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Improved Utilization of DC Intermediate Circuit Voltage for Sliding Mode Control PMSM Drive

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Abstract: *In order to optimize the dynamic performance of the permanent magnet synchronous motor (PMSM)speed regulation system, a nonlinear speed-control algorithm for the PMSM control systems using sliding-mode control (SMC) is developed. First, a sliding-mode control method based on a new sliding-mode reaching law (NSMRL) is proposed. This NSMRL includes the system state variable and the power term of sliding surface function. In particular, the power term is bounded by the absolute value of the switching function, so that the reaching law can be expressed in two different forms during the reaching process. This method can not only effectively suppresses the inherent chattering, but also increases the velocity of the system state reaching to the sliding-mode surface. Based on this new reaching law, a sliding-mode speed controller (SMSC) of PMSM is designed. Then, considering the large chattering phenomenon caused by high switching gain, an improved anti-disturbance sliding-mode speed controller(ADSMSC) method, called SMSC+ESO method, is developed. This method introduces an extended state observer (ESO) to observe the lumped disturbance and adds a feed forward compensation item based on the observed disturbances to the SMSC. Finally, simulation and experimental results both show the validity of the proposed control method..*

Keywords: PMSM (Permanent Magnet Synchronous Motor) SMC (Sliding-Mode Control) NSMRL (New Sliding-Mode Reaching Law)

I. INTRODUCTION

Permanent magnet synchronous motor (PMSM) has many advantages, i.e., simple structure, high power density and highn efficiency. PMSM has been widely used in the fields of high precision CNC machine tools, robot, aerospace and other fields But at the same time, the PMSM is a complex control object with multi variable, strong coupling, nonlinear, and variable parameters. If the traditional linear control method such as proportional-integral (PI) is adopted, the control precision can only be met within a certain range. At the same time, the PI control method depends on the accuracy of the system model, which is highly susceptible to external disturbances and internal parameter changes. All these may make the control system deviating from the expected target.

Therefore, in order to solve the problems of traditional PI controller, some nonlinear control theories are proposed and developed, e.g., fuzzy control, auto disturbance rejection control , predictive control , sliding-mode control (SMC) and neural network control . Among them, sliding-mode control has become a research hotspot because of its low requirement on model accuracy and strong robustness to external interference. Sliding-mode control has been successfully applied in motor speed regulation system . A fuzzy sliding mode speed controller applied to PMSM can be found. In a hybrid control method based on sliding-mode controller was applied to the closed loop control system of PMSM, and the results are very conclusive regarding the effectiveness of the sliding-mode controller.

In addition, a neural network sliding-mode control method was proposed in to improve speed tracking precision. However, the sliding-mode method is not flawless; indeed, in practical applications, there are time delays in switching control law, which leads to high-frequency dynamics, known as chattering. Thus, many alternative methods have been proposed to overcome the chattering phenomenon, such as reaching law method high-order sliding-mode method non-singular terminal sliding-mode and fractional-order sliding-mode. .Among them, since the reaching law method can directly act on the reaching process, it can more effectively solve the chattering problem. In a practical discrete-time fractional-order terminal sliding-mode variable structure speed controller was designed. The experimental results show that the dynamic performance of the controlled system is improved. In the terminal switching gain term was added on the basis of the conventional exponential approach law, and the saturation function was designed to replace the switching function. The simulation results show the effectiveness of the proposed method.

II. LITERATURE REVIEW

[1]It is used genetic algorithm to optimize the gain of the variable pi controller for doubly salient permanent magnet motor drive system. This system shows better dynamic performance based on variable pi controller when compared to fixed gain pi controller, though this system doesn't provide the magnetic saturation effects on drive system.

[2] It studied the performance of various current controllers for pmsm drive system at high speeds. In this investigation, the comparison between current controller of flux linkage model and pi controller system is given. In this comparison, model based system provides better performance than conventional pi controller. However, the model based systems have a steady state error because the given controller didn't take any prevention in voltage drop. The voltage is dropped in phase winding and power converters of the system.

