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New Control Strategy for PMSM Driven Bucket Wheel Reclaimers using GA-RBF Neural Network and Sliding Mode Control

Li Qin, Xincong Zhou, Pengju Cao

School of Energy and Power Engineeri, Wuhan University of Technology; Huangpi Campus, Air Force Radar Academy, Heping Load, 1040#, Wuhan 430063, P. R. China, phone: +86 27 86554969, e-mail: 175387517@qq.com

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Introduction

The control performance of the reclaimers is directly related to the quality of the products, productivity and working reliability [1]. High control performance is the key issue of the double bucket wheel reclaimers [1]. Given that the permanent magnet synchronous motor (PMSM) has the advantages of large energy density, high efficiency, long service life and low complexity [2–5], how to design high performance controller for PMSM has become a hot topic in the field of the double bucket wheel reclaimers.

Up to date, the $i_d = 0$ vector control strategy has been proven very effective for PMSM [3]. Based on $i_d = 0$ strategy, some intelligent control methods have been developed [2-4]. Since the sliding mode variable structure (SMVS) is a kind of nonlinear control in nature, it has many advantages [2–5], such as the fast response, not sensitive to disturbance, no need of online model identification, etc. Hence it has gained considerable attentions in all kinds of control system. However, the sliding mode control has inherent chattering problem, which can affect its control stability and control precision. Therefore, how to integrate the advanced control technologies to eliminate the chattering in the SMVS has been the focus of the scholars' attention. At present, the mixed control methods that combine the neural network control or fuzzy control with the SMVS are very efficient to eliminate the chattering problem. As well known, the neural network technology has strong self-learning ability and can be approximate any nonlinear function accurately [6], therefore the neural network technology has been applied widely in engineering. However, very limited work has been done for the control of PMSM driven reclaimers. To address this issue, this paper presents the neural network sliding mode controller for the PMSM driven reclaimers. The SMVS controller is established and the radial basis function (RBF) neural network optimization is used to eliminate the chattering of the SMVS. Meanwhile, the genetic algorithm (GA) [7] is used for structure optimization of the RBF network. In order to validate the designed controller, the DSPACE hardware simulation platform has been applied for the PMSM vector control. The proposed control method was compared with the traditional equivalent sliding mode approach. The test results show that the proposed GA-RBF neural network based sliding mode controller can accurately track the motor speed, and provide quick dynamic response and good robustness. In addition, the control performance of the proposed method is superior to the traditional equivalent sliding mode controller.

Mathematical model of PMSM

Hypothesis as follows: (1) the stator core saturation is ignored, and the magnetic path is linear, (2) the induced source voltage of stator armature winding is sine wave, (3) the core eddy and hysteresis losses are not considered and (4) the permanent magnetic field of the rotor is sine distribution in the air gap space. Then the stator current mathematical model of the surface permanent magnet synchronous motor (SPMSM) in the rotation (d-q) coordinate is as follows [3]:

$$\begin{cases} u_q = Ri_q + p\psi_q + \omega_r\psi_d, \\ u_d = Ri_d + p\psi_d - \omega_r\psi_q. \end{cases} \tag{1}$$

The flux linkage equations is:

$$\begin{cases} \psi_q = Li_q, \\ \psi_d = Li_d + \psi_f. \end{cases} \tag{2}$$

The motor torque is as

$$T_e = 3P\psi_f i_q / 2. \tag{3}$$

The motor motion equation is as

$$Jp\omega_r = T_e - T_L\,, \tag{4}$$

where i_d, i_q are the d, q axial components of stator current; u_d, u_q are the d, q axial components of stator voltage; R, L are the stator winding resistance and the inductance; ψ_r is the rotor permanent magnet flux; ω_r is the angular velocity; J is the rotor rotating inertia; T_L is the loading moment; P is the pole pairs.

According to Eq. (3) it can be seen that the motor drive torque is only directly proportional to i_q. In order to get the maximum motor torque, i_q is expected to be maximum. Hence the $i_d = 0$ control strategy is adopted to obtain max value of i_q [3]. The neural network sliding mode control is adopted for realizing $i_d = 0$ strategy for PMSM control in this paper. The principle diagram of the control system is shown in Fig. 1, and the control principle is as follows:

1. Firstly, the motor position signal θ is got through the photoelectric encoder and compared with position command θ*. The position error is then obtained as the input for the SMVS position controller, and the output is speed command ω*.
2. Secondly, the rotor actual speed ω is compared with the speed command ω* and speed error e can be got.
3. The speed error e is then taken as the input of the designed RBF-SMVS controller and the needed q axis current signal i_q* can be obtained. The current signal i_q* along with the d axis current reference are the input reference signals of the current loop PI controller.
4. The motor current signals can be got by using current sensor and the actual current value of d-q axis can be calculated through the Clack transform and Park transform.
5. The d-q axis actual currents are compared with the current reference signals. Then the voltage reference signals can be got through PI regulation and the space vector PWM technology (SVPWM) is used for computing the duty ratio of the inverter.

