Tuning PI-Controller Using Swarm Algorithm For Control Of Permanent Magnet Synchronous Motor For Electric Vehicle

A. S. Elwer S. A. Wahsh
Electronics Research Institute
Dokki ,Giza-Egypt

M.O.Khalil A.M.Nour-Eldeen
Cairo University
Giza-Egypt

Abstract

Electric Vehicle (EV) is a dream for the human being city traffic without exhausting gas and with low noise. Permanent Magnet Synchronous Motor (PMSM) became at the top of ac motors in high performance drive systems such as EV. This paper presents a modern approach of speed control for PMSM using Particle Swarm Optimization (PSO) algorithm to optimize the parameters of PI- Controller. The overall system will be simulated under various operating conditions and an experimental setup is prepared. The use of PSO as an optimization algorithm makes the drive robust, with faster dynamic response, higher accuracy and insensitive to load variation. The system is tested for a step change in load, the simulation results showing good dynamic response with fast recovery time.

1.Introduction

Global warming by carbon dioxide and air pollution in urban is getting serious these days. In the mean time EV are very inferior. Petroleum resources being exterior in one charge travel distance with eliminating emission. Recent developments in microprocessors, magnetic materials and semiconductors technologies have offered an excellent opportunity to use AC motors in high performance drives systems. PMSM became at the top of ac motors in the medium range of power and it became very popular choice in drive technology over the last few years due to some of its inherent advantages. These advantages include high torque to current ratio, large power to weight ratio, higher efficiency and robustness. The application of PMSM drive to an EV allows an enlarged speed range with an inverter size lower than in a conventional flux-oriented induction motor drive [1]. The intelligent PI speed controller uses the PSO algorithm to optimize the PI-parameters(Kc and τ_I) instead of the traditional trail and error method, the drive system plays an important role to meet the other requirements. It should enable the drive to follow any reference speed tacking into account the effects of load impact, saturation and parameter variation. **MATLAB SIMULINK** software packages are utilized to simulate each part of the system under study. The simulation of the overall system is composed of these simulated components when they are properly interconnected

2. Methods for Tuning PI-Controllers

For the last 50 years, PI-controllers have had remarkable success in various industries. They have been applied to control almost any process one could think of, from aerospace to motion control, from slow to fast systems. Alongside this success, however the problem of tuning PI-controllers has remained an active research area. Furthermore, with changes in system dynamics and variation in operating points PI-controllers should be retuned on a regular basis. This has triggered extensive research on the possibilities and potentials of the so called adaptive PI-controllers. Loosely defined, adaptive PI-controllers avoid time-consuming manual tuning by providing optimal PI-controllers settings automatically as the system dynamics or operating points change [2].

2.1 Trial and error

PI-Controller equation is:

$$p(t) = K_c\left[e(t) + \frac{1}{\tau_I}\int_0^t e(t)dt \right] \qquad (1)$$

1. Eliminate the integral action by setting and τ_I to as large a value as possible
2. Set K_c at a low value
3. Increase the controller gain K_c by small increments until continuous cycling occurs after a small set point or load change. The term “continuous cycling” refers to a sustained oscillation with constant amplitude.
4. Reduce K_c by a factor of 2.
5. Decrease τ_I in small increments (this INCREASES integral control) until continuous cycling occurs again. Set τ_I to 3 times this value

Disadvantages

1. It is quite time consuming if a large number of trial are required or if the process dynamics are slow. Testing can be expensive because of lost productivity or poor product quality
2. Continuous cycling may be objectionable because the process is pushed to the stability limit. Consequently, if external disturbances

or a change in the process occurs during controller tuning, unstable operation or a hazardous situation could result.

The tuning process is not applicable to processes that are open loop unstable because such processes typically are unstable at high and low values of Kc but are stable at an intermediate range of values.

