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SINGLE MACHINE POWER COEFFICIENT PARAMETER LIMITS FOR T-S FUZZY MODELING AND CONTROL ANALYSIS

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Abstract

Takagi-Sugeno (T-S) fuzzy model based control of a load frequency deviation in a single machine with limit nonlinearity on power coefficient is presented in the paper. Two T-S fuzzy rules with only rotor angle variable as input in the premise part, and linear state space models in the consequent part involving characteristic matrices determined from limits set on the power coefficient constant are formulated, state feedback control gains for closed loop control was determined from the formulated Linear Matrix Inequality (LMI) with eigenvalue optimization scheme for asymptotic and exponential stability (speed of response). Simulation of the developed system object was carried out, results generated for both the open and closed loop systems showed, despite limits imposed on the power coefficient parameter during modeling, the control scheme provides acceptable load frequency performance.

Keywords: *Takagi-Sugeno Fuzzy Model, Power Coefficient Parameter, Linear Matrix Inequality and Parallel Distributed Compensation.*

Background to the Study

Takagi-Sugeno (T-S) fuzzy modeling techniques have become useful in modeling nonlinearity in complex dynamic systems. Its inherent ability to combine fuzzy heuristic and classical modeling techniques gives it importance among knowledge based modeling tools (Tanaka & Wang, 2001; Herra-Espinosegi, Salazer-Del-Moral & portollo-Mendez, 2000).

A state feedback control method the Parallel Distribution Compensation (PDC) has been in use in the frame work of Linear Matrix Inequality (LMI) for achieving asymptotic stabibity when applied to systems T-S fuzzy models (Jing, Nieman & Tanaka, 2005;Chung-Hsum, Wen-June & Wei-Wei, 2007;Khaber, Zehar & Hamzaoui,2006; Abdelkarim, Ghorbel & Benrejeb, 2010;Nachidi, Benzaouiia, Tadeo & Rami, 2008). To achieve speed of response, eigen value minimization algorithm defined in the LMI formulation is used (Salem & Arino, 2008;Song-Teo, 2010; Wang & Sun,2002;Najat & Noureddine, 2011; Khairy, Elshafei & Emara-Hassan, 2009).

In power system T-S fuzzy modeling and control, the concept was developed and applied to single area single machine network (Shehu & Dan-Isa, 2011; Shehu, Salawu & Hamisu, 2014; Shehu & Usman & Dan-Isa, 2014) . In Francis & Chidombaram, (2012) and Lee, pack & Joe, (2006) T-S fuzzy modeling and LMI based state feedback control was developed and implemented for the control of load frequency deviation in two area interconnected power network considering valve limit nonlinearity. In this paper, we intend to introduce limit nonlinearity on power coefficient parameter when modeling single area single machine power network in T-S fuzzy form. Performance of the controlled power network would be asses and compared with one under uncontrolled condition.

Methodology

To develop fuzzy state feedback control scheme for a single area single machine based on T-S fuzzy model defined over a limit set on system power coefficient parameter requires basically two steps:

1. Defining two T-S fuzzy rules in which rule's outputs are equations characterized by the two limits of the power parameter.
2. Forming control loop of the model based on a specific control principle; here the LMI-PDC.

The Single Machine T-S Fuzzy Model

Let ΔP_1 and ΔP_u be the lower and upper values (limits) of the machine's power parameter, Taking load frequency as input, the two T-S fuzzy rules relating system dynamics associated with the limits and corresponding input fuzzy partition can be written as

Rule 1: $1Fx_1$ is $u_1(x_1)$ Then $x = A_1 x + Bu$

Rule 2: Fx_1 is $u_2(x_1)$ Then $x = A_u x + Bu$

Where $u_1(x_1)$ and $u_2(x_1)$ are fuzzy membership function, $x(t) = A_{1,u} + Bu(t)$ is local linear model at the two limits on power coefficient parameter. Global T-S fuzzy model when the two rules are combined is

$$\dot{x} = (\varphi_1 \mathbf{A}_l + \varphi_2 \mathbf{A}_u)x + (\varphi_1 \varphi_2)\mathbf{Bu} \qquad (1)$$