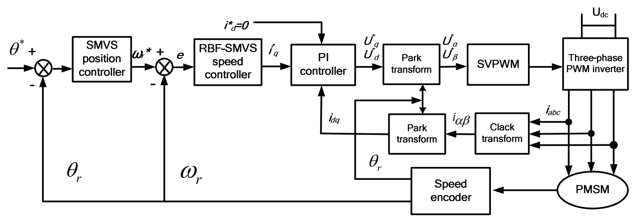

Fig. 1. The proposed control scheme

Position loop sliding mode controller

The SMVS controller is adopted in the position loop. The position tracking error is selected as state variables

$$x = \theta^* - \theta_r\,, \tag{5}$$

where θ_r is the actual position and θ* is the position reference.

If the position sliding model controller is designed as

$$s_1 = \kappa x\,, \tag{6}$$

where κ is a constant and the derivate of s is

$$\dot{s}_1 = \kappa \dot{x} = -\kappa \omega_r\,. \tag{7}$$

Use the principle of exponential approximation to yield

$$-\varepsilon \cdot \mathrm{sgn}(s_1) - ks_1 = -\kappa\omega_r\,, \tag{8}$$

where ε and k are constants and the output of the controller can be deduced as

$$\omega^*_r = [\varepsilon \cdot \mathrm{sgn}(s_1) + ks_1] / \kappa\,, \tag{9}$$

where ω_r^* is the reference of the speed loop.

Speed loop RBF-SMVS controller

In the speed control processing, the velocity error and its variation rate are taken as the state variables:

$$\begin{cases} x_1 = \omega^*_r - \omega_r\,, \\ x_2 = \dot{x}_1 = -\dot{\omega}_r. \end{cases} \tag{10}$$

Ignored the speed friction loss then Eq. (10) can be rewritten as:

$$\begin{cases} \dot{x}_1 = -\dot{\omega}_r = -(1.5P\psi_f i_q - T_L)/J, \\ \dot{x}_2 = \ddot{x}_1 = -\ddot{\omega}_r = -1.5P\psi_f \dot{i}_q / J\,. \end{cases} \tag{11}$$

The state space of the system is

$$\begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} x_2 \\ x_3 \end{bmatrix} + \begin{bmatrix} 0 \\ -A \end{bmatrix} u\,, \tag{12}$$

where $A = 1.5P\psi_f / J$ and $u = \dot{i}_q$.

The switch function is

$$s_2 = \lambda x_1 + x_2\,, \tag{13}$$

where λ is a constant and the derivativeof s_1 is

$$\dot{s}_2 = \lambda \dot{x}_1 + \dot{x}_2 = \lambda x_2 + \dot{x}_2 = \lambda x_2 - A\dot{i}_q\,. \tag{14}$$

If $\dot{s}_2 = 0$, the equivalent controller can be expressed as

$$u_{eq} = \int \dot{i}_q = \int \lambda x_2 dt / A\,. \tag{15}$$

The model perturbation and environmental interference may induce sliding model fluctuating, so the switch controller is adopted to overcome this problem. The form of the switch controller is

$$u_s = \eta\,\mathrm{sgn}(s_2)\,, \tag{16}$$

where η is a constant and $\mathrm{sgn}(\cdot)$ is the sign function. Therefore, the designed SMVS controller is

$$u = u_{eq} + u_s\,. \tag{17}$$

Combine Eq. (8)~(11) to yield

$$s_2\dot{s}_2 = s_1 \cdot (-\eta \cdot \mathrm{sgn}(s_2)) = -\eta |s_2| \le 0 . \quad (18)$$

It can be seen that the SMVS controller is stable according to Lyapunov function [3].

The RBF network can approach any continuous function with arbitrary precision [3]. Hence, the integration of RBF and SMVS can eliminate the sliding mode chattering.

The RBF based sliding model controller is as

$$u' = u_{eq} + \alpha u_{vs} , \quad (19)$$

where the switch gain α ($0 \le \alpha \le 1$) is the output of RBF network. The interference item can be removed by on-line tuning the switch gain, thus the chattering can be eliminated. The estimation formula of the RBF network is as

$$\alpha = \omega^T \phi(s_2) , \quad (20)$$

where ω^T is the weights of the RBF network and $\phi(\cdot)$ is the radial basis function. In general, the Gaussian function is taken as the radial basis function

$$\phi(x) = \exp(-\frac{\|x - c\|}{2\sigma^2}) , \quad (21)$$

where c is the network center and σ is the width of the basis function. Proper c and σ are crucial to the performance of the RBF. Hence, the GA is adopted to search suitable values of parameter c and σ.

