PMSM Direct Torque Control Based on Genetic Algorithm and Neural Network

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Abstract: To reduce the bigger torque ripple in the system of direct torque control(DTC) of permanent magnet synchronous motors(PMSM), genetic algorithm(GA) is introduced in the speed PI controller to realize self-tuning of PI parameters, neural network(NN) is introduced in space vector modulation(SVM) to achieve the desired space voltage vector. Starting from the dynamic mathematical models of PMSM, the system of DTC of PMSM based on GA and NN is proposed. Then, concrete implementation methods of self-tuning PI controllers and NN SVM are analyzed in detail. Finally, modeling and simulation are performed by MATLAB/Simulink. The results show that the proposed control method has the advantages of fast speed response, small speed overshoot and lower torque ripple. The system has better static and dynamic performances.

Keywords: Permanent Magnet Synchronous Motor, Direct Torque Control, Genetic Algorithm, Neural Network

1. INTRODUCTION

Direct torque control (DTC) has been widely researched and used in permanent magnet synchronous motors due to its advantages of simple structure, simple algorithm, fast torque response and strong robustness to parameter changes [1,2].

Different from traditional vector control, DTC provides optimized voltage or current switching vectors to the inverter, and directly and independently controls the stator flux linkage and electromagnetic torque of the motor. But the PMSM DTC system has some shortcomings such as large torque ripple.

Compared with the traditional control system, the intelligent control system based on fuzzy logic, neural network, genetic algorithm and expert system has special advantages and has been widely used in motor drive [3,4]. As a global optimization probability algorithm, genetic algorithm has the advantages of strong adaptability, wide search range, high efficiency and better effect, but there are problems such as premature convergence. Neural networks have the advantages of strong robustness and self-learning of unknown nonlinear systems, but they cannot know inference rules, and they need sufficient data to support them, and they require high hardware requirements [5]. Therefore, the torque ripple of PMSM cannot be effectively reduced by genetic algorithm or neural network only.

For the shortage of large torque ripple in PMSM DIRECT torque control system, according to the advantages and disadvantages of genetic algorithm and neural network respectively, the following control scheme is proposed in this paper. The genetic algorithm is introduced into the speed PI regulator to realize self-tuning of PI. Neural network is introduced into space vector modulation to realize off-line training of switching functions. Based on the dynamic mathematical model of PMSM, the structure diagram of PMSM DIRECT torque control system based on genetic algorithm and neural network spatial modulation is presented. Secondly, the methods of PI self-tuning by genetic algorithm and space vector modulation off-line training by neural network are analyzed in detail. Finally, MATLAB/Simulink software was used for modeling and simulation. The simulation results show that the proposed control system can significantly reduce the torque ripple of PMSM, so it has a good application prospect.

2. DYNAMIC MATHEMATICAL MODEL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

The voltage, current and flux of the PMSM in the DQ coordinate can be obtained from the following two coordinate transformations, the transformation from the three-phase *(a-b-c)* coordinate system to the two-phase(α-β) static coordinate system, then transform to two-phase rotating *(d-q)* coordinate system. The dynamic mathematical model of permanent magnet synchronous motor in the d-q coordinate system can be expressed as: [6]

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \begin{bmatrix} i_d & -\psi_q \\ i_q & \psi_d \end{bmatrix} \begin{bmatrix} R_s \\ \omega_e \end{bmatrix} + p \begin{bmatrix} \psi_d \\ \psi_q \end{bmatrix} \quad (1)$$

$$\begin{cases} \psi_d = L_d i_d + \psi_f \\ \psi_q = L_q i_q \end{cases} \quad (2)$$

$$T_e = \frac{3}{2} n_p (\psi_f i_q + (L_d - L_q) i_d i_q) \quad (3)$$

$$\frac{d\omega_e}{dt} = \frac{n_p}{J}(T_e - B\omega_e - T_L) \quad (4)$$

$$\omega_e = p\theta_e = n_p \omega_r \quad (5)$$

In the above formula, u_d and u_q stand for stator two phase voltage in the formula, i_d and i_q stand for stator two phase current, ψ_d and ψ_q stand for stator two phase flux linkage, the Rs for the stator resistance, θ_e for rotor electrical angular position, ω_e and ω_r stand for rotating electrical, mechanical rotor angular velocity, Ψ_f stands for permanent magnet flux linkage, T_e for the electromagnetic torque, n_p for the motor logarithm, J is the moment of inertia, B is damping coefficient ,*TL* is the load torque , L_d and L_q stand for direct axis and quadrature axis inductance, respectively, p for the differential operator.

3. THIS PAPER PRESENTS A DIRECT TORQUE CONTROL SYSTEM FOR PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM)

3.1. Control System Block Diagram

The direct torque control system of permanent magnet synchronous motor based on genetic algorithm and neural network is shown in Figure 1.

The torque and flux estimation module gets the actual electromagnetic torque and flux from the mathematical model in the two-phase static coordinate system. The mechanical rotational speed deviation is given by self-tuning PI regulator. The switch vectors S_a, S_b and S_c required by the inverter are obtained after the deviation between the given electromagnetic torque and the actual electromagnetic torque is modulated by the output of the hysteresis comparator and the flux linkage deviation is modulated by the neural network space together with the output of the hysteresis comparator and the electrical Angle position of the motor.

