The control of the chaotic single-machine-infinite bus (SMIB) power system using two different methods

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Abstract: In this paper is performed chaos control for the single-machine-infinite bus (SMIB) power system using control methods based on sliding mode control and passive adaptive control. The single-machine-infinite bus (SMIB) power system creates chaotic oscillation when the amplitude of the power of the machine falls into a certain area. Designed the controllers for the complete chaos control of SMIB are obtained using sliding control theory, Lyapunov stability theory and passive adaptive control theory. Since the Lyapunov exponents are not required for these calculations, the sliding mode control method is very effective and convenient to achieve chaos control of similar systems. The designed passive controller which is introduced an adaptive law into to eliminate the influence of undeterministic parameter can be asymptotically stabilized at any desired fixed points. Numerical simulations are presented to demonstrate the effectiveness and validate the chaos control of the single-machine-infinite bus (SMIB).

Key words: The Single-Machine-Infinite Bus System, Chaos, Chaos Control, Nonlinear System

1. Introduction

Power systems are complex and highly nonlinear structured dynamical systems. In addition, the complexity of the power systems has been increased with the large-scale interconnected power systems developing. This case caused to increase the chaotic oscillations. The chaotic oscillations can be caused to the losing stabilization in some of the major power systems. Thus, the chaotic oscillations in power systems must be suppressed. In recent years, considerable efforts have been made to enhance the dynamic performance of power systems. To this end, for ensure the control of the power systems has been used different control methods. However, the research of chaos control in power systems is few. The main aim of this paper is to propose a suitable and applicable method for controlling chaos in SMIB power system.

Power systems basically have a nonlinear structure. For power systems investigation Single-Machine infinite-bus system is basic model. In this study chaotic behavior of SMIB model is controlled two different methods.

Sliding mode control (SMC) is known as a very effective way to control a system for its advantages, such as insensitivity to parameter variations, external disturbance rejection, and fast dynamic response. So, sliding mode control method is especially preferred due to its capability to suppress disturbances and dynamic model uncertainties by many researchers [1-7].

It is known that the passive control has many advantages as clear physical interpretation, less control effort required or ease in implementation. Therefore, passive adaptive control (PAC) of nonlinear uncertain systems has attracted the attention of many researchers lately [8-17]

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This paper contributes to the development of chaos control based on the SMC and the PAC for the single-machine-infinite bus (SMIB) power system. This paper is organized as follows. In the Section 2, the mathematical model of SMIB is described. The SMC to ensure chaos control of the SMIB system is designed in Section 3. Chaotic SMIB Power System is applied passive adaptive control in Section 4. Some numerical simulations are illustrated to confirm the validity of the proposed methods in Section 5. Finally, conclusions are given.

2. Description of Single Machine Infinite Bus System(SMIB)

In this section, we have been described SMIB and gyroscope systems which have been made synchronization.

The single-machine-infinite bus (SMIB) power system is investigated detail in reference (18). The SMIB power system (called swing equation) is given by:

$$M\ddot{\theta} + D\ddot{\theta} + P_{max}sin\theta = P_m \tag{1}$$

where θ denotes the angle of generator, M is the moment of inertia, D is the damping constant, P_m is the power of the machine, and $P_{\max}$ is the maximum power of generator. The P_m is also assumed to be as P_m =Asinωt, where A and ω are amplitude and frequency of the power of the machine, respectively.

For simplicity, $x_1=\theta$, $x_2=\dot{\theta}$ notations are introduced. By using these notations, the equation of motion in convenient first order form can be written as follow:

$$\left.\begin{aligned} \dot{x_1} &= x_2 \\ \dot{x_2} &= -cx_2 - \beta sinx_1 + fsin\omega t \end{aligned}\right\} \tag{2}$$

where $c=D/M$, $\beta=P_{max}/M$, $f=A/M$

In the realistic SMIB power system mode, parameters c$, \omega, \beta$ are deterministic and positive, the parameter f has uncertainty, which is influenced by work conditions.