There are four operations for the GA to optimize the RBF parameters, including the coding, selection, crossover and mutation. Details about the GA searching processing can be found in [7].

Hardware in-the-loop simulation via DSPACE platform

DSPACE real-time simulation system is a set of hardware in-the-loop simulation platform based on MATLAB/Simulink. The DSPACE simulation system can realize the seamless connection with MATLAB/Simulink/RTW-RTI. The hardware in-the-loop simulation platform is mainly constituted of the main controlling computer, simulation computer, control computer (prototype machine), D/A connector and related energy equipments, etc.

DS1104 controller board has been employed for DSPACE hardware system in this paper. The motor control real-time simulation platform is build as shown in Fig. 2, and the software control algorithm has been compiled according to Fig. 1.

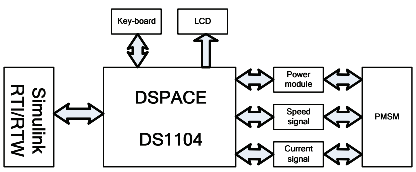

Fig. 2. Hardware in-the-loop simulation system

The simulation parameters used in the simulation were as follows: the stator resistance R = 1.5 Ω, the stator inductance L = 0.0075 H, the permanent magnetic flux ψ_r = 0.35 Wb, the inertia $J = 0.5\times10^{-4}$ kg·m^2, the pole pairs P = 4. Considering the motor load torque perturbation, a external dynamical load was introduced by $T_L = 0.05 * \sin(100\pi t)$. Two case studies using two different position reference commands have been investigated to verify the proposed control method.

1. Case one: the initial value of given position reference θ^* was 0.5π rad and step to -0.5π rad in 0.5 s. The test results are shown in Fig. 3 and Fig. 4.
2. Case two: the given position reference θ^* varied as a sine, i.e. $\theta^* = \pi * \sin(3\pi t)$. The test results are shown in Fig. 5 and Fig. 6.

In the experiments, the 1-10-1 structure was adopted for the RBF network, and the RBF basis function parameters c = 1.35, σ = 2.22. The GA parameters were as follows: the population was 300, the iterative times were 200 times, the cross rate was 0.95, the variation rate was 0.01.

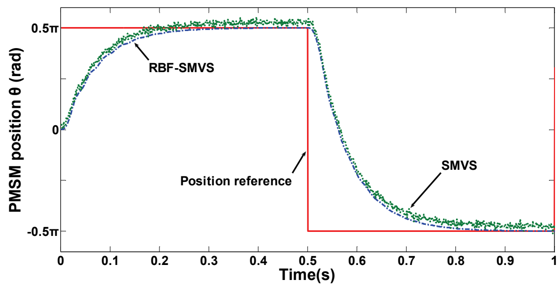

Fig. 3. The speed tracking performance

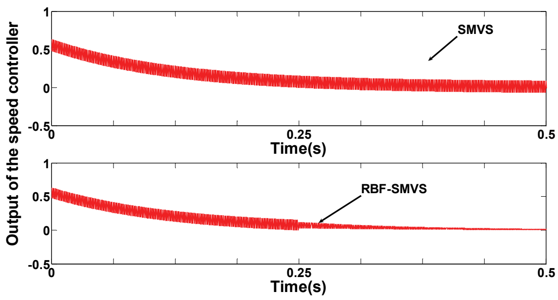

Fig. 4. Comparison of the chattering of the SMVS and RBF-SMVS speed controller

From Fig. 3, it can be seen that both the RBF-SMVS controller and the traditional SMVS controller can track the position instructions quickly, but the respond speed and accuracy of the RBF-SMVS controller is slightly better than the traditional SMVS controller. From Fig. 4 it can be noticed that a certain chattering appears in the traditional SMVS controller; however this problem can be controlled efficiently by the RBF-SMVS controller. Hence, although the motor load changes frequently, the proposed control system can track the position reference precisely and has good robustness.

Form Fig. 5 and Fig. 6, it can be seen that both the RBF-SMVS controller and traditional SMVS controller can obtain high accurate position tracking performance under the time-varying reference signal. However, owing to the advantages of the RBF network, the chattering problem can be overcome. Therefore, the control performance of the RBF-SMVS controller is superior to the traditional SMVS controller.