[3] It developed a modular control strategy using iterative learning control (ilc) for surface mounted pmsm drive system. This system creates the reference current for pmsm drive system. The cyclic torque and the reference current of the system are recorded over one cycle, then next cycle reference current is recorded using above recorded signal. The advantage of the control approach of this system minimizes the torque pulsations. However, the control technique of this system is not suitable for high performance of the pmsm drive system.

[4] It implemented a self-tuning method for fixed gain pi controller of pmsm drive system. In this method, the gains of the proportional and integral system are changed with predetermine range. The performance of the self-tuning method is carried over matlab software. The drawback of this system is that the changes of the proportional and integral were varied with different operations condition of the pmsm drive system.

[5]It is developed an optimal control theory for on-line tuning of the fixed gain pi controller of the pmsm drive system. The optimal control theory is developed based on eigenvalue assignment method and it applied for multi input multi output vector controller pmsm servo drive system. The performance of the control theory is applied for speed, load torques and changes in the motor parameters. However, the optimal control theory model is not applicable for real time applications.

[6] Itdeveloped a pmsm drive system based on sensor less control strategy system. This system depends on the d-axis current regulator of the pi regulation system. The flux linkage of the permanent magnet is considered by this system. The results reveal the effectiveness of the proposed system and it, also shows that it doesn't conduct the drive test for various dynamic operating conditions. The system also shows that steady state speed ripples for changes in load torque at low speed.

III. METHODOLOGY AND ALGORITHM

3.1 Equivalent Circuit and Vector Diagram of a PMSM

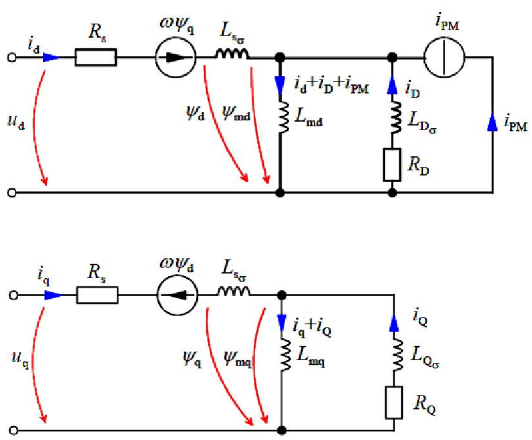

Fig. 3.1 Equivalent circuits of a PMSM in the d- and q-directions.

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Similarly as separately excited synchronous machines, the PM synchronous machines are usually treated in a dq reference frame fixed to the rotor, Figure 2.3. The equivalent circuit of the machine is almost the same as for a separately excited synchronous machine.

Equivalent circuits of a PMSM in the d- and q-directions. The permanent magnet can be depicted by a current source *i*PM in the rotor circuit; in the magnetizing inductance, this current source produces the permanent magnet's share of the air gap flux linkage

PM = *i*PM*L*md.

If also the damper windings are included in the model, the voltage equations of a PM machine differ from a separately excited synchronous machine only by the fact that the equation for the field winding is lacking.

Thus, the voltage equations of the PM machine are given in the rotor reference frame in the familiar form:

$$u_{sd} = R_s i_{sd} + \frac{d\psi_{sd}}{dt} - \omega\psi_{sq},$$
$$u_{sq} = R_s i_{sq} + \frac{d\psi_{sq}}{dt} + \omega\psi_{sd},$$
$$0 = R_D i_D + \frac{d\psi_D}{dt},$$
$$0 = R_Q i_Q + \frac{d\psi_Q}{dt}.$$

The flux linkage components in the equations are determined by the equations

$$\psi_{sd} = L_{sd} i_{sd} + L_{md} i_D + \psi_{PM},$$
$$\psi_{sq} = L_{sq} i_{sq} + L_{mq} i_Q,$$
$$\psi_D = L_{md} i_{sd} + L_D i_D + \psi_{PM},$$
$$\psi_Q = L_{mq} i_{sq} + L_Q i_Q.$$

The flux linkage PM of the permanent magnet can be considered to be generated by the field Current

$$i_{PM} = \frac{\psi_{PM}}{L_{md}},$$

now the definitions for the flux linkages do not deviate from the definitions of a separately excited synchronous machine. However, it is worth noticing that due to the saturation of the magnetizing inductance *L*md, *i*PM is not constant.

