

Design of Sliding Mode Power System Stabilizer via Genetic Algorithm

Tsong-Liang Huang Chih-Han Chang Ju-Lin Lee Hui-Mei Wang

Department of Electrical Engineering
Tamkang University
#151, Ying-Chuan Rd. Tamsui, Taipei Hsien, Taiwan 25137, R.O.C
Tel : +886-2-26215656 Ext 2615
Fax : +886-2-26221565
E-mail : huang@ee.tku.edu.tw

Abstract

This paper proposes a new approach for combining genetic algorithm and sliding mode control to design the power system stabilizers (PSS). The design of a PSS can be formulated as an optimal linear regulator control problem. However, implementing this technique requires the design of estimators. This increases the implementation and reduces the reliability of control system. These reasons, therefore, favor a control scheme that uses only some desired state variables, such as torque angle and speed. To deal with this problem, we use the optimal reduced models to reduce the power system model into two state variables system by each generator. We use the genetic algorithm to find the switching control signals and use sliding mode control to find control signal of the generator. The advantages of the proposed method are illustrated by numerical simulation of the multi-machine power systems.

Keywords : PSS, Sliding Mode, Genetic Algorithm

1 Introduction

The power system stabilizers[1] are added to the power system to enhance the damping of the electric power system. The design of PSSs can be formulated as an optimal linear regulator control problem whose solution is a complete state control scheme [2]. But, the implementation requires the design of state estimators. These are the reasons that a control scheme uses only some desired state variables such torque angle and speed. Upon this, a scheme referred to as optimal reduced order model whose state variables are the deviation of torque angles and speeds will be used. The approach retains the modes that mostly affect these variables. The model is used to design an output states feedback controller. By using only the output feedback, the control strategy can be implemented easily.

The traditional PSSs strategies adopt the previous information of the system to decide the control signal so that it is hard to control the power system before it is going

to change. In this paper, we use the two-level sliding mode power system dynamic stabilizer via genetic algorithm to stabilize the system. We use the genetic algorithm to find the switching control signals and use sliding mode control to find the control signal of the generator. The advantages of the proposed method are illustrated by a numerical simulation of the multi-machine power systems. It appears that the proposed method reduces the oscillation and enhances the dynamic stability of the power system. Then, the proposed method will be compared with optimal control method and optimal reduced order method [4][5][6].

2 Two-Level Stabilization

2.1 Full Order Model

An example of the time optimal position control of a multi-machine system is used to illustrate the implementation and to evaluate the performance of the "OPEM" algorithm.

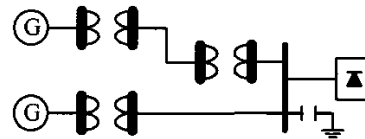


Fig.1 The multi-machine system

The multi-machine power system full order model given by [6] is shown Fig. 1.

$$\dot{x} = Ax + Bu \quad (1)$$

where $x = [\omega_1 \ \delta_1 \ \Delta e'_{q1} \ V_{\Delta 1} \ \omega_2 \ \delta_2 \ \Delta e'_{q2} \ \Delta V_{F2}]^T$

Δ : denotes deviation from operation point

ω_i : denotes speed

δ_i : denotes torque angle

e'_q : denotes voltage proportional to direct axis flux linkages

V_F : denotes generation field voltage

2.2 Two-level Optimal Design

The two-level optimal design given in [4] is shown in Fig. 2.

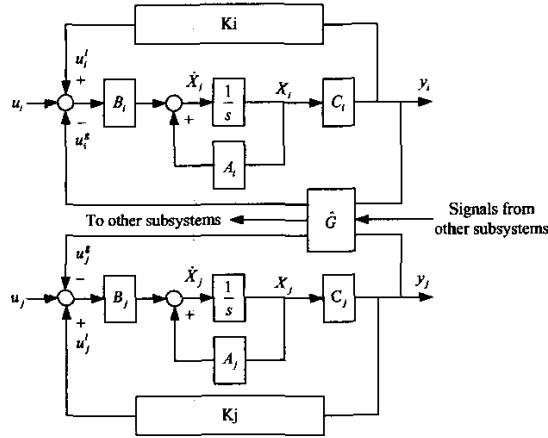


Fig.2 The two-level optimal design

It is indicated from the simulation results that the system response is highly oscillatory.