3. Particle Swarm Optimization

The particle swarm optimization was originally designed by Kennedy and Eberhart [3]-[5]. The technique involves simulating social behavior among individuals (particles) "flying" through a multidimensional search space, each particle representing a single intersection of all search dimensions. The particles evaluate their positions relative to a goal (fitness) at every iteration, and particles in local neighborhood share memories to adjust their own velocities and thus subsequent positions. The original PSO formulate define each particle as a potential solution to a problem in D-dimensional space, with particle j represented as:

$X_j = (X_{j1} , X_{j2} , \ldots\ldots\ldots , X_{jD})$

Also, each particle maintains a memory of its previous best position as

$P_j = (P_{j1} , P_{j2} , \ldots\ldots\ldots , P_{jD})$

And velocity along each dimension represented as:

$V_j = (V_{j1} , V_{j2} , \ldots\ldots\ldots\ldots , V_{jD})$

At each iteration, the P vector of the particle with the best fitness in the local neighborhood, designated g, and the P vector of current particle are combined to adjust the velocity along each dimension, and that velocity is then used to compute a new position for the particle as follow [6]:

$$V_{j,i} = wV_{j,i} + C_1 r_1 (P_j - X_j) + C_2 r_2 (P_{gj} - X_j) \qquad (2)$$

$$X_j := X_j + V_j \qquad (3)$$

3.1. Basic method

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 V_x (the velocity of x-axis) and V_y (the velocity of y-axis) . Modification of the agent position is realized by the position and velocity information. Bird flocking optimizes a certain object function. Each agent knows its best value so, far (pbest) and its XY position. This information is analogy of personal experiences of each agent. Moreover, each agent knows the best value so, far in the group (gbest) among bests. This information is analogy of knowledge of how the other agents around them have performed. Namely, each agent tries to modify its position as shown in fig.(1).

- The current position (X,Y)
- The current velocities(V_x, V_y)
- The distance between the current position and pbest

The distance between the current position and gbest [7]:

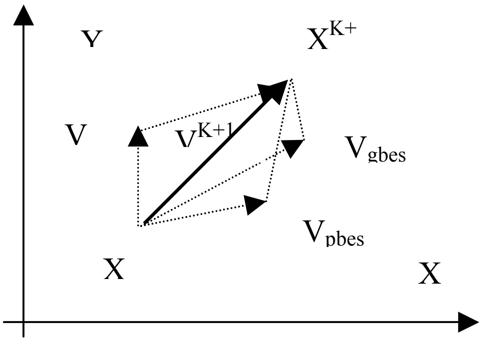

Fig. (1) concept of modification of a searching point by PSO

3.2. Implementation of PSO

The implementation of PSO program is very easy and takes a few lines in the program so, reduce the time of the whole program, the steps of the PSO program is described as follows:

Step.1 Generation of initial condition of each agent

Initial searching points(X_i^o) and velocities(V_i^o) 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 the 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 changing using (1) and (2)

Step.4 Checking the exit condition

The current iteration number reaches the predetermined maximum iteration number then exit. Otherwise , go to step 2 [7].

4. Modeling of PMSM in rotor reference frame

4.1 The electrical system

$$v^r_q = (r_s + pL_s) i^r_{qs} + \omega_r L_s i^r_{ds} + \omega_r \lambda'^r_m \qquad (4)$$

$$v^r_d = (r_s + pL_s) i^r_{ds} - \omega_r L_s i^r_{qs} \qquad (5)$$

$$v_{os} = (r_s + pL_{ls}) i_{os} \qquad (6)$$

The expression for electromagnetic torque is obtained by expressing as follows[8]:

$$T_e=(3/2)(P/2)\lambda'^{r}_{m} i^{r}_{qs} \qquad (7)$$

4.2 The mechanical system

$$\frac{d}{dt}\omega_r = \frac{1}{J}(T_e - B.\omega_r - T_m) \qquad (8)$$

5. Designing of PI-controller using PSO

PI-controller is a good controller in the field of machine control, but the problem is the mathematical model of the plant must be known in order to solve the overall system and the PI-parameters are obtained, so several methods are introduced to tune PI-controller Our proposed method is using PSO to optimize the PI-controller parameters ,the PSO algorithm used on-line to update the PI-parameters(K_c and τ_I), as shown in fig.(2)