The vector diagram of the PMSM is a modification of the vector diagram of a synchronous machine, Figure 2.4. Permanent magnets create the flux linkage PM of the permanent magnets in the stator winding.

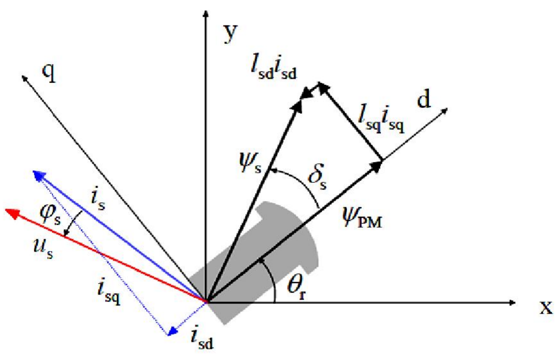

Fig. 3.2 Vector diagram of a PMSM

Vector diagram of a PMSM. Stator reference frame (xy) and rotor reference frame (dq). At its nominal operating point, the machine operates as a motor.

IV. RESULT ANALYSIS

4.1 Implementation Of Methodology By Using Simulation

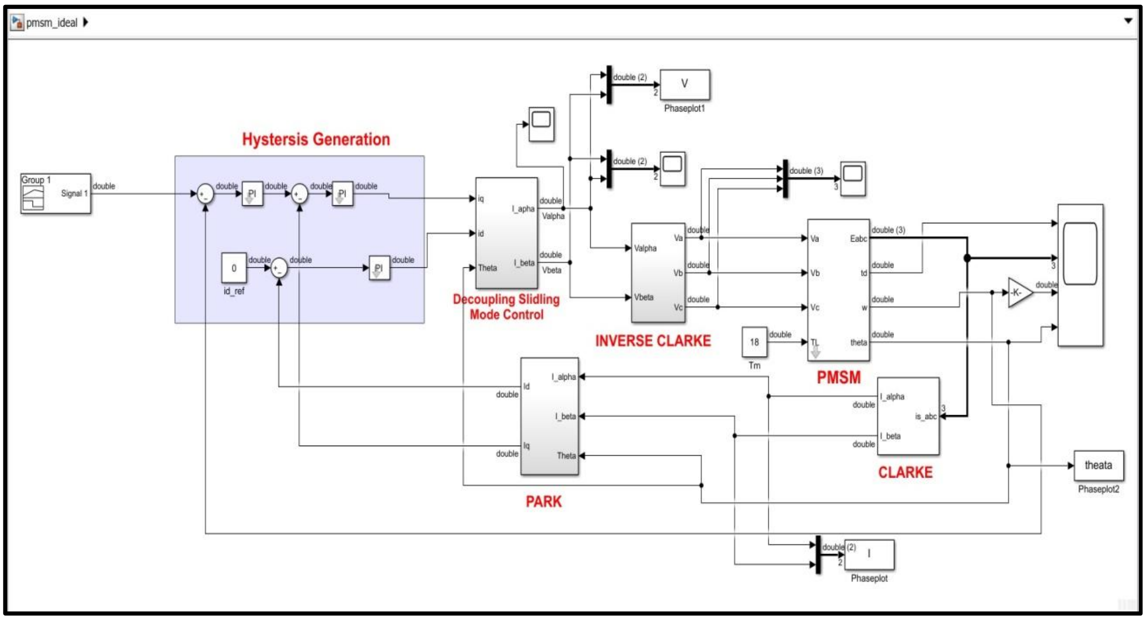

Fig. 4.1 Simulation Model for Adaptive SMC Speed Control Design for Permanent Magnet Synchronous Motor Drives

An adaptive proportional–integral–derivative (SMC) speed control scheme for permanent magnet synchronous motor (PMSM) drives. The simulation is divided into two groups, and the simulation parameters are set as follows. For group one, the simulation time t is set to 0.4 s, and the given speed is 1000 r/min. The group one simulation results are shown in Fig.4.1.

