STATE FEEDBACK CONTROLLER DESIGN OF POWER SYSTEM STABILIZER (PSS) BY USING FUZZY MODEL

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State Feedback Controller Design of Power System Stabilizer (PSS) by using Fuzzy Model

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Abstract—**Power system stabilizer (PSS) is used to damp the mechanic electro oscillation that is the disturbance of PSS. Some methods of PSS control design are adaptive control, robust control. The other side of fuzzy logic is also influence by the performance increasing of PSS. The stability analysis and performance gain can be obtained by using the Linear Matrix Inequality (LMI). In this paper, we study how to build the Takagi-Sugeno fuzzy model, determine the LMI condition such that system stable, design state feedback controller and also simulate the performance of PSS. Here, we make program by using Matlab software.**

Keywords—**LMI, Takagi-Sugeno fuzzy model, state feedback**

I. INTRODUCTION

In power system generation, power system stabilizer (PSS) is use to damp the mechanic electro oscillation. This oscillation is a disturbance of system. Some disturbances are due to continuing variation of power, changing the set point and others. Some methods of PSS design controller are direct feedback linearization (Tamaji, 2009; Yadaiah & Ramana, 2006), adaptive control and robust control beside that fuzzy logic is influence to increase the performance of PSS. The stability analysis and performance gain of fuzzy model control system can be obtained by Linear Matrix Inequality (LMI) (Tanaka & Wang, 2001 in Soliman, 2009).

In this paper, we design the state feedback controller of single machine infinite bus (SMIB). The mathematical model of SIMB system is non linear system (Soliman, 2009; Yadaiah & Ramana, 2006). To design the controller of this PSS, at the first time, we change the mathematical model of SIMB into fuzzy model T-S, after that we define the fuzzy state feedback controller, we determine the LMI condition such that the system is stable, determine the feedback gain and finally we make simulation to analyze the performance of PSS.

II. SMIB FUZZY MODEL

Single machine infinite bus is a simple model of power system. This system consist of single power which connect with two line parallel transmission respect to large networking and approximate by infinite bus. This system is showed in Figure 1.

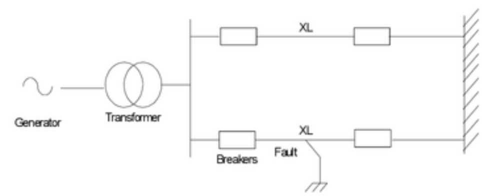

Figure 1. SMIB power system

The generating power system is a non linear system (Soliman, 2009; Tamaji, 2009) as follows:

$$\begin{aligned}\dot{\delta} &= \omega_0 - \omega \\ \dot{\omega} &= (T_m - E_q^{'} I_q - (x_q - x_d^{'}) I_d I_q)/M \\ \dot{E}_q^{'} &= (-E_q^{'} - (x_q - x_d^{'}) I_d + E_{fd}^{'})/T_{d0}^{'} \\ \dot{E}_{fd}^{'} &= \frac{K_E}{T_E}(V_{ref} - V_T + u_{pss}) - \frac{1}{T_E} E_{fd}^{'}\end{aligned} \quad (1)$$

The state variable $\delta, \omega, E_q^{'}, E_{fd}^{'}$ is angle, angular velocity, induced EMF proportional to field current and generator field voltages, respectively. From Yadaiah & Ramana, 2006, we know that

$$P_e = \frac{E_q^{'} V_s}{x_{dc}^{'}} Sin\delta ; \quad (2)$$

$$Q = \frac{E_q^{'} V_s}{x_{dc}^{'}} Cos\delta - \frac{V_s^2}{x_{d\alpha}^{'}} ; \quad (3)$$

$$V_T = \sqrt{V_d^2 + V_q^2} ;$$

$$V_d = -X_e I_q + V_s Sin\delta \quad (4)$$

$$V_q = X_e I_d + V_s Cos\delta \quad (5)$$

Such that by substituting equation (2) and (3) into equation (4) and (5) we obtain

$$V_d = -X_e I_q + \frac{P_e x'_{d\varepsilon}}{E'_q}; V_q = X_e I_d + \left(Q + \frac{V_s^2}{x'_{d\alpha}}\right)\frac{x'_{d\varepsilon}}{E'_q};$$

