive Using SVPWM -Inverter" Power Electronics(IICPE), 2012 IEEE India International Conference on, pp. 1-6, 6-8 Dec.2012

[2] HU. H, HU.Q, LU .Z, XU. D, " Optimal PID Controller Design in PMSM Servo System Via particle Swarm Optimization" Industrial Electronics Society, 2005. IECON 2005. 31ht Annual Conference of IEEE, 6-10 Nov.2005

[3] Nasri. M, Nezamandi-Pour. H, Maghfoori. M, " A PSO-Based Design of PID Controller for a Linear Brushless DC Motor" World Academy of Since Engineering and technology 2007

[4] Krishnan. R, "Permanent Magnet Synchronous and Brushless DC Motor Drives", Taylor & Francis Group, 2010

[5] Balda. Juan C, Pillay. Pragasen, "SPEED CONTROLLER DESIGN FOR A VECTOR CONTROLLED PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE WITH PARAMETER VARIATIONS ", IEEE, 1990

[6] Ghnabari .M, Motalebi Saraji .A, Ahmadian .A " Parameters Estimation of Fractional Order Systems with Dominant Pole Using Particle Swarm Optimization (PSO) Algorithms" published in European Journal of Scientific Research , vol,113, ISSUE 4 , 2013

[7] Ayyar. K, Ramesh. K , Gurusamy. G, " Design of Speed Controller for Permananent Magnet Synchronous Motor Drive Using Genetic Algorithm Based Lower Order System Modelling" Journal of Computer Science 8 (10): 1700-1710, 2012

[8] YU. R, Li-meng. Z, " PMSM Control Research Based on Particle Swarm Optimization BP Neural Network" International Conference on Cyberworlds 2008

[9] Altaf. Q.H, Badar. Umre. B.S., Junghare. A.S., " Reactive power control using dynamic Particle Swarm Optimization for real power loss minimization" Electrical Power and Energy Systems 41 (2012) 133–136

[10] Portone. A, "Model reduction techniques intokamak modelling" Proceedings of the 36th IEEE Conference on Decision and Control, IEEE Xplore Press, San Diego, CA, pp: 3691- 3696. DOI: 10.1109/CDC.1997.652430,1997

Nomenclature

v_{qs}^{r}	q-axis voltage on rotor reference frame
Rs	Stator resistance
L_q	Self-inductance
p	derivative
i_{qs}^{r}	q-axis vector current on rotor reference f
ω_r	Reference speed
λ_{af}	Flux linkage
P	Number of poles
T_e	Electromagnetic torque
T_l	Load torque
J	inertia
B_1	Friction coefficient
B_l	Load constant
ω_m	Rotor mechanical speed
B_t	Total Friction coefficient