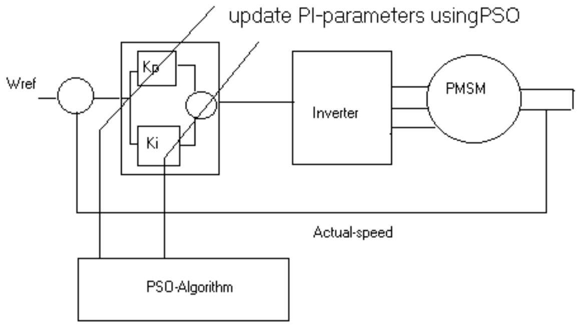

Fig.(2) Tuning PI-Controller Using PSO

6. The simulation results

The overall system is simulated and tested when it is subjected to a step increase in load torque. Three cases are studied to indicate the effect of increasing the number of iteration for the PSO in optimizing the PI-parameters. The first case of study, the number of iteration was 10,000 the results of this case are indicated through fig.3 to fig.5 ,In Fig.3 the speed response of the system for 1.0 p.u. step change in speed reference is indicated due to a step change in the load which is indicated in fig.4

.In fig.5 three-phase currents of the motor in the stationary reference frame is indicated. In the second case , the number of iteration is increased to 100,000 iteration, the results of this case are indicated through fig.6 to fig.8, from these figures it is shown that as the number of iteration increase the harmonics are decreased. A speed tracking include acceleration and deceleration is shown through fig.9 to fig.11

6.1 Case one (10kHz, 10,000 iteration)

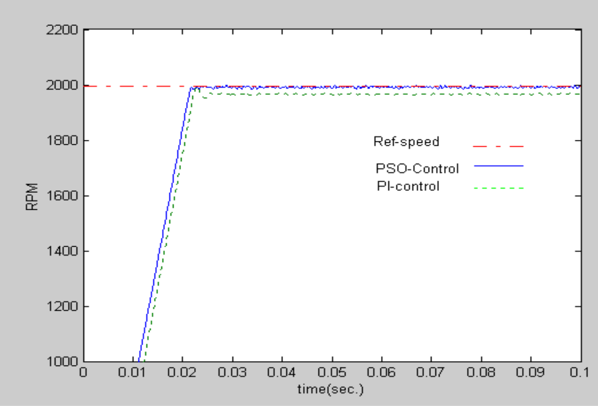

Fig.(3) speed response for a step change in load torque(3N.m) for 10kHz, 10,000 iteration

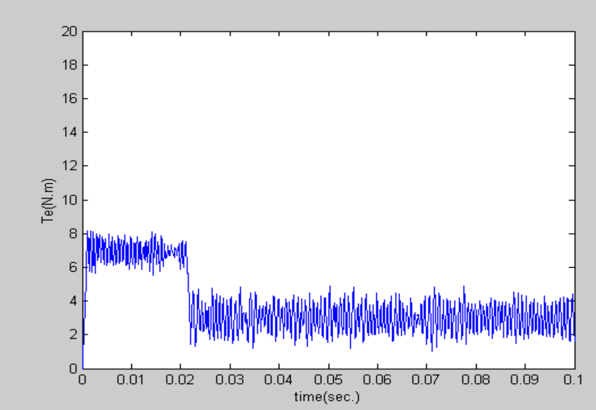

Fig.(4) Electromagnetic torque for a step change in load torque(3N.m) for 10kHz, 10,000 iteration