For the other group, the simulation time t is also set to 0.4 s. In order to verify the dynamic response of the load disturbances, the motor starts with no-load torque, and when running to 0.2 s, the load torque suddenly increases to 1.27 N-m, and at 0.3 s, the load torque is discharged to 0.65 N-m.

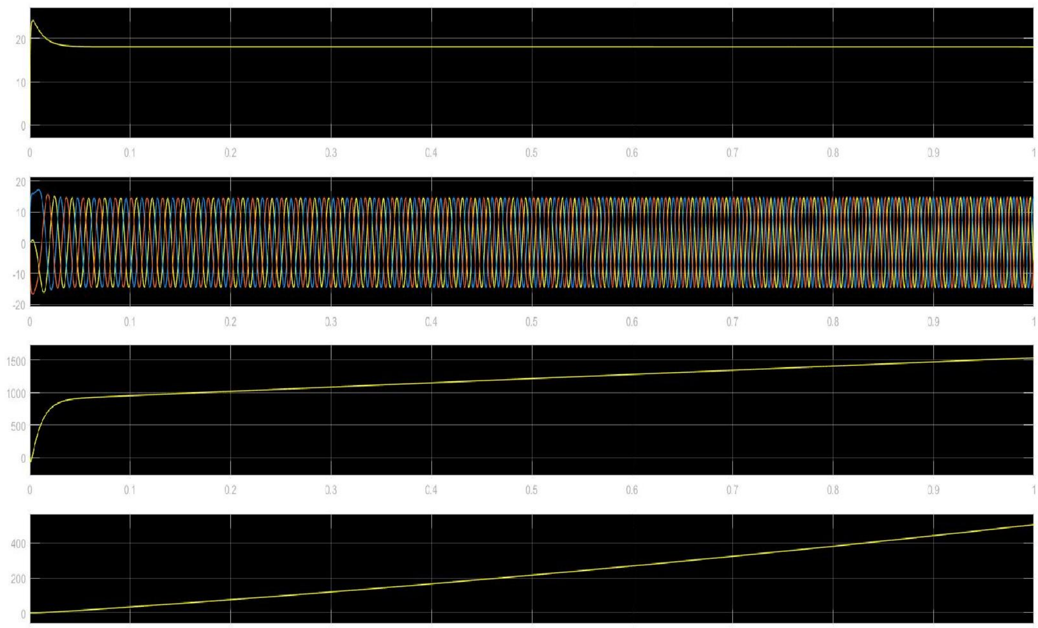

Fig. 4.2 Output of Permanent Magnet Synchronous Motor Drives using Adaptive SMC Controller.

The output speed response of the controller for the given reference speed of 100 rad/sec is appeared. It can be seen that while using the bio-inspired particle swarm optimization technique, the overshoots obtained is zero when contrasted with the situation. When the SMC controller is tuned by utilizing traditional techniques Shown in Fig. 4.2 The settling time is also lesser in case of the ABC Optimization, also the rise time is decreased.