or $$I_q = \frac{P_e x'_{d\varepsilon}}{E'_q X_e} - \frac{V_d}{X_e},$$

There are some methods to design the controller of non linear system such that adaptive controller, robust control, linear direct feedback and by building the fuzzy model T-S. In this paper we use the building the fuzzy model T-S to design controller. At first the system in equation (1) we arrange into state space system

$$\begin{bmatrix} \dot\delta \\ \dot\omega \\ \dot E'_q \\ \dot E'_{fd} \end{bmatrix} = \begin{bmatrix} \frac{\omega_0}{\delta} & -1 & 0 & 0 \\ 0 & S_1 & \frac{P_e x'_{d\varepsilon}}{E'_q X_e M} - \frac{V_d}{X_e M} & 0 \\ 0 & 0 & -S_2 & \frac{1}{T'_0} \\ 0 & 0 & S_3 & -\frac{1}{T_E} \end{bmatrix} \begin{bmatrix} \delta \\ \omega \\ E'_q \\ E'_{fd} \end{bmatrix} \quad (6)$$

$$+ \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_E}{T_E} \end{bmatrix} u_{pss}$$

where

$$S_1 = \frac{(T_m - (x_q - x'_d) I_d I_q)}{M\omega}; S_2 = \frac{-(x_q - x'_d) I_d}{T'_0 E_q};$$

$$S_3 = \frac{K_E}{T_E E_q}(V_{ref} - V_T)$$

In this problem we define the fuzzy variable are P, Q, X_e, where

$$P \in [P^- \quad P^+], P \in [Q^- \quad Q^+], P \in [X_e^- \quad X_e^+]$$

such that we can derive the fuzzy rules as follows:

Rule Model 1

$$IF.....P(t).is..P^-..AND..Q(t).is..Q^-AND$$
$$...X_e(t).is..X_e^-THEN.....\dot x(t) = A_1 x(t) + B\,u(t)$$
$$y(t) = C\,x(t)$$

Rule Model 2

$$IF.....P(t).is..P^-..AND..Q(t).is..Q^-AND...X_e(t).is..X_e^+$$
$$THEN.....\dot x(t) = A_2 x(t) + B\,u(t)$$
$$y(t) = C\,x(t)$$

....

Rule Model 8

$$IF.....P(t).is..P^+..AND..Q(t).is..Q^+AND...X_e(t).is..X_e^+$$
$$THEN.....\dot x(t) = A_8 x(t) + B\,u(t)$$
$$y(t) = C\,x(t)$$

Define the member functions of P are

$$L_1 = \frac{P - P^-}{P^+ - P^-}; L_2 = \frac{P^+ - P}{P^+ - P^-},$$

the member functions of Q are

$$M_1 = \frac{Q - Q^-}{Q^+ - Q^-}; M_2 = \frac{Q^+ - Q}{Q^+ - Q^-},$$

and the member functions of X_e are

$$N_1 = \frac{X_e - X_e^-}{X_e^+ - X_e^-}; N_2 = \frac{X_e^+ - X_e}{X_e^+ - X_e^-},$$

Suppose

$$h_1 = L_1 M_1 N_1; h_2 = L_1 M_1 N_2; h_3 = L_1 M_2 N_1; h_4 = L_1 M_2 N_2$$

and

$$h_5 = L_2 M_1 N_1; h_6 = L_2 M_1 N_2; h_7 = L_2 M_2 N_1; h_8 = L_2 M_2 N_2$$

If we define

$$\alpha_i = \frac{h_i}{\sum_{j=1}^{8} h_j}; i = 1,2,...,8 \quad (7)$$

Then the state space system in equation (6) can be written as model fuzzy

$$\dot x = \sum_{i=1}^{8} \alpha_i A_i x + Bu \quad (8)$$

and the output

$$y = Cx \quad (9)$$

After we build the state space fuzzy model, we design the state feedback controller based on equation (8) and it call Parallel Distributed Compensation (PDC).