Where φ is fuzzy scale factor. Including the target controller, the closed loop fuzzy model is

$$\dot{x}(t) = (A - (\varphi_l K_l - \varphi_u K_u)B)x \qquad (2)$$

Where A = $(\varphi_1 \mathbf{A}_l + \varphi_2 \mathbf{A}_u)$ $K_{l,u}$ is state feedback gain to be determine via LMI strategy. To incorporate speed of response requirement, optimization of the LMI eigenvalues can be achieved as proposed in Shehu, Salawu & Hamisu, (2014) and Shehu, Usman & Dan-Isa, (2014) by use of the following LMI:

$$\begin{bmatrix} 2\vartheta \mathbf{QY} & \mathbf{A}_i^T \mathbf{Y} - \mathbf{\Omega}_i^T \mathbf{B}_i^T \\ \mathbf{Y}A_i - \mathbf{B}_i \mathbf{\Omega}_i & \mathbf{I} \end{bmatrix} < 0 \qquad (3)$$

Where $Q > 0$ is weighting matrix to be selected, Υ and Ω_i are dummy variables and are to be determined utilizing the Matlab LMI toolbox. The feasible P matrix and feedback gain matrix is calculated using the relations:

$$\mathbf{P} = \Upsilon^{-1}, \quad \mathbf{K}_i = \Omega_i \Upsilon^{-1}$$

Simulation

To apply the above concept, we consider the linear model of the single area single machine load frequency deviation (Sadat, 1999):

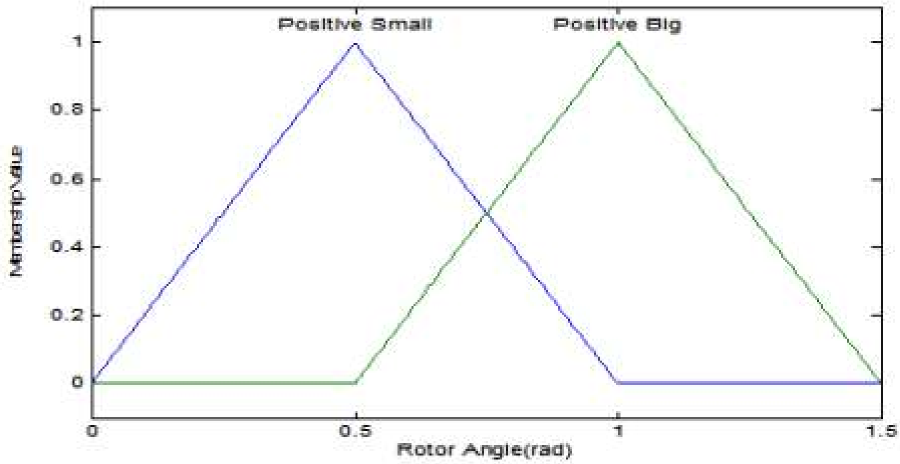
$$\begin{bmatrix} \Delta\dot{x}_1 \\ \Delta\dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ -\omega_n^2 & -2\zeta\omega_n \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} \Delta P_L$$

$$y = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta x_1 \\ \Delta x_2 \end{bmatrix}$$

Where ΔP_L is per unit input load deviation, ω_n *is* natural frequency, f_o is damping ratio, expressed as

$$P_s = \frac{|E||V|}{X} \cos\theta \qquad (7)$$

Where E is generator voltage, V is system terminal voltage, is power angle. We take the following system values: $V = 1 \angle\theta^o$, $E = 1 \angle\theta^o$ .35, X = 0.65p.u, H = 8.89, D = 0.138, f_o = 50Hz. At the limits, P_s values are 49.8 and 60.8 respectively. The system matrices in (4) are therefore



$$A_l = \begin{bmatrix} 0 & 1 \\ 882 & -2.2097 \end{bmatrix} A_u = \begin{bmatrix} 0 & 1 \\ 1.076 \times 10^3 & -2.6962 \end{bmatrix}$$

Fuzzy Membership Shape

Let the load frequency range = [0.5, 2]. Partitioning the space using triangular shape center into Positive Small (: [0 1 1.5] and Positive Big (: [1 1.5 2.0] is plotted in Fig.1.

