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Research on braking technology of permanent magnet synchronous motor of new energy vehicle

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Abstract: The permanent magnet synchronous motor (PMSM) of new energy vehicles has such superior characteristics as relatively high working efficiency, relatively high torque/inertia ratio, relatively high energy density, environmental protection and energy saving, so it is of great significance to the research of PMSM braking technology. Because the motor is running process will be affected by some disturbances, the speed of the motor deviates from the original rated speed, so we pass based on the analysis of the mathematical model, we put the motor rotation speed deviation rate and rotation speed deviation e DE/dt is as the input variables to make the system automatically adjust the motor speed to keep them at rated speed, not only has rapid response speed, no overshoot amount and immunity performance is good, can better improve the permanent magnet synchronous motor speed control system of dynamic and static characteristics, but also in the interference of nonlinear factors on the system has a certain inhibitory effect.

1. Introduction

As early as 1886, the first car in the world was invented by German Carl Benz. Up to now, thanks to the great and unimaginable progress made in science and technology and manufacturing technology, the harvest level of human beings has been greatly improved. At the same time, the number of cars in the world continues to increase rapidly[1]. However, while cars provide convenience to human beings, they also increase the consumption of oil and energy and aggravate human's pollution of the natural environment[2]. More and more attention has been paid to green cars. Electric vehicles refer to vehicles that meet the requirements of road traffic and relevant laws and regulations, are driven by electric energy and driven by motors. Compared with traditional internal combustion engine vehicles, electric vehicles have the renewable energy of electric energy, and have the characteristics of little environmental pollution. Because electric cars are driven by electric motors, the feasibility of electronic braking is established, and the structure of the vehicle is simpler than that of traditional internal combustion engine models. To this end, governments and car manufacturers all over the world are researching and developing various electric vehicles[3]. It can be predicted that electric vehicles will be an important means of transportation in the 21st century. Motor in the electric vehicle according to the different models (hybrid car, pure electric car) plays a part of the replacement of the engine or the role of complete replacement of the engine, so motor brake system is one of the core technologies of electric vehicles[4]. Since the 1970s, the United States, France, Germany, Japan and other powerful countries in the automotive industry began to study motor braking system for electric vehicles. Since the tenth five-year plan, various enterprises, universities and scientific research institutions have focused on the research of motor braking system for electric vehicles.

Motor brake system includes motor, motor brake. Motor brake also includes frequency converter and brake circuit. Ac induction motor with high reliability, no maintenance, small size, light weight, low price, high efficiency,It has many advantages such as simple structure, high specific power, high speed, easy cooling, wide range of power capacity, long service life and large variation of power factors. The basic speed regulation mode of ac induction motor includes voltage regulation speed regulation, pole variation speed regulation and frequency conversion speed regulation[5-6]. Among them, variable frequency braking mainly has three technologies: constant voltage frequency

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ratio braking, rotational difference frequency braking and vector braking. At present, vector braking has excellent dynamic and static performance, which is comparable with dc speed regulation. Because of its simple braking, good dynamic performance and little influence by motor parameters, DTC brake shows a broad application prospect in locomotive traction and other fields.

With the development of computer technology, braking theory, power electronics technology and microelectronics technology, the speed regulation method of permanent magnet synchronous motor (PMSM) is also developing constantly. At present, vector braking and weak magnetic braking are mainly used to speed regulation braking of PMSM. Due to the rapid development of power electronics technology and control technology, the permanent magnet synchronous motor control technology is now more skilled and in the process of continuous optimization, the current permanent magnet synchronous motor has been used in the past range of synchronous motor has been greatly expanded. We can say that the permanent magnet synchronous motor has been continuously extended use scope, the speed is controlled from the general to the fuzzy intelligent control of high precision speed control, from the field of industrial production to can touch all kinds of advanced science and technology, it has been called the best motor performance, and it can only make prospects will be more and more obvious. We can see that the permanent magnet synchronous motor will be toward high efficiency, direct drive, high speed, high accuracy, high performance, extensive, intelligent control and network modularization and other directions will continue to make progress.