3. Sliding Mode Control (SMC) of Chaotic Single Machine Infinite Bus System (SMIB)

Suggested SMIB chaotic system is described in equation (2). Thus the controlled chaotic system of Single Machine Infinite Bus System is attained as follows:

where u_1, u_2, are control signals.

$$e = x - x_d \tag{3}$$

where e =$[e_1\ e_2]^T$ is the tracking error vector. The error dynamics may be written as below:

$$\dot{e} = \dot{x} - \dot{x}_d = Ax + Bg + Bu - \dot{x}_d \tag{4}$$

where A is the system matrix, B is the control matrix, and g represents the system nonlinearities plus parametric uncertainties in the system. The control problem is to get the state x= $[x_1\ x_2]^T$ to track a specific time varying state x_d= $[xd_1\ xd_2]$T in the presence of nonlinearities.

$$A = \begin{bmatrix} 0 & 1 \\ 0 & -c \end{bmatrix};\quad B = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix};\quad g = \begin{bmatrix} 0 \\ G \end{bmatrix} \text{ where, } G = \beta sin x_1 + f sin\omega t$$

Now, a time varying proportional plus integral (PI) sliding surface s (e, t) $\in R^3$ is defined by the scalar equation s = s (e, t) as

$$s = Ke - \int_0^t K(A - BL)e(\tau)d\tau \tag{5}$$

where $K \in R^{3x3}$, which must satisfy det(KB) ≠ 0, is a gain matrix, and $L \in R^{3x3}$, which must have a stable A-BL, is a gain matrix, namely, the eigenvalues λ_i (i=1,2,3) of the matrix A-BL are negative (λ_i |< 0). It is well known that when the system operates in the sliding mode, the sliding surface and its derivative must satisfy s = ṡ = 0 [19-20]. The equations may be written as below:

$$\dot{s} = KBg + KBLe + KBu + KAx_d - K\dot{x}_d = 0 \tag{6}$$

Since KB is non-singular, the equivalent control in the sliding mode is given by

$$u_{eq} = -[\ \hat{g} + Le\ ] - (KB)^{-1}\ [\ KAx_d - K\dot{x}_d\ ] \tag{7}$$

where g is not exactly known, but guessed as ĝ, and the estimation error on g is presumed to be restricted by some known function G such that ‖ g - ĝ ‖ ≤ G. In addition, it reveals that the stability of systems in the sliding motion can be guaranteed just by selecting an appropriate matrix L using any pole assignment method. To ensure the achievement of the reaching condition indicated in equation (6), a control law is proposed as:

$$u = u_{eq} - (KB)^{-1}[\varepsilon + \| KBG \|\ ]sign(s) \tag{8}$$

where $\varepsilon > 0$.

4. Passive Adaptive Control (PAC) of Chaotic Single Machine Infinite Bus System (SMIB)

In this section a passive adaptive control (PAC) is studied for chaotic SMIB system.

The nonlinear system is described as follow [8-9]:

$$\begin{cases} \dot{x_1} = f(x) + g(x)u \\ y = h(x) \end{cases} \tag{9}$$

where, $x \in R^n$, $u \in R^m$ and $y \in R^m$, state variable , external inputs and outputs vectors respectively, m columns of f and g are smooth vector fields, h is smooth mapping. Moreover, vector field f has an equilibrium point at least.

System (9) is said to be passive if there exists a real constant ε, such that for $\forall t \geq 0$, the following inequality holds:

$$\int_0^t u^T Y(\tau) d\tau \geq \varepsilon, \forall t \geq 0$$

or if there exist a constant ρ equal to or greater than zero, i.e. $\rho \geq 0$, and a real constant ε, such that

$$\int_0^t u^T(\tau) Y(\tau) d\tau + \varepsilon \geq \int_0^t \rho Y^T(\tau) Y(\tau) d\tau$$

The second equation 2 which has been added the controller is expressed as follows:

$$\left.\begin{aligned} \dot{x_1} &= x_2 \\ \dot{x_2} &= -cx_2 - \beta sinx_1 + fsin\omega t + u \end{aligned}\right\} \quad (10)$$

Designed the controller u:

$$\left.\begin{aligned} u &= -k_1 x_2 - x_1 + \beta sinx_1 - \hat{f} sin\omega t \\ \dot{\hat{f}} &= k_2 x_2 sin\omega t \end{aligned}\right\}. \quad (11)$$

Where k_1 is an arbitrary real positive constant; $\hat{f}$, is the estimate value of undeterministic parameter f ; $\hat{f}$ is adaptation algorithm; k_2 is an arbitrary positive scalar, which can adjust the performance of adaptation algorithm. The chaotic oscillations in SMIB power system will be asymptotically stabilized at the equilibrium point.

