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Sliding mode control for chaotic permanent magnet synchronous motor drive system

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***Abstract*—This paper proposed a sliding mode control approach for chaotic permanent magnet synchronous motor drive system. By using the sliding mode control technique and Lyapunov stability theory, a sliding manifold is introduced and a control law is constructed. Numerical simulations are done to show the effectiveness of the proposed method.**

***Index Terms*—sliding mode control; chaotic systems; permanent magnet synchronous motor;**

I. Introduction

Chaos is a periodic long-term behavior that exhibits sensitive dependence on initial conditions [1-2]. The fundamental characteristics of chaotic behavior come from its internal structure. Chaotic behaviors are very complicated. Now, chaos has been seen to have many useful applications in many engineering systems such as in genetic control systems, chemical reactors, lasers, power converters, and communication systems. Chaos can be useful in processes, such as in convective transfer. However, the chaotic behavior also can lead to undesirable effects such as uncontrolled oscillations in power grid. The occurrence of chaos in motor driver systems was reported by [3] in the late 1980s. From then on, it has been one of the interesting topics in nonlinear sciences. Many researchers have paid attention to the control in several kinds of motor drive systems, such as DC motor drives, induction motor drives, step motors, synchronous reluctance motor drives, and so on [4-8].

Modern electrical drives based on permanent magnet synchronous motors (PMSM) are wildly used in industrial applications due to their high efficiency, high speed, large torque to inertia ratio and high power performance. However, it is still a hard problem to control the PMSM to get the perfect dynamic performance because the dynamic model of it is nonlinear, and even experiences hopfbifurcation and chaotic attractors. Now, many control methods such as OGY method, feedback linearization, time delay feedback control, the adaptive control method and sliding mode control have been successfully used to control chaos in PMSM [5,7-10]. Among these methods, sliding mode control (SMC) systems have been studied extensively and have received many applications. Design the controller that drive the system to reach and remain on the sliding surface. The dynamic performance of a SMC system is determined by the prescribed switching surface upon which the control structure is switched [1,11-12]. The objective of this paper is to construct a sliding mode controller to stabilize the dynamical chaotic system of PMSM. A sliding mode surface is introduced, and by satisfying the reach-ability condition, a suitable sliding mode control law is developed.

II. Mathematical Model of Chaotic PMSM Drive System

The dimensionless mathematical model of a permanent magnet synchronous motor can be described as [8]

$$\begin{aligned} \dot{\omega} &= \sigma(i_q - \omega) - \tilde{T}_L \\ \dot{i}_q &= -i_q - i_d\omega + \gamma\omega + \tilde{u}_q \\ \dot{i}_d &= -i_d + i_q\omega + \tilde{u}_d \end{aligned} \tag{1}$$

where ω, i_d, i_q are sated variables. ω is angular speed and i_d, i_q denote the axis currents. $\sigma, \gamma > 0$ are system parameters. $\tilde{T}_L, \tilde{u}_q, \tilde{u}_d$ denote axis voltages and load torgue, respectively. If we select $\tilde{T}_L = \tilde{u}_q = \tilde{u}_d = 0$, then system (1) becomes unforced system:

$$\begin{aligned} \dot{\omega} &= \sigma(i_q - \omega) \\ \dot{i}_q &= -i_q - i_d\omega + \gamma\omega \\ \dot{i}_d &= -i_d + i_q\omega + \end{aligned} \tag{2}$$

The PMSM presents chaos with $\sigma = 5.45$ and $\gamma = 20$. The chaotic attractor is shown in Fig.1.

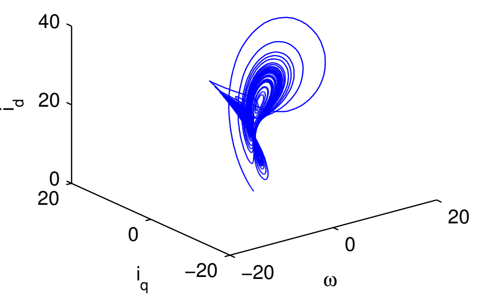

Fig.1. Chaotic attractor in PMSM.

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The chaotic oscillations can reduce the performance of the PMSM drive system. In order to control chaos in PMSM, we use $u(t)$ as an adjustable variable. For simplicity, the we introduce the following notations: $x=\omega, y=i_q, z=i_d$. Then the dynamic model of PMSM driver system can be rewritten as

$$\begin{aligned} \dot{x} &= \sigma(y-x)+u(t) \\ \dot{y} &= -y-xz+\gamma x \\ \dot{z} &= -z+xy \end{aligned} \tag{3}$$

The control objective of this paper is to design an sliding mode controller such that the state variables convergence to origin.

III. Sliding Mode Controller Desgin

In order to design the sliding mode controller, there are two steps. First, we must define a sliding mode surface and second, we determine the suitable control law. Inspired by [11], we define the adaptive switching surface as

$$s(t)=x(t)+f(t) \tag{4}$$

where $s(t)\in R$ and $f(t)$ ia an adaptive function satisfy

$$\dot{f}=rx-\gamma xy \tag{5}$$

where $r>0$ is design parameter. When the system operates in the sliding mode, the following equations must be satisfied:

$$s(t)=x(t)+f(t)=0 \tag{6}$$

and

$$\dot{s}(t)=\dot{x}(t)+\dot{f}(t)=0 \tag{7}$$

Then we have

$$\dot{x}(t)=-\dot{f}(t)=-rx+\gamma xy \tag{8}$$

Therefor for Eq.(8) the sliding mode dynamics can be rewritten as

$$\begin{aligned} \dot{x} &= -rx+\gamma xy \\ \dot{y} &= -y-xz+\gamma x \\ \dot{z} &= -z+xy \end{aligned} \tag{9}$$