2. Permanent magnet synchronous motor control speed regulation method

2.1 Mathematical model of permanent magnet synchronous motor control system

The equations of permanent magnet synchronous motor include voltage equation, motion equation, current equation and torque equation, etc., which are the basis of its mathematical model. It is very important to establish the mathematical model of the controlled object to accurately reflect the different characteristics of the controlled object. The servo control system, which makes the tracking target value change at will, is called servo control system, which takes the moving direction, position and speed of the object as the controlled object. This servo drive control is an important part of a typical electromechanical integration system. The input power factor should be high and the output load impedance should be low. The transient response of permanent magnet synchronous motor (PMSM) should be rapid and the steady-state accuracy should be high. Permanent magnet synchronous motor reliability is good, in the premise of safety, the motor operation should be economic, efficient; Motor to resist electromagnetic interference, to prevent electromagnetic interference and affect the efficiency of power; Permanent magnet synchronous motor to intelligent direction of development. Due to the traditional motor with adjustable frequency, which is mostly controlled by analog circuit, it is difficult to achieve higher requirements. In order to facilitate our analysis, we assume that:

(1) the magnetic circuit is unsaturated, and the motor inductance is not affected by current changes, and eddy current and hysteresis losses are not considered;

(2) ignore the influence of tooth groove, phase change process and armature reaction;

(3) the three-phase winding is symmetrical, and the magnetic field of the permanent magnetic steel is sinusoidal distributed around the air gap;

(4) armature windings are uniformly and continuously distributed on the inner surface of the stator;

(5) drive diode and secondary diode are ideal components;

(6) rotor flux is sinusoidal in the air gap. The rotor flux linkage in each phase winding is respectively

$$\begin{bmatrix} \Psi_{\mathrm{A}} \\ \Psi_{\mathrm{B}} \\ \Psi_{\mathrm{C}} \end{bmatrix} = \Psi_{\mathrm{f}} \begin{bmatrix} \cos\theta \\ \cos(\theta - 2\pi/3) \\ \cos(\theta + 2\pi/3) \end{bmatrix} \tag{1}$$

2.2 Voltage balance equation

For the production of permanent magnet synchronous motor voltage, it is produced by the stator windings of three phase current, but also a permanent magnet rotor is also produced a contrary electromotive force, the stator three phase winding and our daily life of ordinary motor, three-phase winding is 120 degrees of difference in space, the difference is that the permanent magnet synchronous motor rotor is of permanent magnets to generate counter electromotive force.

Thus, the stator voltage equation can be obtained:

$$u_{\mathrm{A}} = R_{\mathrm{s}} i_{\mathrm{A}} + p\Psi_{\mathrm{A}} \tag{2}$$

$$u_{\mathrm{B}} = R_{\mathrm{s}} i_{\mathrm{B}} + p\Psi_{\mathrm{B}} \tag{3}$$

$$u_{\mathrm{C}} = R_{\mathrm{s}} i_{\mathrm{C}} + p\Psi_{\mathrm{C}} \tag{4}$$

Where: $u_{\mathrm{A}}, u_{\mathrm{B}}, u_{\mathrm{C}}$ - three-phase winding voltage;

R_{s} - resistance of each phase winding;

$i_{\mathrm{A}}, i_{\mathrm{B}}, i_{\mathrm{C}}$ - three-phase winding phase current;

$\Psi_{\mathrm{A}}, \Psi_{\mathrm{B}}, \Psi_{\mathrm{C}}$ - magnetic chain of three-phase winding turns;

$p = d/dt$ -differential operator.

2.3 Magnetic chain equation

In the flux equation, the flux of the stator is closely related to the three-phase winding current, the excitation magnetic field of the rotor permanent magnet pole, and the spatial vector position of the rotor. Therefore, the flux equation of the stator can be clearly expressed as:

$$\Psi_{\mathrm{A}} = L_{\mathrm{AA}} i_{\mathrm{A}} + M_{\mathrm{AB}} i_{\mathrm{B}} + M_{\mathrm{AC}} i_{\mathrm{C}} + \Psi_{\mathrm{fA}} \tag{5}$$

$$\Psi_{\mathrm{B}} = M_{\mathrm{BA}} i_{\mathrm{A}} + L_{\mathrm{BB}} i_{\mathrm{B}} + M_{\mathrm{BC}} i_{\mathrm{C}} + \Psi_{\mathrm{fB}} \tag{6}$$

$$\Psi_{\mathrm{C}} = M_{\mathrm{CA}} i_{\mathrm{A}} + M_{\mathrm{CB}} i_{\mathrm{B}} + L_{\mathrm{CC}} i_{\mathrm{C}} + \Psi_{\mathrm{fC}} \tag{7}$$

Where: $L_{\mathrm{AB}}, L_{\mathrm{BB}}, L_{\mathrm{CC}}$ - mutual inductance of each phase winding;

$M_{\mathrm{AB}} = M_{\mathrm{BA}}, M_{\mathrm{BC}} = M_{\mathrm{CB}}, M_{\mathrm{CA}} = M_{\mathrm{AC}}$ - mutual inductance of two-phase winding;

$\Psi_{\mathrm{fA}}, \Psi_{\mathrm{fB}}, \Psi_{\mathrm{fC}}$ - three-phase winding turns the chain of the flux chain of the rotor to each pole of the permanent magnet flux.