5. Numerical Simulations for Chaos Control of the Single Machine Infinite Bus System (SMIB)

In this section, the Single Machine Infinite Bus System (SMIB) is controlled to a chaotic orbit by a sliding mode control (SMC) and passive adaptive control (PAC). Numerical simulations are applied to confirm the effective and the feasible of the proposed control methods.

5.1 Applied sliding mode control method to the SMIB system

The second equation (2) which has been added the controller is expressed with the numerical values as follows:

$$\left.\begin{aligned} \dot{x_1} &= x_2 + u_1 \\ \dot{x_2} &= -cx_2 - \beta sinx_1 + fsin\omega t + u_2 \end{aligned}\right\} \quad (12)$$

Where c=0.5, β=1, f=4.45, ω=1

A $=\begin{bmatrix} 0 & 1 \\ 0 & -0.5 \end{bmatrix}$; B=$\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$; g= $\begin{bmatrix} 0 \\ G \end{bmatrix}$

Where $G = -\beta sinx_1 + fsin\omega t$

Here, the gain matrix K is chosen as K = diag (1, 1) such that KB = diag (1, 1) is nonsingular. The desired eigenvalues of the matrix A-BL are taken as P = [-5 -5.001]. The gain matrix L is found as follows by using the pole placement method:

L = $\begin{bmatrix} 5 & 1 \\ 0 & 4.501 \end{bmatrix}$.

As a result, the matrix K(A-BL) is computed as K(A-BL) = diag (-5, -5.001). The PI switching surfaces are obtained as follows:

$$\left.\begin{aligned} s_1 &= e_1 + \int_0^t 5e_1(\tau)d\tau \\ s_2 &= e_2 + \int_0^t 5.001e_2(\tau)d\tau \end{aligned}\right\} \tag{13}$$

For this numerical simulation, the initial points of the system are employed as [$x_1(0)$, $x_2(0)$] = [-0.2, 0.1]. The constant controller coefficient ε is selected as 0<ε<0.5. The reference states xd_1, xd_2, are selected as $xd_1 = xd_2 = x_d$. Therefore, the control signals may be attained as:

$$\left.\begin{aligned} u_1 &= [\dot{x}_d - e_2 - 5e_1 - x_d - \varepsilon \text{sign}(s_1)] \\ u_2 &= \Big[\dot{x}_d - 4.501e_2 + \frac{x_d}{2} + \sin x_1 - 4.45sint \\ &\qquad -\text{sign}(s_2)(\varepsilon + |\sin(x_1) - 4.45sin|)] \end{aligned}\right\} \tag{14}$$

5.2 Applied passive adaptive control (PAC) method to the SMIB system

The equation (10) which has been added the controller is expressed with the numerical values as follows:

$$\left.\begin{aligned} \dot{x_1} &= x_2 \\ \dot{x_2} &= -cx_2 - \beta sinx_1 + fsin\omega t + u \end{aligned}\right\} \tag{15}$$

Where c=0.5, β=1, f=4.45, ω=1

$$\left.\begin{aligned} u &= -k_1x_2 - x_1 + \beta sinx_1 - \hat{f} sin\omega t \\ \dot{\hat{f}} &= k_2x_2sin\omega t \end{aligned}\right\} \tag{16}$$

Where, $k_1 = 0.5$, $\beta = 1$, $k_2 = 1$, $\omega = 1$

According to numerical simulations, time series of SMIB power system have been obtained as respectively shown in Figure 1; without controlled SMIB system, in Figure 2; controlled SMIB system with SMC, in Figure 3; controlled SMIB system with PAC, in Figure 4; applied the control signals to the SMIB system after 8s.