III. Design Controller Fuzzy Model of SMIB

Parallel Distributed Compensation-PDC is a fuzzy design controller of fuzzy model Takagi-Sugeno (Fuzzy Model T-S). There are some designs controller such as state feedback controller $u = -Fx$, and output feedback controller $u = Fy$, where y is output such as equation (9). In this paper we design the controller by using the state feedback controller. State feedback fuzzy controller is constructed by PDC is

$$u(t) = -\sum_{i=1}^{8} \alpha_i F_i x(t) \qquad (10)$$

We substitute equation (10) into equation (8), we obtain

$$\dot{x} = \sum_{i=1}^{8} \alpha_i A_i x - B \sum_{i=1}^{8} \alpha_i F_i x$$

Or we can write as

$$\dot{x} = \sum_{i=1}^{8} \alpha_i (A_i - BF_i) x \qquad (11)$$

The design controller is to determine the matrix F_i such that the system in equation (11) is stable. One of methods to analyze the stability of system is by determining the eigen value of $\sum_{i=1}^{8} \alpha_i (A_i + BF_i)$ and the other is by defining the Lyapunov function. The system is stable if the real part of eigen value is negative or lay on the left half plane of complex space. The stability analyze by Lyapunov method is define the Lyapunov function

$$V(t) = x^T Q x \geq 0; \; Q \text{ positive definite} \qquad (12)$$

System (11) is stable if we can find positive definite matrix Q which satisfy equation (12) and

$$\dot{V}(t) = \dot{x}^T Q x + x^T Q \dot{x} \qquad (13)$$

is negative definite.

Substitute equation (11) into equation (13) we get

$$\dot{V}(t) = \dot{x}^T Q x + x^T Q \dot{x}$$

$$\dot{V}(t) = \left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) x \right)^T Qx + x^T Q \left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) x \right)$$

$$\dot{V}(t) = x^T \left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right)^T Qx + x^T Q \left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right) x$$

$$\dot{V}(t) = x^T \left[\left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right)^T Q + Q \left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right) \right] x$$

So $\dot{V}(t)$ is negative if

$$\left[\left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right)^T Q + Q \left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right) \right]$$

negative definite, or

$$\left[\left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right)^T Q + Q \left(\sum_{i=1}^{8} \alpha_i (A_i - BF_i) \right) \right] < 0 \qquad (14)$$

Inequality (13) is called linear matrix inequality (LMI). So, in the Lyapunov method is we must determine matrix $F_i, i = 1, 2, \ldots, 8$ such that there is matrix positive definite Q which satisfy equation (14) (We solve the inequality (14)).

At this moment, we use the eigen value method to determine matrix $F_i, i = 1, 2, \ldots, 8$.

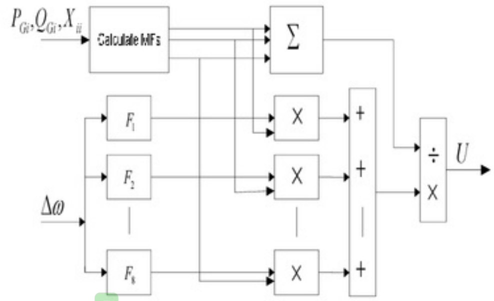

Figure 2. Schematic diagram for the proposed stabilizer on Gen # i

IV. Simulation and Result

We take the parameter value as follows: [Soliman, 2009]

$x_d = 1.8; x_d' = 0.3; x_q = 1.7; M = 13; T_{d0} = 8;$

$\omega_0 = 377; K_E = 200; T_E = 0.001; V_s = 1$

with fuzzy parameter

(P, Q, X_e)

$P \in [0.4 \quad 1]; Q \in [-0.2 \quad 0.5]; X_e \in [0.2 \quad 0.4]$

We make computer program for simulation by Matlab software. We use Matlab function "pole placement method" (place) to determine the feedback gain matrix $F_i, i = 1, 2, \ldots, 8$. We desire the pole or eigen value of matrix $\sum_{i=1}^{8} \alpha_i (A_i - BF_i)$ is $[-1 \quad -2 \quad -3 \quad -5]$.