Genetic algorithm and neural network are applied to PI regulator and space vector modulation module respectively to achieve their respective goals.

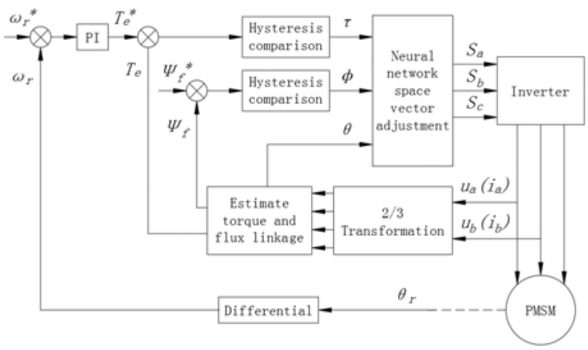

Fig. 1 Block diagram of PMSM direct torque control system based on genetic algorithm and neural network

3.2. PI Self-adjusting Based on Genetic Algorithm

Genetic algorithm is a method of modeling, searching and parameter optimization based on Darwin's theory of biological evolution. Similar to the gene sequence of DNA, the chromosome of genetic algorithm is also composed of many encoded genes, which is a searching mechanism based on the principles of neural selection and population genetics. Each individual is usually represented as a string of features and a string of Numbers. The search node is used to encode the feature string and the number string in the search space. The most suitable individuals that can survive in the population pass on their good genes to the next generation through the basic steps of selection, crossover and mutation. Each chromosome is a possible choice for the problem being optimized, and each bit represents a value or variation in the gene. The flow chart of genetic algorithm is shown in Figure 2.

In this paper, the proportional coefficient and differential coefficient of the PI controller can be solved through the GA. First, the initial populations are randomly generated inside the variable ranges. Then, the fitness of each individual is calculated. The individuals with good fitness will be retained and those with bad fitness will be removed, which is the selection operator. The new individuals are generated by the crossover operator which acquire the variable values of each dimension from two remaining individuals. In addition, the mutation will randomly occur in the crossover step that one variable value will change to a random value inside the range at random. Afterwards, the new iteration will be carried out until the convergence.

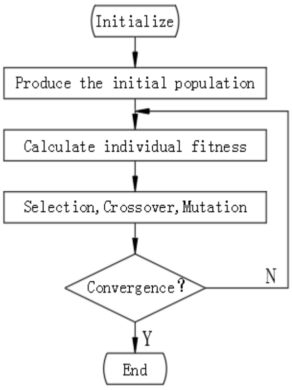

Fig. 2 Flow chart of genetic algorithm

The fitness function of each chromosome [7]

$$f = \frac{1}{M + T + 1} \tag{6}$$

In the above formula, M is the speed overshoot adjustment, and T is the stabilization time. Genetic algorithm parameters were selected as follows: population number was 80, crossover rate was 0.85, mutation rate was 0.01, evolutionary algebra was 80 generations, and chromosome length was 24 bits.

3.3. Neural Network Space Vector Modulation

The look-up table method with the idea of function approximation is commonly used to realize space vector modulation, but the look-up table method requires the expansion of RAM and limits the control accuracy[8]. Neural network is an artificial intelligence control algorithm based on human thinking process. It uses high-density interconnect computing nodes to approximate nonlinear functions with arbitrary precision, which has unique advantages in data fitting. Therefore, the introduction of neural network into space vector modulation not only has the advantages of space vector modulation, but also overcomes the influence of nonlinear computing[9] .It is important to select the most suitable switching state. Figure 3 is the schematic diagram of neural network space vector modulation [10]. As shown in figure 3, the torque control signals tau, flux control bits and rotor angular position theta as a space vector modulation module of the three input layer neurons, using back propagation algorithm of neural network to switch vector selection, hidden layer for the realization method of neural network, output layer 3 switch state.

The number of the neurons is a compromise between training time, output precision, and generalization capabilities. On one hand, if the number of the neurons is small, the NN will take a long time to converge or will not converge to a satisfactory error. On the other hand, with a large number of neurons, the NN will memorize the training vectors and give a large error for generalization vectors. Hence, in this paper, the number of neurons is set as 8 considering the inputs and outputs.

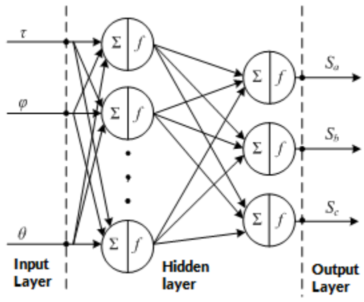

FIG. 3 Schematic diagram of neural network space vector modulation

4. MODELING AND SIMULATION BASED ON MATLAB/SIMULINK

In order to verify the correctness and feasibility of the proposed control method, the direct torque control system of permanent magnet synchronous motor based on genetic algorithm and neural network was modeled and simulated by MATLAB/Simulink software. Permanent magnet synchronous motor parameter selection are as follows: the stator resistance R_s=1.4 Ω, direct axis inductance $L_d=6.6\ mH$, quadrature axis inductance $L_q=5.8\ mH$. Damping coefficient $B=0.0004\ Nm/rad{\cdot}s$, moment of inertia of the motor J=0.00182Kg·m^2, flux linkage ψ_f = 0.76 Wb.