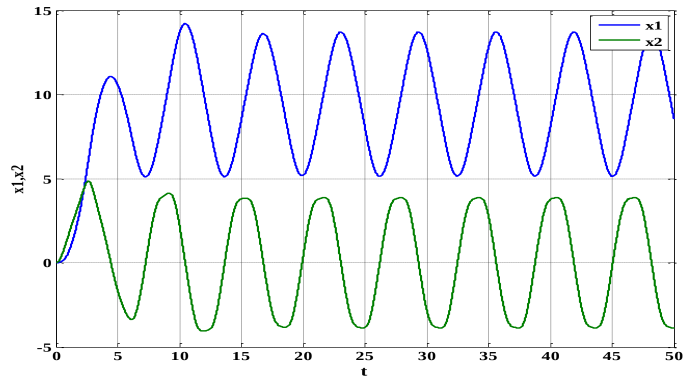

Figure 1. Time series of without controlled SMIB system in x1-x2-t plane

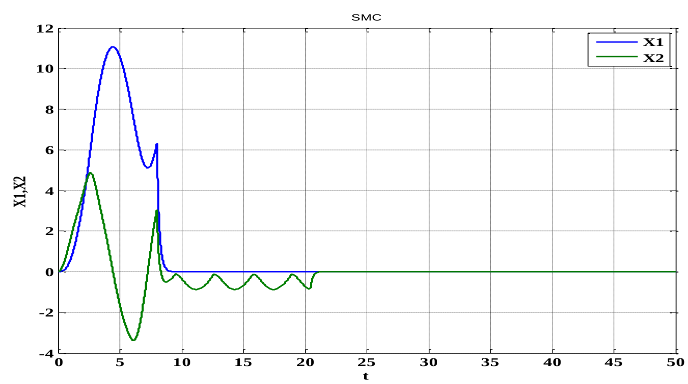

Figure 2. Time series of controlled SMIB system in x1-x2-t plane with SMC after 8s

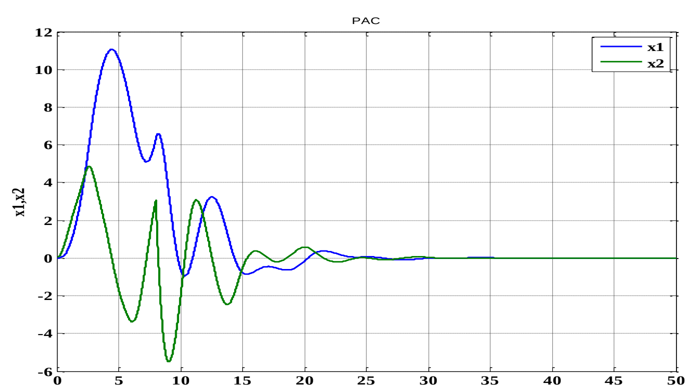

Figure 3. Time series of controlled SMIB system in x1-x2-t plane with PAC after 8s

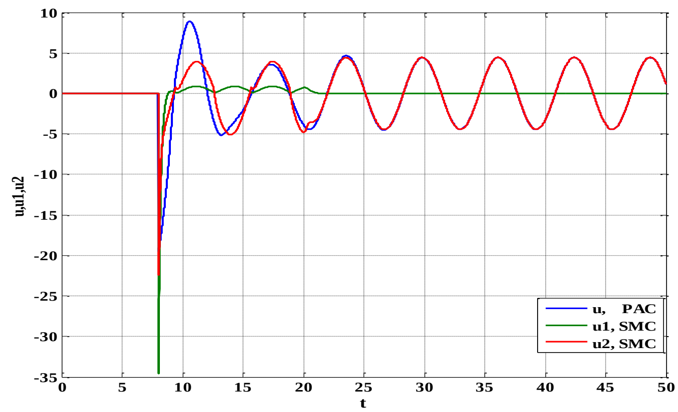

Figure 4. Applied the control signals to the SMIB system after 8s

6. Conclusions

In this paper, an effective control technique has been suggested to stabilize chaos SMIB power chaotic system. A sliding mode control law is applied by using a PI switching surface. So, it is found the stability of the error dynamics in the sliding mode that easily ensured by the PI switching surface. Designed SMC controller is rather satisfactory to a nonlinear controller to eliminate the undesirable chaotic oscillations. Several simulations results are presented. The simulation results indicate that the proposed control scheme works well. The control scheme was able to stabilize the chaotic SMIB power system around user-defined set-points. In addition, the control was able to induce chaos on the stable SMIB power system. In this paper, proposed S.M. Controller can be performed in similar systems. Furthermore, for the control of chaos in the SMIB power system have designed passive adaptive control (PAC) with unknown parameter. Simulation results indicate that the proposed passive adaptive control method is very effective and robust against the uncertainties in system parameter. Finally, numerical simulations are provided to show the effectiveness of proposed methods. The reaching results are satisfied in view of.

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