Now we can analysis the stability of the closed-loop system based on the Lyapunov stability theory. Let us consider the following Lyapunov function candidate

$$V=\frac{1}{2}(x^2+y^2+z^2) \tag{10}$$

Its time derivative is given by

$$\begin{aligned} \dot{V} &= x\dot{x}+y\dot{y}+z\dot{z} \\ &= x(-rx+\gamma xy)+y(-y-xz+\gamma x)+z(-z+xy) \\ &= -rx^2-y^2-z^2 \end{aligned}$$

That is, $\dot{V}(t)\leq 0$. According to Lyapunov stability theory, we can see that the sliding mode motion on the sliding mode manifold is stable and guarantees

$$\lim_{t\to\infty}\|x,y,z\|=0 \tag{11}$$

Having established the suitable switching manifold, the next step is to design a sliding mode control scheme to drive the system trajectories onto the sliding mode $s=0$.

When the closed-loop system is in the sliding mode, we know that $\dot{s}=0$. Then we have

$$u(t)=-\sigma(y-x)-rx+\gamma xy-k\text{sign}s \tag{12}$$

where $k>0$ is design parameter.

From above discusses, now we are ready to get the following results.

Theorem 3.1: For chaotic PMSM system (3), if the sliding mode surface is selected as (4) and the control input is designed as (12), then the trajectory of the closed-loop system converges to the sliding surface $s=0$.

Proff 1: Let us consider the following Lyapunov function candidate:

$$V=\frac{1}{2}s^2 \tag{13}$$

Its time derivative is given by

$$\dot{V}=s\dot{s}=s(\dot{x}+\dot{f}) \tag{14}$$

From (3)-(5) we have

$$\dot{V}=s\dot{s}=s(\dot{x}+\dot{f}) \tag{15}$$

By using (3),(5), and (12) we can get

$$\dot{V}=-k|s| \tag{16}$$

Then we can conclude that the reaching condition is always satisfied. This complete the proof.

IV. Simulation Studies

This paper presents an illustrative example to verify the effectiveness of the proposed control approach. The initial value $[x,y,z]^T=[-10,-10,-1]^T$. The design parameters are chosen as $r=2, k=2$. The system parameters are selected as $\sigma=5.45, \gamma=20$. If $u(t)=0$, the responses of the state variables of the chaotic PMSM is shown in Fig.2.

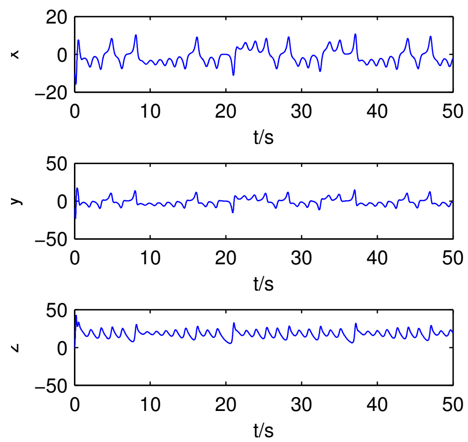

Fig.2. The time responses of state variables with $u(t)=0$.

Then if we use the control input as (12), the simulation results are shown in Fig.3-7.

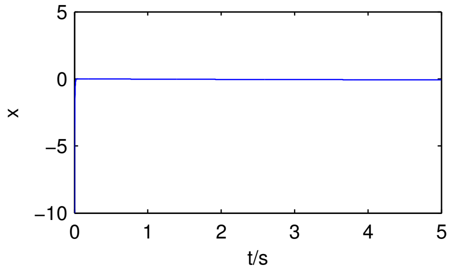

Fig.3. The time response of state variable x.

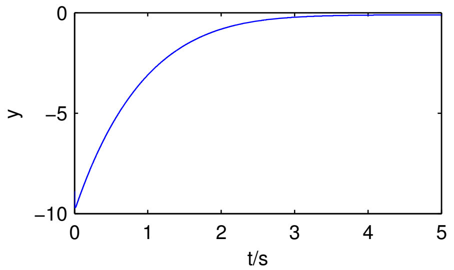

Fig.4. The time response of state variable y.

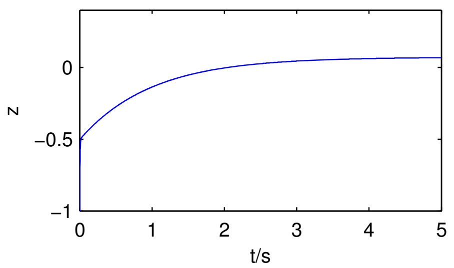

Fig.5. The time response of state variable z.

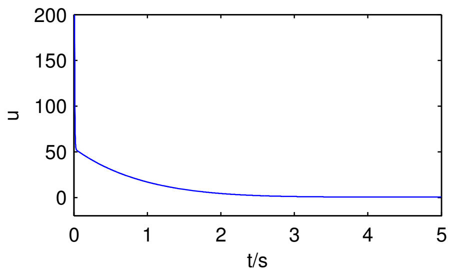

Fig.6. The control input.

The simulation results show that the proposed method is successful in controlling chaotic PMSM system, and the tracking performance is good.

V. Conclusion

In this paper, a sliding mode control method has been proposed to design a controller for chaotic PMSM systems. A switching surface is defined to determine the stability in the sliding mode motion. Lyanpunov based stability analysis and numerical simulation studies verify the effectiveness of this approach.

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