And the stator armature winding has the maximum possible turn chain of the rotor of each pole of the permanent magnet chain:

$$\Psi_{\mathrm{fA}} = \Psi_{\mathrm{f}} \cos\theta \tag{8}$$

$$\Psi_{\mathrm{fB}} = \Psi_{\mathrm{f}} \cos(\theta - 2\pi/3) \tag{9}$$

$$\Psi_{\mathrm{fC}} = \Psi_{\mathrm{f}} \cos(\theta + 2\pi/3) \tag{10}$$

2.4 Induced electromotive force

Due to rotor permanent magnet of the magnetic field generated in the space is sinusoidal, and sinusoidal magnetic field amplitude is also are not change, the position of the rotor of the vector is direct axis of the rotor magnetic pole of permanent magnet, permanent magnet synchronous motor relative to the stator and rotor position Angle is equal to A phase winding axis, the spatial distribution can be expressed as:

$$\Psi_{\mathrm{fg}}(\alpha, \theta) = \Psi_{\mathrm{f}} \cos(\alpha - \theta) \tag{11}$$

$$\Psi_{\mathrm{fg}}(\alpha, \theta) = \Psi_{\mathrm{f}} \cos\alpha \cos\theta + \Psi_{\mathrm{f}} \sin\alpha \sin\theta \tag{12}$$

Since the general rotor is composed of permanent magnets, the position change of permanent magnets (rotor position Angle change) is generated by the rotation of the rotor. It can be seen from equation (12) that the induced electromotive force of a permanent magnet synchronous motor is jointly affected by the ac windings of each phase of the stator of the motor and the counter electromotive force generated by the magnetic field of the permanent magnet of its rotating rotor.

That is, we can have:

$$\Psi_{\mathrm{fA}} = \Psi_{\mathrm{f}} \cos\theta \tag{13}$$

$$\Psi_{\mathrm{fA}\perp} = \Psi_{\mathrm{f}} \sin\theta \tag{14}$$

For each phase of each stator armature winding, the law of electromagnetic induction makes it easy to derive the magnetic field generated by A phase winding by A permanent magnet of A constantly rotating rotor.

The induced potential is:

$$e_{\mathrm{A}} = -p\Psi_{\mathrm{fA}} = \omega\Psi_{\mathrm{f}} \sin\theta \tag{15}$$

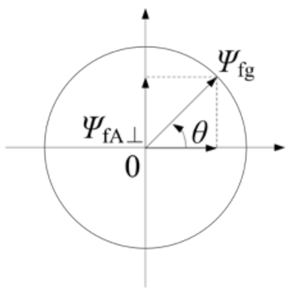

Figure 1 circular magnetic field and pulsed magnetic field

Where the angular velocity of rotor rotation is equal to the differential of rotor position Angle

$$\omega = p\theta \tag{16}$$

$$\Psi_{\mathrm{fB}} = \Psi_{\mathrm{f}} \cos(\theta - 2\pi/3) \tag{17}$$

$$\Psi_{\mathrm{fC}} = \Psi_{\mathrm{f}} \cos(\theta + 2\pi/3) \tag{18}$$

Thus, according to formula (18), the induced potential generated by the superposition of the circular rotating magnetic field in the winding of phase B and phase C can be obtained as follows

$$e_{\mathrm{B}} = \omega\Psi_{\mathrm{f}} \sin(\theta - 2\pi/3) \tag{19}$$

$$e_{\mathrm{C}} = \omega\Psi_{\mathrm{f}} \sin(\theta + 2\pi/3) \tag{20}$$

The induction potential of three-phase winding can also be expressed as follows:

$$e_{\mathrm{X}} = \omega\Psi_{\mathrm{f}} \sin(\theta - \gamma_{\mathrm{X}}) \tag{21}$$

As can be seen from equation (21), the amplitude of induced electromotive force generated by permanent magnetic field in stator armature winding is $\omega\Psi_{\mathrm{f}}$, and the larger the winding chain of three-phase ac winding of stator and the rotating speed of rotor permanent magnet, the larger the induced electromotive force generated in space will be.