3 Sliding Mode Control

3.1 Optimal Switching Hyperplane

Consider the linear time-invariant multivariable system described by the equation

$$\dot{x} = Ax + Bu \quad (2)$$

where $A \in R^{n \times n}$, $B \in R^{n \times m}$

In order to get the optimal switching hyperplane of the sliding mode controller, we define the quadratic cost function of J as follows:

$$J = \int_{t_s}^t x^T Q x dt \quad (3)$$

Where $Q = \begin{bmatrix} Q_{11} & Q_{12} \\ Q_{21} & Q_{22} \end{bmatrix}$, $Q_{21}^T = Q_{12}$, $Q > 0$ and t_s is the starting time which the sliding mode occurs.

$$J = \int_{t_s}^t (x_1^T Q_{11} x_1 + 2x_1^T Q_{12} x_2 + x_2^T Q_{22} x_2) dt \quad (4)$$

Consider the variable v is

$$v = x_2 + Q_{22}^{-1} Q_{12}^T x_1 \quad (5)$$

Such that

$$J = \int_{t_s}^t (x_1^T Q_{11}^* x_1 + v^T Q_{22} v) dt \quad (6)$$

where $Q_{11}^* = Q_{11} + Q_{12} Q_{22}^{-1} Q_{12}^T$.

Assume the equation of x_1 is as follows:

$$\dot{x}_1 = A_{11}^* x_1 + A_{12} v \quad (7)$$

where $A_{11}^* = A_{11} - A_{12} Q_{22}^{-1} Q_{12}^T$.

From eqn.(7), we can use the Riccati equation to find the constant positive definite matrix P .

$$P A_{11}^* + A_{11}^* P - P A_{12} Q_{22}^{-1} Q_{12}^T P + Q_{11}^* = 0 \quad (8)$$

$$v = -Q_{22}^{-1} A_{12}^T P x_1 \quad (9)$$

From eqn.(5) and (8)

$$x_2 = v - Q_{22}^{-1} Q_{12}^T x_1 = Q_{22}^{-1} (A_{12}^T P + Q_{12}^T x) \quad (10)$$

When the sliding mode occurs, the state trajectories of the controlled system will be kept on the pre-specified switching hyperplane. The optimal switch hyperplane s is written as

$$s = C^T x = [A_{12}^T P + Q_{12}^T \quad -Q_{22}] x \quad (11)$$

3.2 Switching Control Signal

The input of the system is obtained as:

$$u(t) = -K^T x(t) \quad (12)$$

The control law can be considered separately by the two control terms and represented by

$$u = u_{eq} + u_h \quad (13)$$

where $u_h = -K_h^T x$ is a discontinuous control signal, and $u_{eq} = -K_{eq}^T x$ is a linear equivalent control signal.

The feedback gain K_h is appropriate chosen as

$$K_h^i = \begin{cases} \alpha_i & \text{for } s \cdot x_i > 0 \\ 0 & \text{for } s \cdot x_i = 0 \\ \beta_i & \text{for } s \cdot x_i < 0 \end{cases} \quad i = 1, 2, \dots, n \quad (14)$$

It is shown that if the gain parameters α_i and β_i are chosen so that $s \cdot \dot{s} \leq 0$ is satisfied, then the hitting will occur.