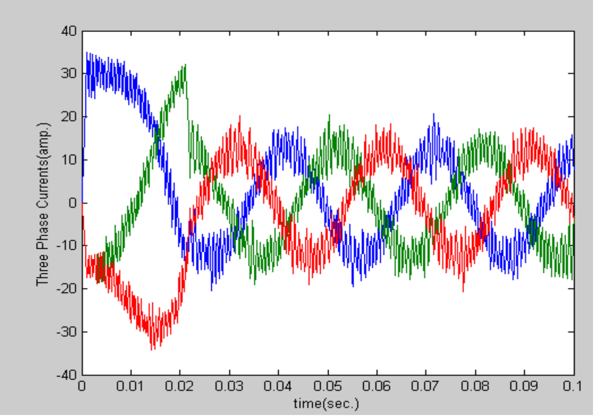

Fig.(5) Three-phase currents for a step change in load torque(3N.m) for 10kHz, 10,000 iteration

6.2 Case Two (10kHz, 100,000 iteration)

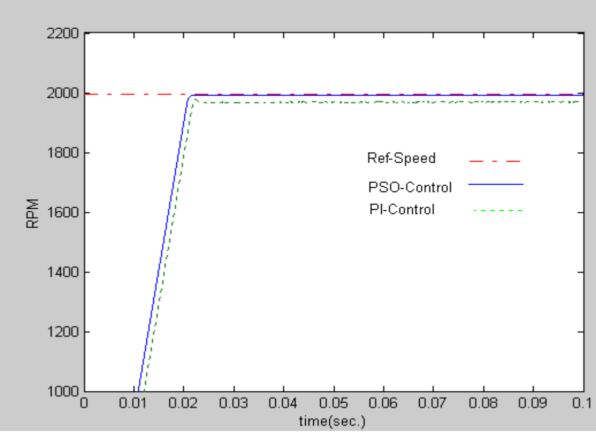

fig.(6) Speed response for a step change in load torque(3N.m) for 10kHz, 100,000 iteration

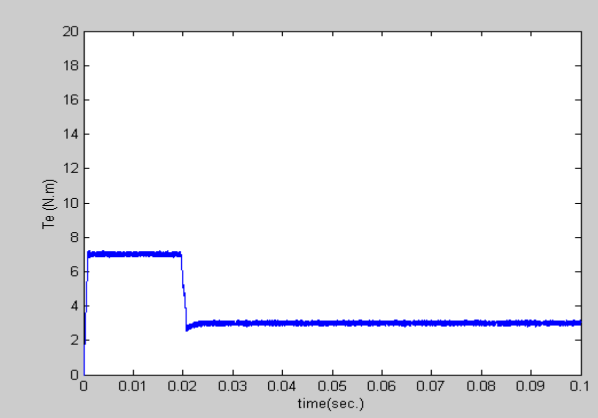

fig.(7) Electromagnetic torque for a step change in load torque(3N.m) for 10kHz, 100,000 iteration

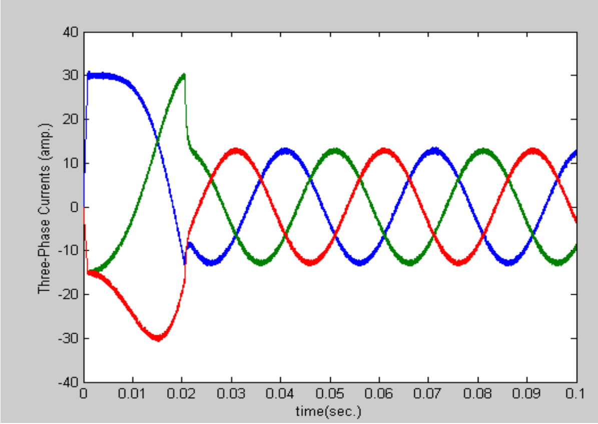

Fig.(8) Three-phase currents for a step change in load torque(3N.m) for 10kHz, 100,000 iteration

