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Intelligent control for PMSM based on online PSO considering parameters change

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Abstract. A novel online particle swarm optimization method is proposed to design speed and current controllers of vector controlled interior permanent magnet synchronous motor drives considering stator resistance variation. In the proposed drive system, the space vector modulation technique is employed to generate the switching signals for a two-level voltage-source inverter. The nonlinearity of the inverter is also taken into account due to the dead-time, threshold and voltage drop of the switching devices in order to simulate the system in the practical condition. Speed and PI current controller gains are optimized with PSO online, and the fitness function is changed according to the system dynamic and steady states. The proposed optimization algorithm is compared with conventional PI control method in the condition of step speed change and stator resistance variation, showing that the proposed online optimization method has better robustness and dynamic characteristics compared with conventional PI controller design.

1. Introduction

Proportional-integral (PI) control technique has been widely used in high performance field orientation controlled PMSM drives.

There are numerous researches on the applications of computational intelligence techniques to controller parameters design for PMSM [1-3]. Among these, Because of its simplicity and computational efficiency [4-5], PSO has been widely used to solve a broad range of optimization problems, such as adaptive tuning of controller gains and parameters identification. However, there still exist some problems/limitations with this method on the optimization of controller gains. Firstly, the PSO optimization applications in designing controller gains for PMSM rely on offline precise calculations of responses of PMSM using mathematical model [3]. It makes optimization effectiveness rely on the fixed PMSM model excessively. Secondly, the online PSO for PMSM controller optimization, however only applied to the speed controller gains without considering current controller optimization. It is difficult to achieve high dynamics and robustness for PMSM drive system. Thirdly, much effort has been made on real-time PSO application in parameters identification, and results show effectiveness because parameters of PMSM are changed slowly [3]. This should be incorporated with the optimization process online.

In this paper, a discrete simulation model of PMSM is set up firstly considering dead-time of inverter to present a real-time simulation condition with a step speed reference signal., while the stator resistance is varying. Simulation results show that this online optimization method is model free and has better robustness and faster optimization ability.

2. Mathematical model of PMSM drives

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The IPMSM model in the rotor reference frame is

$$\begin{bmatrix} u_{d(t)} \\ u_{q(t)} \end{bmatrix} = \begin{bmatrix} R_s & 0 \\ 0 & R_s \end{bmatrix} \begin{bmatrix} i_{d(t)} \\ i_{q(t)} \end{bmatrix} + \begin{bmatrix} p & -\omega_{re(t)} \\ \omega_{re(t)} & p \end{bmatrix} \begin{bmatrix} \phi_{d(t)} \\ \phi_{q(t)} \end{bmatrix} \quad (1)$$

$$\dot{\phi}_{d(t)} = L_d i_{d(t)} + \phi_f \quad (2)$$

$$\dot{\phi}_{q(t)} = L_q i_{q(t)} \quad (3)$$

$$T_{em(t)} = \frac{3}{2} P_n \cdot (\phi_{d(t)} \cdot i_{q(t)} - \phi_{q(t)} \cdot i_{d(t)}) \quad (4)$$

$$T_{em(t)} - T_{L(t)} = \frac{J}{P_n} \frac{d\omega_{re(t)}}{dt} \quad (5)$$

where $u_{d(t)}$, $u_{q(t)}$, $i_{d(t)}$, $i_{q(t)}$, L_d , L_q , $\phi_{d(t)}$ and $\phi_{q(t)}$ are the stator voltages, stator currents, inductances and flux linkages on dq -axis respectively; ϕ_f is permanent flux; $p = \frac{d}{dt}$ is the differentiation operator; P_n is the number of pole pair; $\omega_{re(t)}$ is rotor velocity electrical; $T_{em(t)}$ is generated torque; $T_{L(t)}$ is load torque.

The d - and q -axis current controllers are PI whose transfer functions are $k_{id}(1 + \tau_{id}s)/s$ and $k_{iq}(1 + \tau_{iq}s)/s$, respectively. The reference of q -axis current i_q^{ref} is provided by the speed controller ($k_{s-p} + k_{s-i} \cdot \frac{1}{s}$). A low-pass filter is applied to the measured speed and a rate limitation is applied to the speed reference signal. They are used to reduce the overshoot and settling associated with step commands, while retaining a fast disturbance rejection. The online PSO scheme is implemented with a S-Function. The input variables of the S-Function are references and feedback values of q axis current and rotor speed respectively, the output variables are gains of the q axis current and speed PI controllers respectively.