Because the voltage equation of permanent magnet synchronous motor is very complex, it is not easy to get the desired result by manual calculation directly. Therefore, we have to use computer modeling software to build his mathematical model to facilitate us to solve the problem:

This is a permanent magnet synchronous motor rotor position sensor after space vector control mathematical model of control system, we through the observation of the stator resistance of the three-phase ac winding and direct axis and quadrature axis voltage value, and the size of the inductance of the motor and the mechanical angular velocity of the motor, the motor load moment of inertia of the size of the change and so on, we can solve many complex problems.

And from the above formula we can also see that the permanent magnet synchronous motor is a system controlled by a lot of nonlinear changes. Alpha and beta are coupled. Therefore, it cannot be adjusted independently. This prevents the system from being linearized. The rotor position vector control strategies commonly used in the speed-regulating system of permanent magnet synchronous generator are as follows:

(1) $i_d = 0$ control;

(2) large mechanical electromagnetic torque current ratio control technology:

(3) power factor control technology of unit variable;

(4) control technology and other methods for small system losses. Different control methods have their own advantages and disadvantages. By comparing the control methods of permanent magnet synchronous motor to achieve the desired purpose, it can be concluded that the most commonly used control means in life are mainly methods (1). Because $i_d = 0$ control is used, this complex problem will be better handled.

Fuzzy control is based on people's skilled operation experience. PI control achieves the purpose of engineering system control by removing the error e (k) between the project to be achieved and the actual work process, which is convenient and reliable. Fuzzy control systems have many superior characteristics in linear or nonlinear systems. A large number of practical operation data summarized, using natural language to describe the control strategy, fuzzy principles, fuzzy rules of the program and fuzzy logic thinking reasoning as a relatively simple intelligent computer system control means. Vague comparing traditional classic PI control and PI control method is the biggest difference lies in the vague control does not need to establish a more accurate mathematical model, just need to operating personnel experience or expert knowledge into fuzzy control rules entered into the reasoning module as a rule base, then from the real-time signal fuzzification interface module process input to the reasoning module, and the output, after reasoning output against blur can complete control of the controlled object.

The first step is that we need to change this clear number into a fuzzy number, and map it to a fuzzy subset of k (k=1,2,3...). On, get a real value, find the membership degree of the real value belonging to Ak, that is, the system of fuzzy. We can easily obtain the membership degree by using the membership function of the system:

When the fuzzy domain takes discrete values, the membership function is shown in formula (24).

$$A=\sum \frac{A(X_i)}{X_i} \tag{24}$$

When the continuous value of the fuzzy domain is taken, the membership function is shown in formula (25).

$$A=\int \frac{A(X)}{X} \tag{25}$$

Fuzzy quantity after fuzzy input "reasoning machine", fuzzy PI intelligent control rules, we carry out fuzzy neural network theory to simulate the process of our brain processing problems. The output of approximate reasoning is fuzzy vector, which cannot be directly used as the control quantity of the system. Moreover, it must complete a transformation from fuzzy to clearness, which can be converted into clear quantity for output, that is, defuzzification. In the electromechanical integration control system, the widely used fuzzy method is generally the weighted average method, as shown in formula (26). The characteristics of fuzzy control are shown in literature [7].

$$V_0=\frac{\sum_{i=1}^{m} V_i K_i}{\sum_{i=1}^{m} K_i} \quad (26)$$

3. Conclusion

Based on fuzzy PI intelligent braking speed instead of the traditional use of classical PI brake algorithm applied in permanent magnet synchronous motor speed control system, make good use of the fuzzy PI intelligent brake using simple and convenient, the application of the theory of rules, have their own less able to adapt to the outside world can change at any time immediately reacted correctly the advantages of improving the braking system with permanent magnet synchronous motor speed control performance showed stronger than traditional PI braking features. Through the application of fuzzy PI intelligent braking permanent magnet synchronous motor braking speed regulation system, it can be in the system reaction speed, tends to stability and other convenient dynamic and static performance, system parameters with time changes in the performance of adaptive adjustment ability and robustness are superior to the traditional classical PI braking.

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