6.3 Case Three (10kHz, 100,000 iteration)

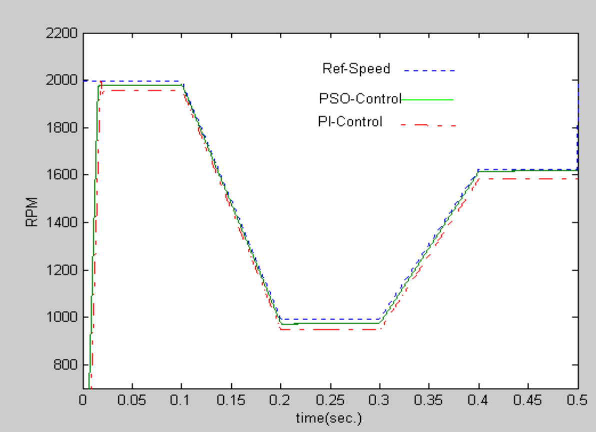

Fig. (9) Speed response for a step change in load torque(6 N.m) for 10kHz, 100,000 iteration

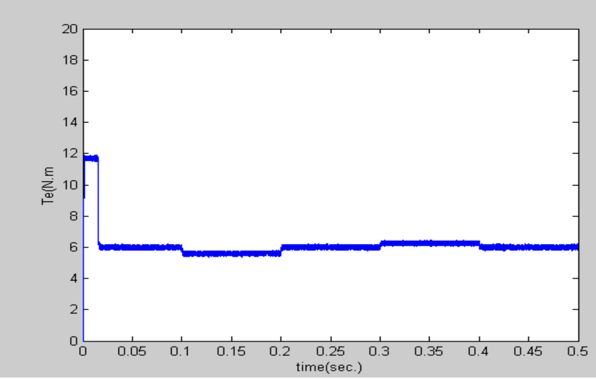

Fig.(10) Electromagnetic torque for a step change in load torque(6N.m) for 10kHz, 100,000 iteration

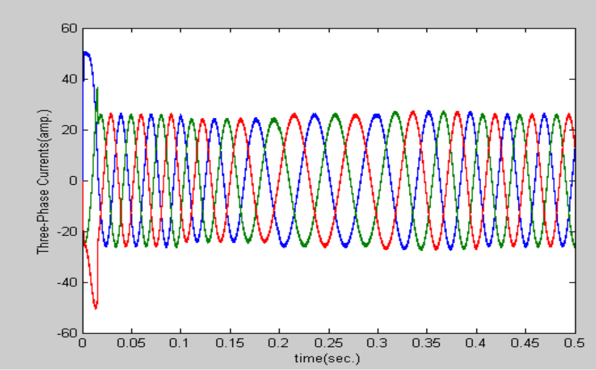

Fig.(11) Three-phase currents for a step change in load torque(6N.m) for 10kHz, 100,000 iteration

7.Experimental Setup

A laboratory setup using PMSM is prepared as shown in fig.(12), some results such as the phase voltage and current are shown in fig(13) and fig.(14). A space vector modulation technique is applied to deliver an intelligent power module , the control software program is achieved using borlandc++, and the system under test to complete the reset of the laboratory results.