Fig.1: Rules Membership Function Fuzzy Shapes

The weighing matrix Q in (3) will be unit identity matrix. System damping would be varied during simulation run as follows:
Case 1: D = 0.138 (nominal)
Case 2: D = 0.0138 (reduced)

Results
The load frequency response to unit input when the system is in open loop (equation 1) and when in closed loop (equation 2) are shown in figures 2 and 3 respectively. The response when driven at reference frequency in closed loop is shown in Fig.4.

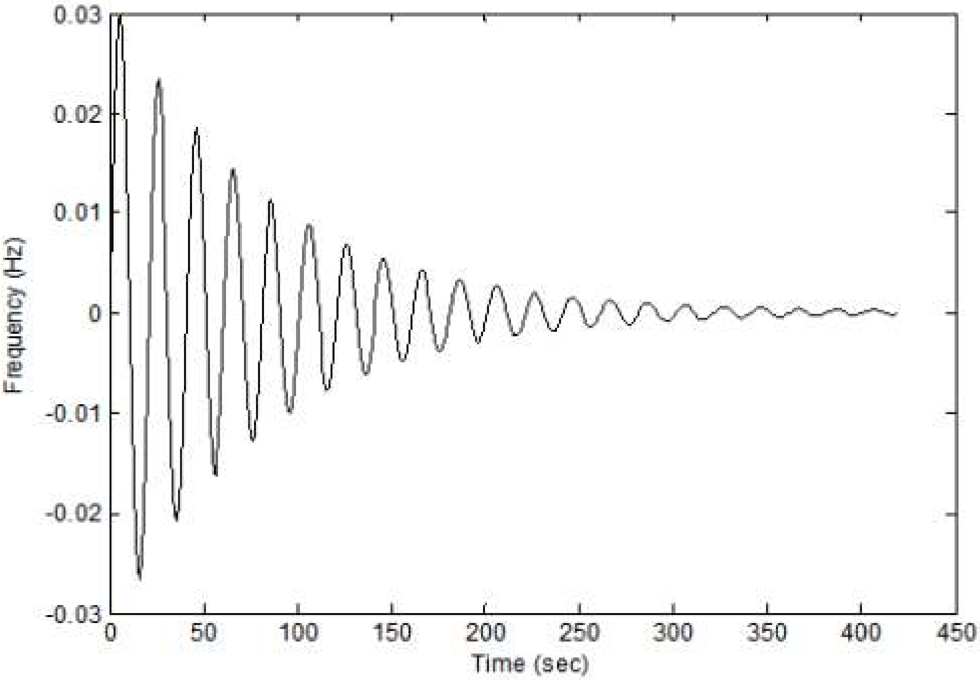


Fig.2:open loop load frequency deviation response to unit perturbation

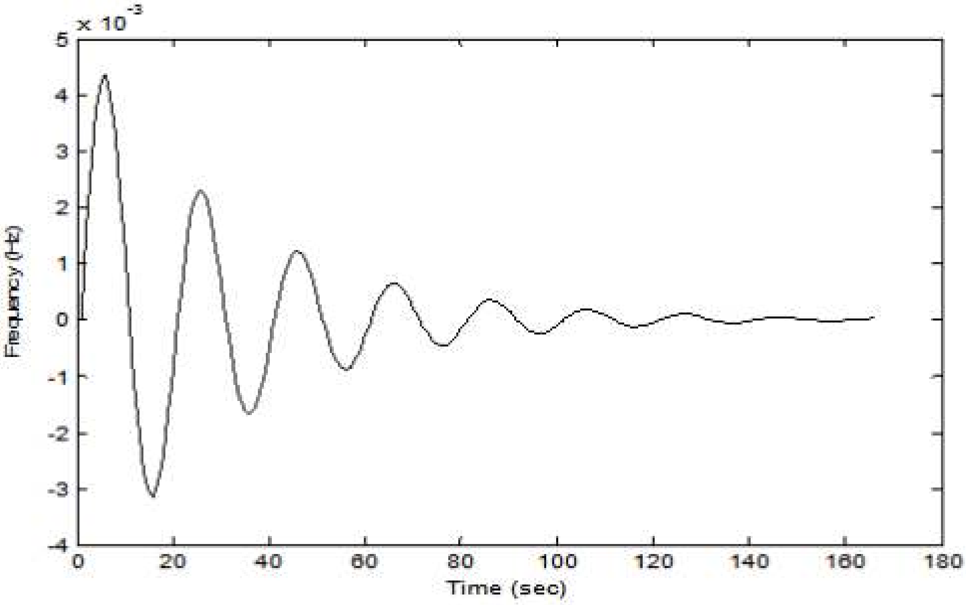


Fig.3: closed loop network's load frequency deviation response

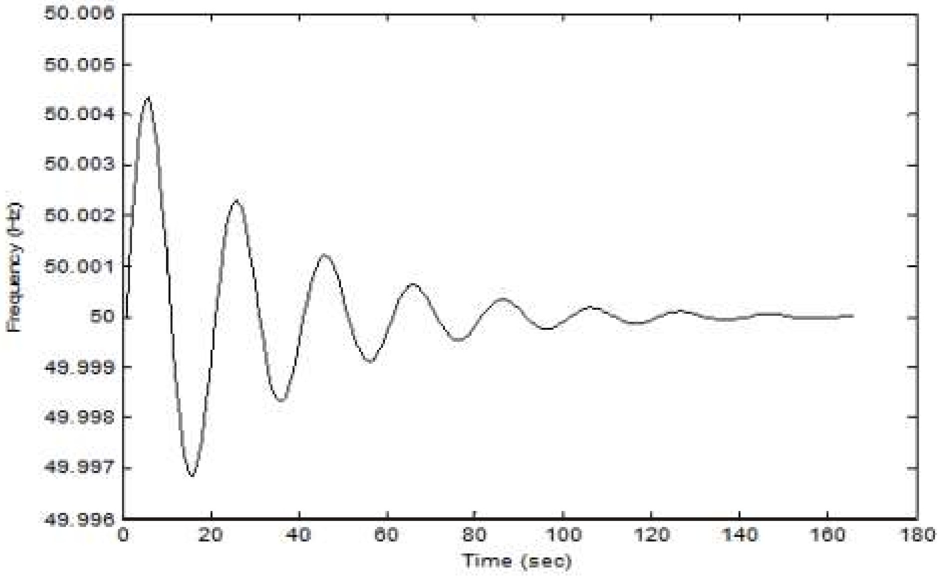


Fig.4: closed loop steady state load frequency response

The feasible common P matrix, the minimum generalized eigenvalue and state feedback gain matrices returned from the simulation run are as follows:

$$\mathbf{P} = (1.0 \times 10^5)\begin{bmatrix} 0.0006 & 0.0137 \\ 0.0137 & -1.5740 \end{bmatrix}$$

$$\vartheta = 0.0022, \quad K_1 = [-0.8791 \quad 3.2614], \quad K_2 = [-1.0738 \quad 4.4139]$$

Results Discussion

Response to unit step input of the network's open loop T-S fuzzy model exhibits significant frequency excursion as shown in Fig.2 with amplitude of 0.03. The response though finally settled after about 300 seconds. Under the action of the developed PDC-LMI with Eigen value minimization, we can a reduction in the both amplitude of the deviation to about 0.0041 and settling time to around 120 seconds as shown in Fig.3. Reference frequency settling was indicated when the controlled plant is driven through the preset frequency of 50Hz as shown in Fig.4.

Conclusion/Recommendation

In the paper, T-S fuzzy model of a single area single machine load frequency deviation power network was developed considering limit on power coefficient parameter. State feedback based control using PDC-LMI with eigenvalue minimization was developed and applied to the model. Simulation results of the closed loop system model for load frequency deviation mitigation have shown improved stability and transient performance relative to open loop situation.

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