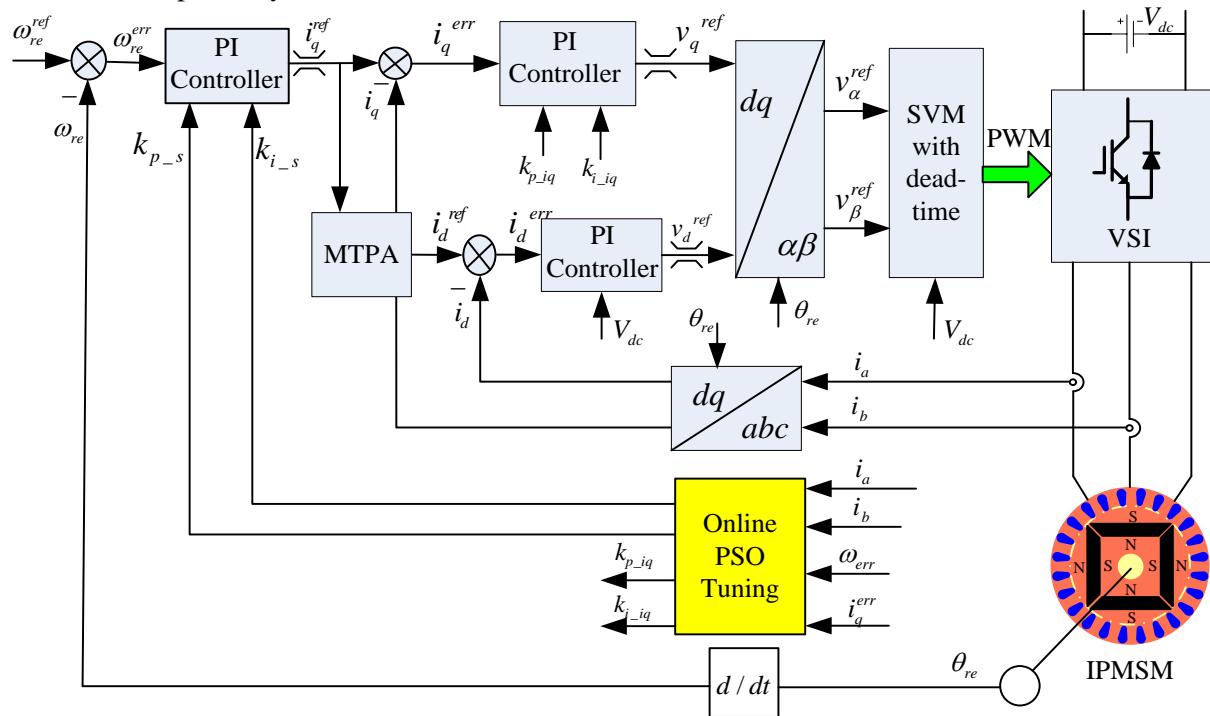


Figure 1. Block diagram of IPMSM drives based on Online-PSO controller

3. Online PSO Parameter Tuning

3.1. Basic principle of the PSO algorithm

Particle swarm optimization algorithm is an evolutionary computation technique developed by Kennedy and Eberhart in 1995. It finds global optimum solution in search space through the interactions of individuals in a swarm of particles. Similar to other evolutionary algorithms, the PSO algorithm firstly produces initial swarm of particles in search space. Each particle represents a candidate solution to the problem and it has its own position X and velocity V . Each row in the position matrix X shows each particle's position, through which we can acquire the evaluation value of the particle. At each iteration, each particle memorizes and follows the tracks of its personal best (P_{best}) and the global best position (G_{best}) vectors to update the velocity matrix V .

3.2. Known these two best positions, particles can change velocities and positions using the following rules:

$$v_{j,g}^{(t+1)} = w \cdot v_{j,g}^{(t)} + c_1 \cdot r_1 \cdot (p_{best}_{j,g}^{(t)} - x_{j,g}^{(t)}) + c_2 \cdot r_2 \cdot (g_{best}_g^{(t)} - x_{j,g}^{(t)}) \quad (6)$$

$$X^{(t+1)} = X^{(t)} + V^{(t)} \quad (7)$$

where $j=1, 2, \dots, m$; $g=1, 2, \dots, n$. The superscripts t and $t+1$ denote the time index of the current and the next iterations respectively. The parameters c_1 and c_2 are called acceleration constant which adjust the maximum step of the particle flight towards P_{best} and G_{best} position.