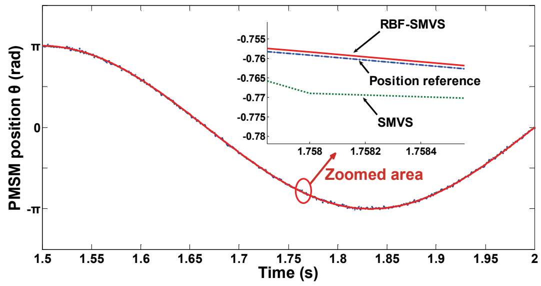

Fig. 5. The position tracking performance

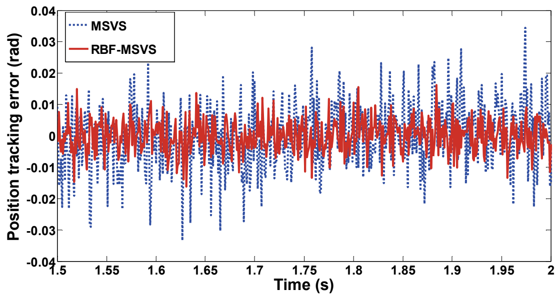

Fig. 6. The position tracking error

Thus, the hardware in-the-loop simulation results show high effectiveness of the proposed control method for the PMSM control in the double bucket wheel reclaimer system.

Conclusions

The double bucket wheel reclaimers driven by PMSM are typical complex and nonlinear systems. It is difficult to get a good control performance by using traditional PID controller. In order to improve the control system performance for the double bucket wheel reclaimers, the RBF network optimized sliding mode controller has been proposed in this paper. The innovation lies in the use of the sliding mode controller to control the position loop and a RBF neural network based sliding model controller in the speed loop. In addition, the RBF network structure is optimized by GA searching. By doing so, the chattering problem of the sliding model controller can be eliminated and a high accuracy control for the PMSM can be obtained. The hardware in-the-loop simulation has been conducted on the DSPACE platform. The testing results demonstrate that the proposed control method is feasible and available for the control of PMSM based double bucket wheel reclaimers.

References

1. **Hong K., Kang D.** Reclaimer control: modeling, identification and a robust Smith predictor // IEEE International Conference on Intelligent Robots and Systems. – IEEE, 1999. – No. 1. – P. 344–349.
2. **Guo S., He J.** Sensorless control of PMSM based on adaptive sliding mode observer // International Journal of Modelling, Identification and Control. – Inderscience Enterprises Ltd, 2009. – No. 4. – P. 321–324.
3. **Gu Y., Shi Y., Wang J.** Sensorless vector control of AC servo system with artificial neural network observer and fuzzy speed controller // Przeglad Elektrotechniczny. – Wydawnictwo Sigma-NOT,2012. – No. 1B. – P. 150–153.
4. **Shafiei S. E., Sepasi S.** Incorporating sliding mode and fuzzy controller with bounded torques for set-point tracking of robot manipulators // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 8(104). – P. 3–8.
5. **Xu J., Panda S., Pan Y., Lee T., Lam B.** A modular control scheme for PMSM speed control with pulsating torque minimization // IEEE Transactions on Industrial Electronics. – IEEE, 2004. – No. 3. – P. 526–536.
6. **Osowski S.** Artificial neural networks - basic network structures and learning algorithms // Przeglad Elektrotechniczny. – Wydawnictwo Sigma-NOT, 2009. – No. 8. – P. 1–7.
7. **Cvetkovski G.** GA based torque optimisation of permanent magnet disc motor // Przeglad Elektrotechniczny. – Wydawnictwo Sigma-NOT, 2007. – No. 7 – P. 100–103.

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The intelligent vector control for the permanent magnet synchronous motor (PMSM) drived bucket wheel reclaimers is presented. Two sliding mode variable structure (SMVS) controllers were designed for the control of the position loop and speed loop of the PMSM. To eliminate the slding chattering, the genetic algorithm optimized RBF network was employed for the SMVS in the speed loop. The hardware in-the-loop simulations using the DSPACE platform has validated the efficiency of the proposed control method. Ill. 6, bibl. 7 (in English; abstracts in English and Lithuanian).

Li Qin, Xincong Zhou, Pengju Cao. Nuolatinių magnetų sinchroninio variklio varomų rotorinių regeneratorių valdymo strategija naudojant GA-RBF neuronų tinklą ir slydimo režimo kontrolė // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 6(122). – P. 113–116.
Pristatomas sumanusis vektorinis nuolatinių magnetų sinchroninio variklio (NMSV) varomų rotorinių regeneratorių valdymas. NMSV padėčiai ir greičiui valdyti buvo suprojektuoti dviejų slydimo režimų kintamos struktūros valdikliai. Siekiant pašalinti slydimo virpesius, buvo panaudotas optimizuotas genetinis RBF tinklo algoritmas. Pasiūlyto valdymo metodo efektyvumas patikrintas naudojant modeliavimą DSPACE platformoje. Il. 6, bibl. 7 (anglų kalba; santraukos anglų ir lietuvių k.).