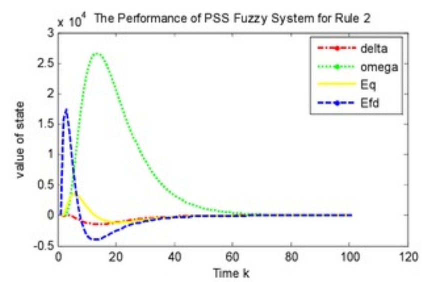

Figure 3. The Performance of PSS for rule 2 , pole $[-1 \quad -2 \quad -3 \quad -5]$

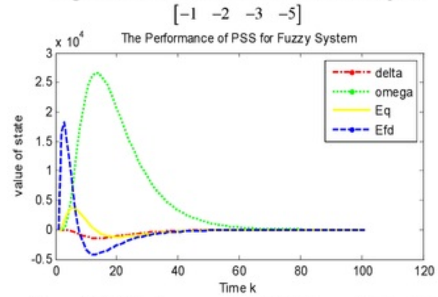

Figure 4. The Performance of PSS for Fuzzy System Pole $[-1 \quad -2 \quad -3 \quad -5]$

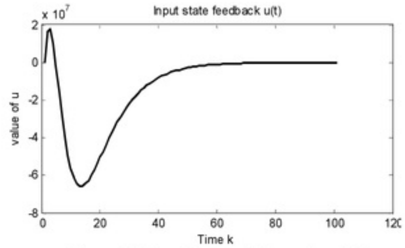

Figure 5. State Feedback Controller, Pole $\begin{bmatrix}-1 & -2 & -3 & -5\end{bmatrix}$

From simulation we know that feedback gain for each rule F_i can be obtained by using pole placement technique, such as figure 3 and the all state variables converge to zero after 60 time step. Figure 4 shows that the performance of fuzzy system and the all variables also go to zero after 60 time step. The state feedback controller $u(t) = -\sum_{i=1}^{8} B\alpha_i x_i(t)$ is showed figure 5, after time set 60 the state feedback converge to zero.

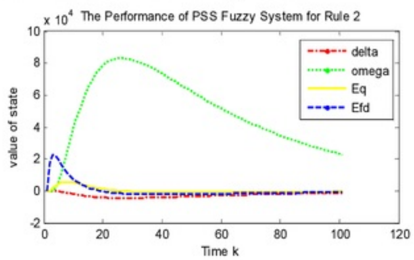

Figure 6. The Performance of PSS for rule 2 , Pole $\begin{bmatrix}-1 & -0.2 & -3 & -5\end{bmatrix}$

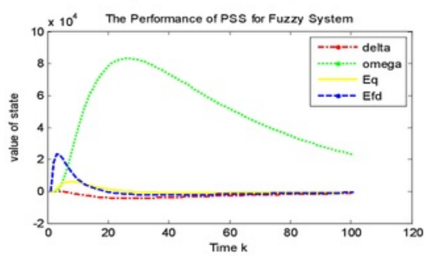

Figure 7. The Performance of PSS Fuzzy system, Pole $\begin{bmatrix}-1 & -0.2 & -3 & -5\end{bmatrix}$

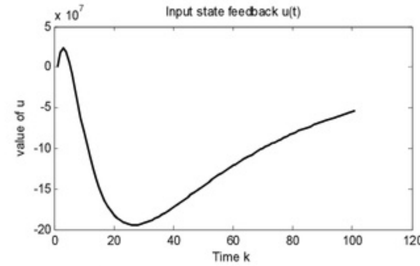

Figure 8. State Feedback Controller, Pole $\begin{bmatrix}-1 & -0.2 & -3 & -5\end{bmatrix}$

The performance of PSS depends on pole which is taken. Figure (6) and (7) show the performance of PSS and state feedback controller if we take pole $\begin{bmatrix}-1 & -0.2 & -3 & -5\end{bmatrix}$. Because the second pole (eigen value) is -0.2 then the state variable ω (the second state variable) need more time to converge to zero. Figure (8) show that the state feedback controller is not yet converge to zero after time 100.

V. CONCLUSION

Based on the discussion above and the simulation result, we conclude that

1. The fuzzy model system can be used to design the non linear PSS system
2. It is necessary to change the non linear system into the fuzzy state space system.
3. The state variable and the state feedback controller will converge to zero at the same time.
4. The speed of convergence of system depend on the choosing pole or eigen value

VI. FURTHER RESEARCH

The research will continue with solving the LMI to determine the feedback gain $F_i, i = 1, 2, \ldots, 8$. Beside that we can design the output feedback controller for fuzzy system of PSS either for SMIB or Multi-machine power system.

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