Usually, parameters c_1 and c_2 are equal to 2, r_1 and r_2 are uniformly distributed random numbers in the interval (0, 1). Parameter w is inertia weight factor that usually decreases linearly from 0.9 to 0.4 in according to (8) over the course of the run. In this way, the algorithm can easily escape from local optimal solution in the early iteration stage as well as speed the convergence in the later iteration stage, and increase the reliability of finding the global optimal solution.

$$w^{(t)} = w_{\max} - t \cdot (w_{\max} - w_{\min}) / iter_{\max} \quad (8)$$

where w_{\max} and w_{\min} are the maximum and minimum values of w , and $iter_{\max}$ is the maximum iteration times. In order to reduce the likelihood of particles leaving the search space, the value of each dimension of the velocity $v_{j,g}^{(t)}$ is clamped to the interval $[-v_g^{\max}, v_g^{\max}]$. The value of v_g^{\max} is usually chosen to be

$$v_g^{\max} = k \cdot x_g^{\max}, \quad 0.1 \leq k \leq 0.5 \quad (9)$$

where x_g^{\max} is the upper bound of search region in the g -th dimension.

3.3. Implementation of online PSO

During the optimization process, to evaluate a candidate solution, such as PI gains, they were kept constant under the whole system simulation, at the same time output errors such as speed errors were added up to evaluate the candidate solution. Usually, PSO algorithm requires a number of iterations to obtain a satisfactory solution. For iteration, the system model has to be simulated once. Then, the model needs to be simulated a number of times to search the best solution. In fact, we can not make IPMSM drive system repeat starting continually with certain load. That means such simulation results can not be acquired in real system. However, it is difficult for each particle of candidate PI parameters to be evaluated within one sampling time, which is usually from 10-100 μ sec. So, in this paper, we adopted a new method for online PSO update calculations of particle positions X , velocity V , P_{best} and G_{best} of the PSO algorithm. We measured speed and current as sampling values, while updating present particle information instead of updating whole swarm information. For example, there is a particle swarm with 30 particles for optimization. That means if the sampling of IPMSM drive system

is 10 μ sec, each particle's information such as position and velocity updates once within 100 μ s, however, P_{best} and G_{best} would be updated completely within 30*10 μ sec.