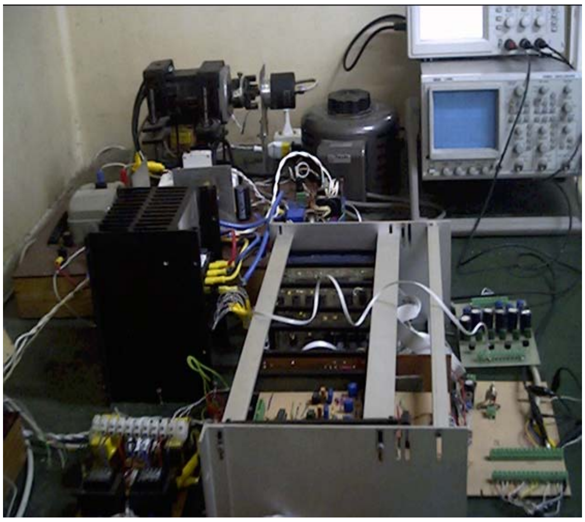

Fig.(12) The overall laboratory system

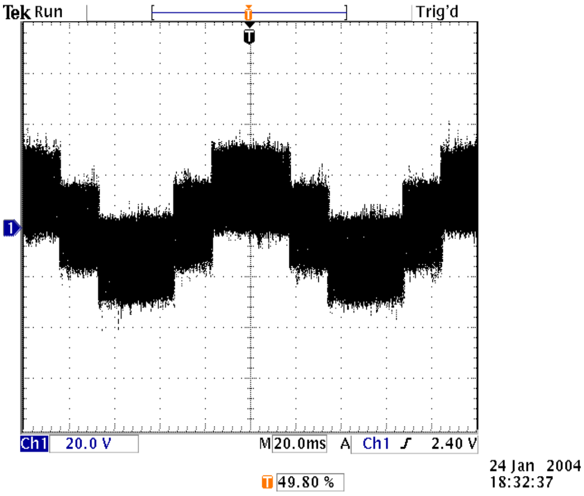

Fig.(13) the phase-a voltage

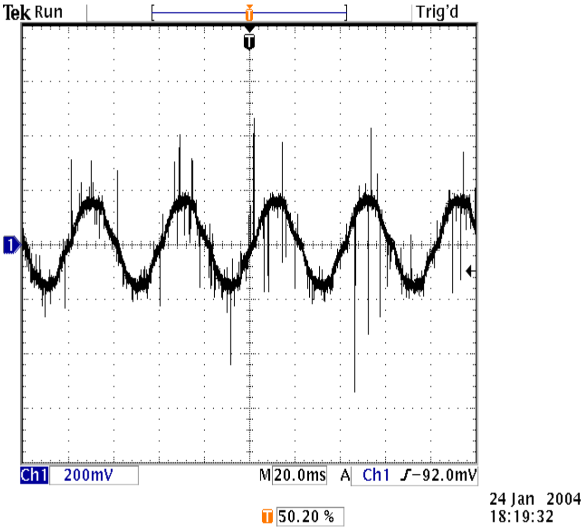

Fig.(14) the phase-a current

7. Conclusion

The system is tested under a step change in reference speed with switching frequency of 10 KHz and 10,000 iteration in order to enable the Particle

Swarm Optimizer to adaptive the PI-controller parameters, but as it seen through fig.3 to fig.5 the currents and the developed torque there is a higher harmonic contents, the harmonics in torque produce a non-uniform stepping or cogging motion on the rotor at low speed and in some applications it increase motor noise. In order to reduce these harmonics the number of iterations to optimize the PSO is increased to 100,000 iteration the result is better than the previous case and the harmonic contents is reduced in and the torque. Implementation of the experimental setup is going on and test result will be reported shortly.

8. References

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8. List of symbols

abc : referring to any quantity in the stationary reference frame
B : combined viscous friction of rotor and load
c1 and c2: Acceleration Coefficient
DQ : referring to any quantity in synchronous reference frame
i_a : the phase-a current
I_d : the current in d-axis of the motor
L_{ss} : the coil inductance
I_q : the current in q-axis of the motor
P_j : a personal best position in search space
r1 and r2 : are random numbers between 0 and 1
r_s : the resistance of the coil
T_e : the electromagnetic torque of the motor
T_m : the shaft mechanical torque
V_a : the phase-a voltage
v^r_q : the quadratur axis voltage
v^r_d : the direct axis voltage
v_{os} : the zero component voltage
V_j : current velocity
V_k : current velocity
V_{k+1} : modified velocity
W : the inertia weight
Xj : current position in search space
X_1 : the starting point of the membership function
X_2 : the end point of the membership function
X_k : current Searching Point
X_{k+1} : modified searching point
ω_r : the angular velocity of the rotor
λ'^{r}_{m} : the amplitude of the flux linkages established by the PM

9. Appendix

The motor parameter

R =0.0086 ohm ,
L_{ss} =1.957mH ,
λ'^{r}_{m}=0.039 volt/rad/s
P =8
B =0.0001 (N.m)/rad/s,
J =0.00155 kg.m^2