When the state is on the sliding surface $\dot{s} = 0$, the purpose of the equivalent control is to keep the state staying on the sliding surface so it can be derived from setting the time derivative of s , and \dot{s} , equal to zero, that is

$$u_{eq} = u \Big|_{\dot{s}=0} \quad (15)$$

The feedback gain K_{eq} is obtained as

$$K_{eq}^T = (C^T B^{-1}) C^T A \quad (16)$$

4 The Genetic Algorithms

GAs are searching techniques using the mechanics of natural selection and natural genetics for efficient global searches [9]. In comparison to the conventional searching algorithms, GAs has the following characteristics : (a) GAs work directly with the discrete points coded by finite length strings (chromosomes), not the real parameters themselves; (b) GAs consider a group of points (called a population size) in the search space in every iteration, not a single point; (c) GAs use fitness function information instead of derivatives or other auxiliary knowledge; and (d) GAs use probabilistic transition rules instead of deterministic rules. Generally, a simple GA consists of the three basic genetic operators : (a) Reproduction; (b) Crossover; and (c) Mutation. They are described as follows[10].

4.1 Reproduction

Reproduction is a process to decide how many copies of individual strings should be produced in the mating pool according to their fitness value. The reproduction operation allows strings with higher fitness value to have larger number of copies, and the strings with lower fitness values have a relatively smaller number of copies or even none at all. This is an artificial version of natural selection (strings with higher fitness values will have more chances to survive).

4.2 Crossover

Crossover is a recombined operator for two high-fitness strings (parents) to produce two offsprings by matching

their desirable qualities through a random process. In this paper, the uniform crossover method is adopted. The procedure is to select a pair of strings from the mating pool at random, then, a mark is selected at random. Finally, two new strings are generated by swapping all characters correspond to the position of the mark where the bit is "1". Although the crossover is done by random selection, it is not the same as a random search through the search space. Since it is based on the reproduction process, it is an effective means of exchanging information and combining portions of high-fitness solutions.

4.3 Mutation

Mutation is a process to provide an occasional random alteration of the value at a particular string position. In the case of binary string, this simply means changing the state of a bit from 1 to 0 and vice versa. In this paper we provide a uniform mutation method. This method is first to produce a mask and select a string randomly, then complement the selected string value correspond to the position of mask where the bit value is "1". Mutation is needed because some digits at particular position in all strings may be eliminated during the reproduction and the crossover operations. So the mutation plays the role of a safeguard in GAs. It can help GAs to avoid the possibility of mistaking a local optimum for a global optimum.

5 Results

The model given in [6] is

$$\dot{x} = Ax + Bu \quad (17)$$

where

$$A = \begin{bmatrix} -0.244 & -0.0747 & -0.1431 & 0 & 0 & 0.0747 & 0.0041 & 0 \\ 377 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -0.046 & -0.455 & 0.244 & 0 & 0.046 & 0.13 & 0 \\ 0 & -398.56 & -19498.8 & -50 & 0 & 398.58 & -3967 & 0 \\ 0 & 0.178 & -0.0433 & 0 & -0.2473 & -0.178 & -0.146 & 0 \\ 0 & 0 & 0 & 0 & 376.99 & 0 & 0 & 0 \\ 0 & 0.056 & 0 & 0 & 0 & -0.0565 & -0.3061 & 0.149 \\ 0 & -677.39 & -10234.22 & 0 & 0 & 677.78 & -13364.16 & -50 \end{bmatrix}$$

$$B = \begin{bmatrix} 0 & 0 & 0 & 2500 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 2500 \end{bmatrix}^T$$

The eigenvalues of the power system are as follows:

$$\begin{aligned} & -25.1741 \pm j67.8187 \quad -25.2392 \pm j30.3072 \\ & -0.0904 \pm j9.843 \quad -0.0006 \\ & -0.2443 \end{aligned}$$

To improve the system damping using the two-level scheme, the decomposed system and control matrices are

as follows:

For system 1

$$X_1 = [\Delta\omega_1 \quad \Delta\delta_1 \quad \Delta e_{q1} \quad \Delta V_{F1}]$$

$$A_1 = \begin{bmatrix} -0.244 & -0.747 & -0.1431 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.046 & -0.455 & 0.244 \\ 0 & -398.56 & -19498.8 & -50.0 \end{bmatrix}$$

$$B_1 = [0 \quad 0 \quad 0 \quad 2500^T]$$

Using the expression given by [7], a reduced order model of system 1 is obtained.

$$\dot{x}_{1r} = F_1 x_{1r} + G_1 u_1 \quad (18)$$

where $x_{1r} = [\Delta\omega_1 \quad \Delta\delta_1^T]^T$, $F_1 = \begin{bmatrix} -0.26 & -0.07 \\ 377 & 0 \end{bmatrix}$, and

$$G_1 = [-0.1826 \quad -0.734^T]^T$$

For system 2

$$X_2 = [\Delta\omega_2 \quad \Delta\delta_2 \quad \Delta e_{q2} \quad \Delta V_{F2}]$$

$$A_2 = \begin{bmatrix} -0.2473 & -0.177 & -0.146 & 0 \\ 377 & 0 & 0 & 0 \\ 0 & -0.0565 & -0.3061 & 0.1492 \\ 0 & 677.78 & -13364.1 & -50.0 \end{bmatrix}$$

$$B_2 = [0 \quad 0 \quad 0 \quad 2500^T]$$

Using the expression given by [7], a reduced order model of system 2 is obtained.

$$\dot{x}_{2r} = F_2 x_{2r} + G_2 u_2 \quad (19)$$

where $x_{2r} = [\Delta\omega_2 \quad \Delta\delta_2^T]^T$, $F_2 = \begin{bmatrix} -0.18 & -0.18 \\ 377 & 0 \end{bmatrix}$, and

$$G_2 = [-0.2688 \quad -2.6202^T]^T$$

The global control matrix G is given by

$$G = \begin{bmatrix} 0.118 & -0.36 & 0.02 & -0.209 \\ 0.0975 & -0.2974 & 0.0141 & -0.1465 \end{bmatrix}$$

And the proposed design is shown in Fig. 3.

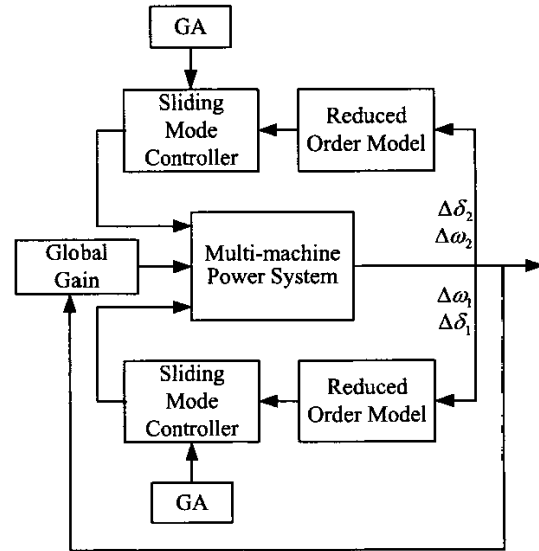


Fig. 3 The structure of the proposed design

In this paper, we propose the genetic algorithm to find the switching surface vector and the switching control signals. Furthermore, in order to find the parameters to facilitate the controlled system with small integral absolute error, we define the following fitness function:

$$f = g_1 \cdot g_2 \quad (20)$$

$$\text{where } g_i (IAE_i) = \left\{ \frac{1}{1 + \left(\frac{IAE_i}{\delta} \right)^2} \right\}^2, \quad i = 1, 2, \text{ and}$$

$$\delta = 1.$$

The following parameters of GAs are considered:

- Population size=40
- Crossover probability=0.9
- Mutation probability=0.03
- Chromosome length=30
- Generations=2000
- Range=[-250 250]

From eqn.(11), and eqn.(16), we can get the optimal switching hyperplane C and the feedback gain K_{eq} of the power system.