Simulation time was 0.2s. When the motor is started, a load torque of 4nm is applied. The load torque mutates from 4 Nm to 10 Nm at 0.1s.FIG. 4, 5 and 6 show the speed response curve, torque response curve and flux circle curve respectively.

As is shown in Figure 4, the speed response is fast, the speed overshoot is small, and the motor can be stabilized and approximated to the given speed within a very short time after starting. It can be seen from Figure 5 that torque ripple is small and has good dynamic and static performance. It can be seen from Figure 6 that the flux is close to the flux circle and has good symmetry and tracking performance.

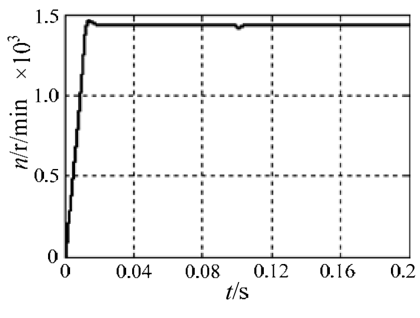

FIG. 4 Speed response curve

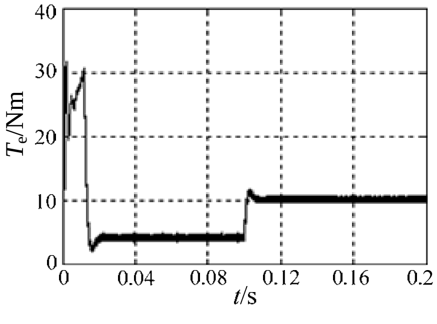

FIG. 5 Torque response curve

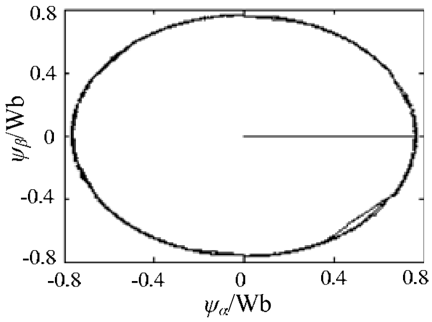

FIG. 6 Flux circle curve

5. CONCLUSION

This paper presents a direct torque control (DTC) method for permanent magnet synchronous motor (PMSM) based on genetic algorithm and neural network. The parameters of the real speed PI regulator are self-tuning by genetic algorithm. In order to obtain the best switching state, the space vector modulation is carried out by using the neural network which abandons the shortcoming of query table. MATLAB/Simulink software was used for modeling and simulation. The simulation results show that the DTC method proposed in this paper is feasible, reliable and efficient. The system has excellent dynamic and static performance, which can strictly track the given speed, small overshoot and small torque ripple.

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REFERENCE

[1] Mei boshan, Chen hui, Ling feng. Performance simulation analysis of direct torque control system [J]. Journal of Shanghai university of electric power,2008,24(3): 203-206.

[2] Wang lei, Wang jing, Zhang yongjun. Research on direct torque control of asynchronous motors based on sliding mode variable structure [J]. Power electronics technology, 2010,44 (1):44-45.

[3] Zhang Jingwei, Wang xuefan, Xiong fei, Kan chaohao. Parameter estimation of brushless doubly-fed motor based on experimental and genetic algorithm [J]. Chinese journal of electrical engineering, 2008,28 (36):103-107.

[4] Fang Gefei, Wang Huixiang, Huang Xiaoshuo. Application of improved genetic algorithm in reactive power optimization [J]. Chinese journal of electrical engineering, 2003,15 (4):15-18.

[5] Han Bing. Study on Nonlinear Time-delay System Control based on Delayed Neural Networks [M]. Dalian: Dalian University of Technology, 2009.

[6] EI Janati EI Idrissi A., Zahid N., Jedra M.. Neuro direct torque control of permanent magnet synchronous motor with genetic algorithm speed controller[J]. Journal of Theoretical and Applied Information Technology, 2012, 35(1):1-6.

[7] USTUN S V, DEMIRTAS M. Modeling and control of V/f controlled induction motor using genetic-ANFIS algorithm[J]. Energy Conversion and Management, 2019, 50(3):786 -791.

[8] Yang Xinhua, Wang Guanping, Hou Hong. Research on the implementation of space vector pulse width modulation based on artificial neural networks [J]. Motor and control applications,2006,33(10):18-20.

[9] Li Jianlin, Li Yuling, Li chun, Zhang Zhongchao. Application of SVM based on back propagation neural network in voltage type converters [J]. Chinese journal of electrical engineering,2005,25(6):71-74.

[10] Choi Young-Sik, Choi Han Ho and Jung Jin-Woo. Feedback Linearization Direct Torque Control With Reduced Torque and Flux Ripples for IPMSM Drives [J]. IEEE Transactions on Power Electronics, 2016, 5(31): 3728-3737.