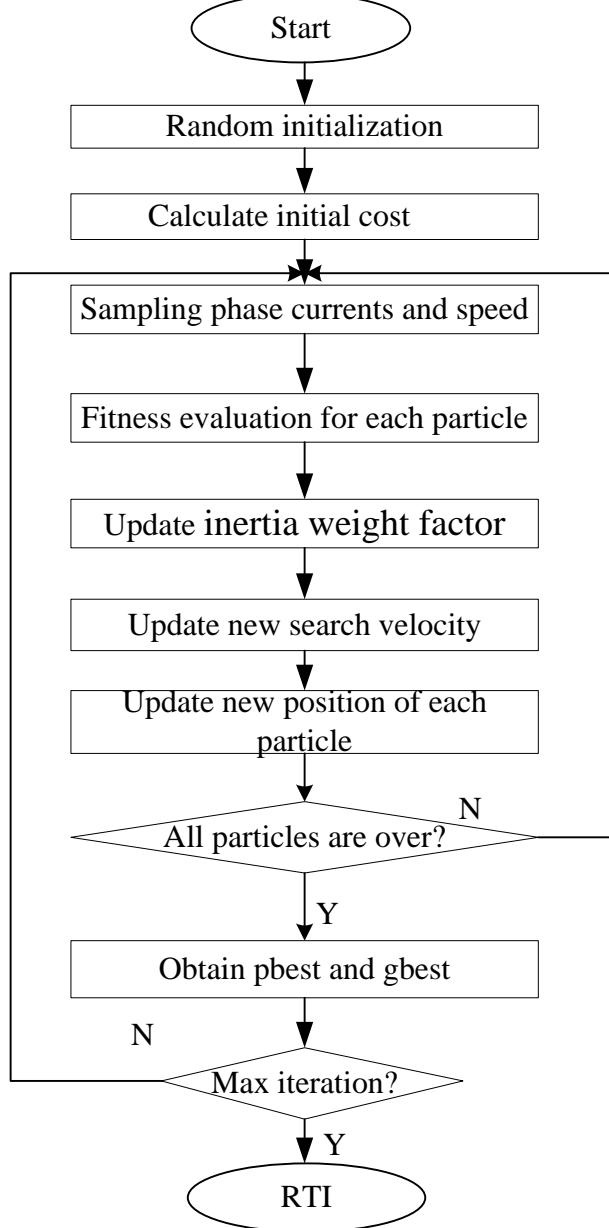


Figure 2. Online PSO flow frame within one sampling period

4. Testing for Online PSO Method

IPMSM parameters are presented in TABLE I, and resistance can be changed with temperature increasing to test the robustness of proposed method.

Table 1. Parameters of IPMSM

Phase resistance 5.8-7.8 Ω	d-axis inductance 0.0448H	q-axis inductance 0.1027H	Rated voltage 230V
Moment of inertia $0.001329 \text{ kg} \cdot \text{m}^2$	Rated speed 4000 rpm	Permanent magnet flux 0.533 wb	Pole pair 2