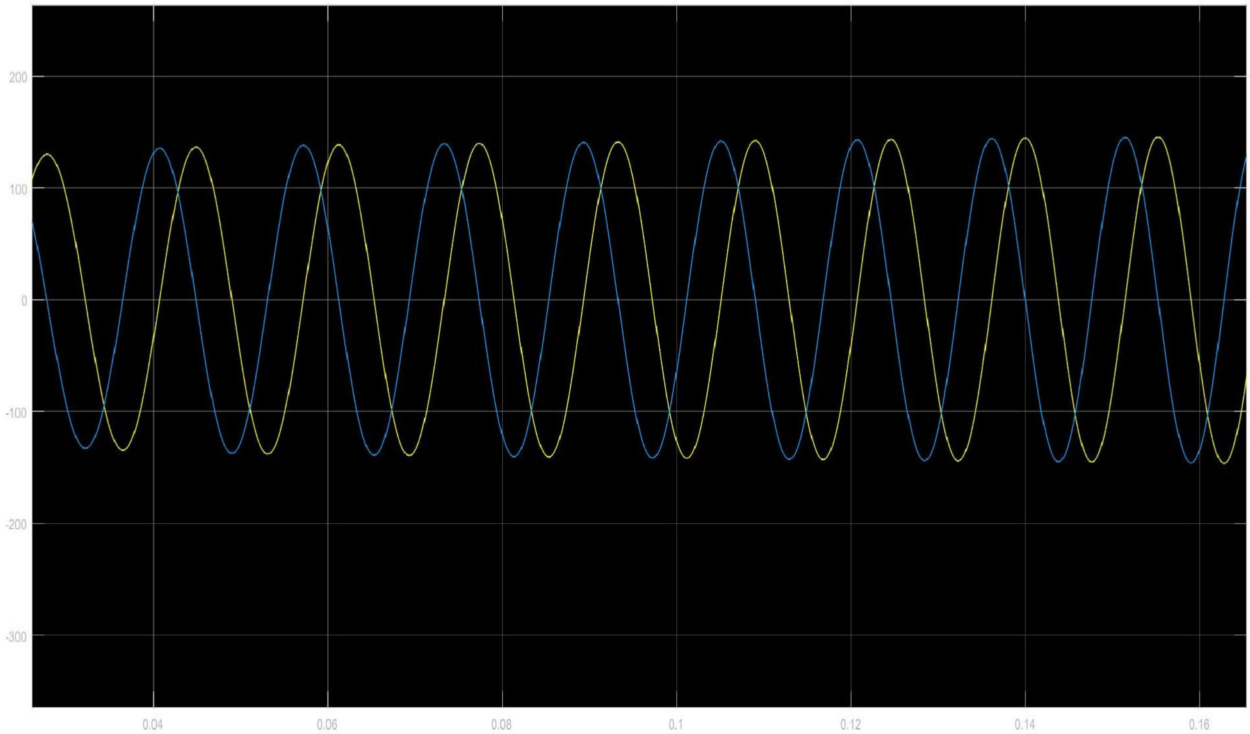

Fig. 4.3 Current supplied to the PMSM Drives

It demonstrates the speed response of the IPMSM motor for the traditional and the proposed controllers. The actual speed of the motor various controllers regarding 1400 rad/min as the reference speed for each 0.02sec.It should be noted that the gains of the conventional SMC controller aretuned under nominal parameters via extensive simulation studies as Shown in Fig. 4.3

The main accomplishments are summarized as follows:

1. It provided a novel adaptive SMC control strategy with a detailed design procedure.
2. It offered the mathematical proof about the stability and zero convergence of the control system with Lyapunov's direct method and related lemmas.
3. It tested the adaptive SMC control scheme that can precisely track the speed of the SPMSM drive under motor parameter variations and external load disturbances.

V. CONCLUSION

A NSMRL has been proposed for optimizing the dynamic performance of PMSM speed regulation system. By establishing the simulation model of s function, it is proved fundamentally that compared with the traditional exponential reaching law and the reaching law in other reference, the reaching velocity of the proposed NSMRL in this paper is faster. Based on the NSMRL, a SMSC is designed to replace the conventional PI controller. Then, considering the large chattering phenomenon caused by high switching gains, an extended state observer based on hyperbolic tangent function is designed to estimate the load disturbance, and it is used as the feed-forward compensation added to the SMSC. The superiority of the proposed method (SMSC+ESO) has been confirmed through simulations and experiments, which results show that the designed method can obtain a satisfying performance with fast transient response, good disturbances rejection ability.

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