For system 1

$$s_1 = [-3.0056 \quad -1.6189] x_{1r} = C_1^T x_{1r}$$

$$K_{eq1}^T = [-350.9 \quad 0.12112]$$

For system 2

$$s_2 = [-1.457 \quad -1.1052 x]_r = C_2^T x_{2r}$$

$$K_{eq2}^T = [-126.66 \quad 0.079773]$$

The transient responses of the angular frequencies with global control to a 5% change in the mechanical torque of system 1 and system 2 are shown in Fig.4 and Fig.5 respectively.

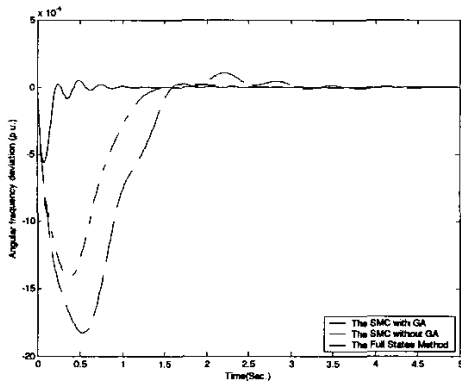


Fig.4 (a) The angular frequency response of system 1

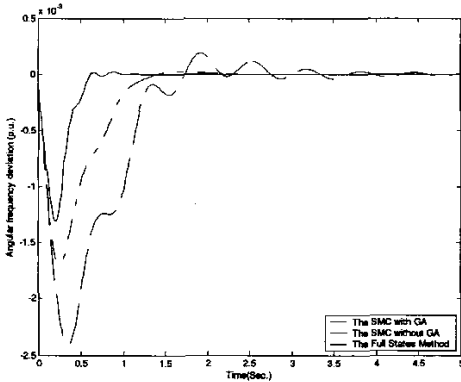


Fig.4 (b) The angular frequency response of system 2

Fig.4 The transient responses of the angular frequencies

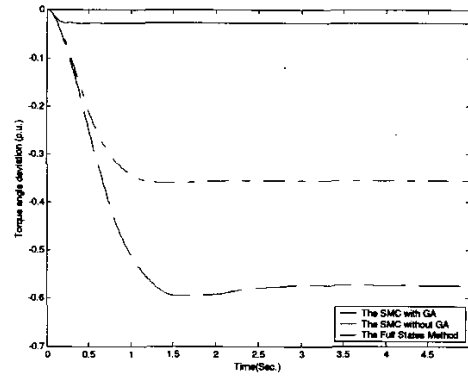


Fig.5 (a) The torque angle response of system 1

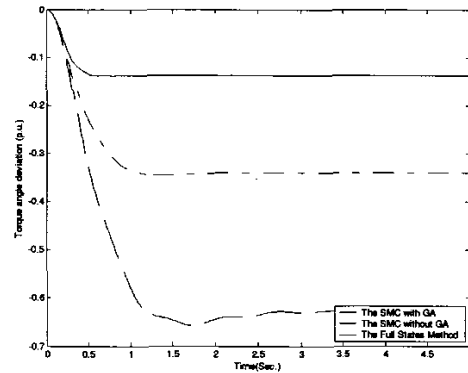


Fig.5 (b) The torque angle response of system 2

Fig.5 The transient responses of the torque angles

6 Summary

This paper proposes a new approach for combining genetic algorithm and sliding mode control to design the power system stabilizers. We use the genetic algorithm to find the switching surface vector and the switching control signals, and use the sliding mode control to find the control signal of the generator. By using the output feedback only, this approach reduces the implementation cost and the reliability of the power system. Comparison of the proposed method with the traditional optimal control method, the effectiveness of the proposed method in enhancing the dynamic performance stability is verified through the simulation results.

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