4.1. Simulation Results

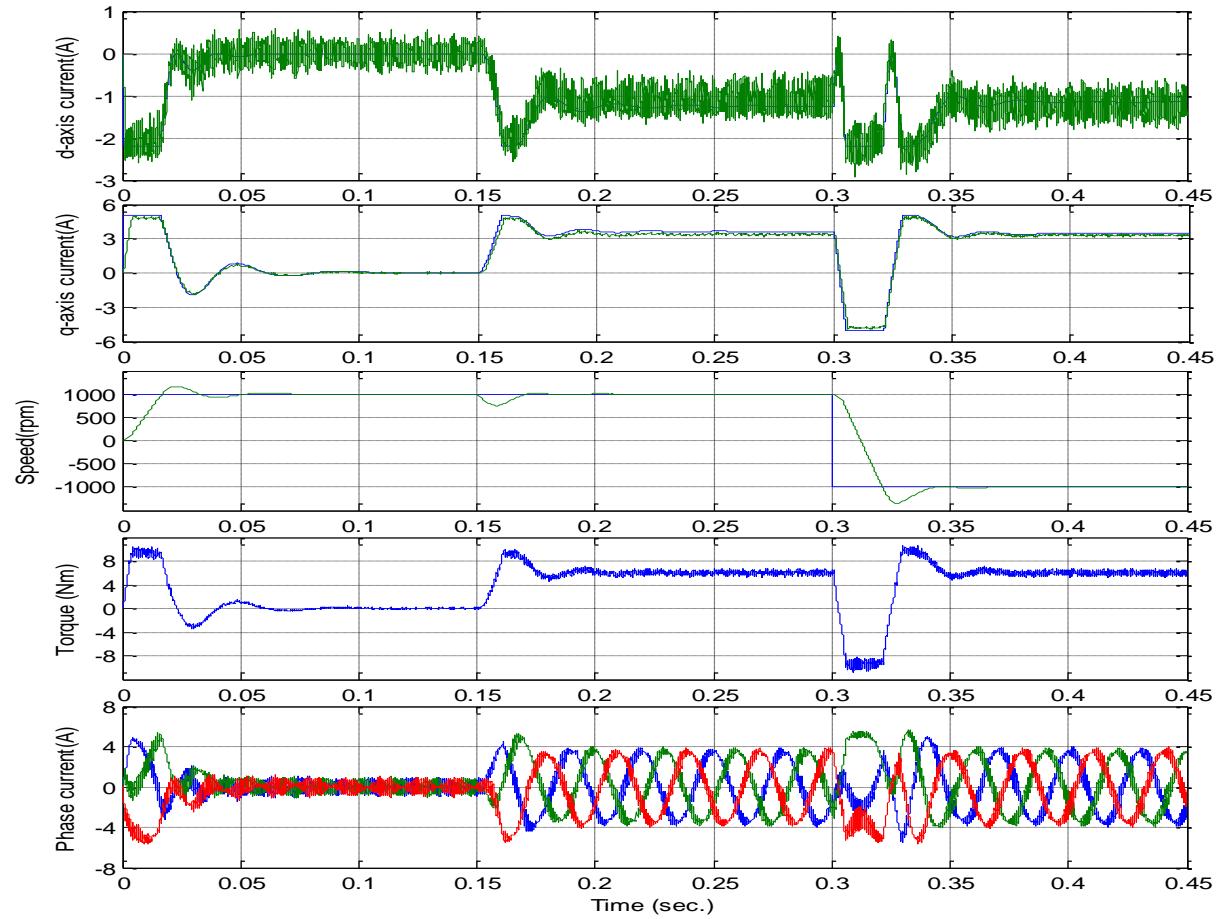


Figure3. Results of IPMSM drive with online PSO-PI controllers

The block diagram of the drive system used for the simulation is shown in Fig.1. The flow chart of online PSO of controllers is shown in Fig. 2. The simulation model includes the encoder, sensor and input nonlinearities. The controllers are in discrete time with the Euler method, to make the simulation to mimic the real experiment closely. The controller sampling time is chosen as 100 μ sec, which is the same as the controller sampling time of real experiment.

Initial swarm size of particles is 30, and each particle has four variables (k_{p_iq} , k_{i_iq} , k_{p_s} , k_{i_s}) representing its position vectors in search space. After 30 iterations, the results of G_{best} would be updated as optimized outputs. Fig.3 shows the change of fitness value of PSO for IPMSM drives and its decline rate is very fast. In order to test the proposed method in this paper, two different controllers were applied on IPMSM drive, and comparison results between conventional PI controllers and online PSO-PI controllers for IPMSM drives are presented in Fig.4 and Fig.5. Where (a) is i_d current response curve; (b) is i_q current response curve; (c) is speed response curve; (d) is torque response curve; (e) are three phase current curves. These results clearly show the effectiveness of the PSO method proposed in this paper.

4.2. Experimental Results

Unlike DC motor and asynchronous motor, before the start we need to know the accurate rotor initial position of permanent magnet synchronous motor (PMSM), to complete the coordinate transformation realization of vector control strategies. We usually use the incremental encoder to obtain the rotor position, and incremental encoder generally provide 3 group of pulses, A, B, and Z.

the A and B combined pulse rotor speed and positive & negative information can be obtained, and also when the rotor to rotate a circle with A\ Z pulse. After the encoder is actually installed to the rotor shaft, there is a certain angle between the initial angle of the rotor and the mechanical position of the Z pulse, which is called the initial installation angle. Only when the initial installation angle is accurate, can the position of the rotor be acquired in the condition of standstill or rotation.

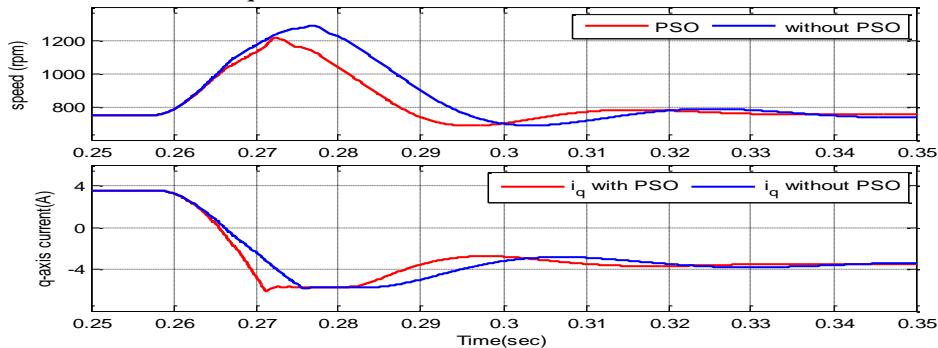


Fig4. Experimental results for IPMSM drives with PSO or NOT

5. Conclusion

In this paper, a novel online particle swarm optimization method is proposed to design speed and current PI controllers of vector controlled interior permanent magnet synchronous motor drives, taking into account stator resistance variation. The speed and current controllers are optimized online as PSO update is carried out in each sampling cycle for the position and velocity of particle which represent the performance of the controllers. Furthermore, optimization process does not rely on the preciseness of IPMSM model excessively, because when stator resistance changes within 15%, the dynamic and steady-state performance of the drive system has been improved by optimization of speed and current controller at the same time.

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