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Routh Hurwitz and Pole Placement Fuzzy Logic Control for Power System Stability Improvement

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Abstract – *Control Design of Generator Power Systems is important to stabilize the electricity supply. The single machine infinite bus is one of generator power system models. The Power System Stabilizer (PSS) is used to damp the mechanic electro oscillation in electricity power systems. Here, the output feedback controller of single machine infinite bus is designed. The mathematical model of systems is non linear, so before designing the controller, some researchers approached it as a linear system. Here, those non linear systems are approached by applying the Takagi-Sugeno fuzzy method, with active power (P), reactive power (Q) and external reactive (Xe) as fuzzy parameters. In this paper, the performance of system without controller, with controller without fuzzy and with fuzzy controller were compared. Some types of P, Q and Xe are given to see the performance of fuzzy output feedback controller in single machine infinite bus.*

***Keywords**: Single Machine Infinite Bus, Output Feedback, Takagi-Sugeno Fuzzy Control, Pole Placement, Routh- Hurwitz*

Nomenclature

δ	Angle
ω	Angular velocity
E_q	Induced *emf* proportional to field current
E_{fd}	Generator field voltage
ω_0	Initial angular velocity
T_m	Mechanical Torque
T_E	Electrical torque
I_q	Current on the axis q
I_d	Current on the axis d
x_d'	Generator synchronous reactances
x_d	D-axis synchronous reactances
x_q	Q-axis synchronous reactances
M	Inertia coefficient
T_{d0}'	Open circuit direct axis transient
K_E	Constant excitation
V_{ref}	Reference value of generator field voltage
V_T	Terminal voltage
V_d	The voltage on the axis d
V_q	The voltage on the axis q
X_e	External reactive
P	Active power
Q	Reactive power

I. Introduction

Control design of generator power systems is an important aspect to keep the stability of electricity supply [1]-[14]. One of generator power system models is the single machine infinite bus (SMIB). The mathematical model of SMIB is a non linear system, so some researchers linearized those mathematical models of system before designing the controller, such as in the Improved Swarm Optimization to stabilize the SMIB [1], the robust control PSS based on pole placement and LMI [2][3]. Direct feedback linearization is applied to design the controller for SMIB [4], [5]. Fuzzy logic controller was also applied to enhance the stability of SMIB [6][7] and power system stability is enhanced through a novel stabilizer developed around an adaptive fuzzy sliding mode approach which applies the Nussbaum gain to a nonlinear model of a single-machine infinite-bus (SMIB) [8]. The other research about the stability of SMIB was also proposed based on a PSO-Tuned H2 Controller [9]. All those papers design the control system by defining the linear system of SMIB model. The other control method for SMIB is an Adaptive Backstepping Coordinated Excitation [10]; in this method, the estimation parameter construction and nonlinear gain was introduced to stabilize the SMIB. The second version of non-dominated sorting genetic algorithms (NSGA-II) is proposed to tune stabilizer parameters on a wide range of loading conditions to create a data base, two eigenvalue-based objective functions are considered to place the closed-loop system eigenvalues in the D-shape sector [11].

In this paper, the output feedback controller of SMIB

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was designed. Here, the non linear system was approached in different ways with previous research. The non linear system was written in state space form and then the Takagi-Sugeno fuzzy method was applied with active power (P), reactive power (Q) and external reactive (Xe) as fuzzy parameters. There are eight fuzzy rules, therefore, there are eight systems and the controllers were designed for every rule of the fuzzy system. The output feedback gain is determined by using pole placement and Routh Hurwitz method for each rules and then applying defuzzyfication to get the stable overall system.

The performance of output fuzzy feedback controller between Pole Placement and Routh Hurwitz method were compared.

II. Mathematical Model of SMIB

The Single Machine Infinite Bus of the generator power system can be modeled as a non linear model [4]:

$$\dot{\delta} = \omega_0 \omega \tag{1}$$

$$\dot{\omega} = \left(T_m - E_q' I_q - \left(x_q - x_d'\right) I_d I_q\right) / M \tag{2}$$

$$\dot{E}_q' = \left(-E_q' - \left(x_q - x_d'\right) I_d + E_{fd}'\right) / T_{d0}' \tag{3}$$

$$\dot{E}_{fd}' = \frac{K_E}{T_E}\left(V_{ref} - V_T + u_{pss}\right) - \frac{1}{T_E} E_{fd}' \tag{4}$$

with:

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

$$V_d = -X_e I_q + V_s \sin\delta$$

$$V_q = X_e I_q + V_s \cos\delta$$

$$P = \frac{E_q' V_s}{x_{d\varepsilon}'} Sin\delta$$

$$Q = \frac{E_q' V_s}{x_{d\varepsilon}'} Cos\delta - \frac{V_s^2}{x_{d\alpha}'}$$

The non linear SMIB system without controller is presented in Figure 1. The SMIB system is unstable, δ tends to 0.305, ω tends to 4, E_q tends to 300, at time $t = 200 \times 0.001$ s, and the overshoot of E_{fd} is 2×10^5 with settling time $t = 200 \times 0.001$ s. Therefore, it is necessary to apply the output feedback controller.

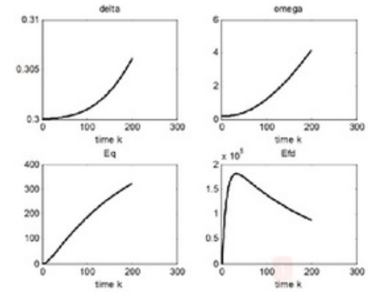

Fig. 1. SMIB Performance without control

The output feedback controller for system Eqs. (1)-(4) was designed. First, the state space system was built. Here, it was built the state space system without linearizing the system. The state space system is proposed as below:

$$\begin{bmatrix} \dot{\delta} \\ \dot{\omega} \\ \dot{E}_q' \\ \dot{E}_{fd}' \end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ 0 & a & -b & 0 \\ 0 & 0 & -c & \frac{1}{T_0'} \\ 0 & 0 & d & -\frac{1}{T_E} \end{bmatrix} \begin{bmatrix} \delta \\ \omega \\ E_q' \\ E_{fd}' \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_E}{T_E} \end{bmatrix} u_{pss} \tag{5}$$

where:

$$a = \frac{\left(T_m - \left(x_q - x_d'\right) I_d I_q\right)}{M\omega}$$

$$b = \left[\left(\frac{P x'_{d\varepsilon}}{E_q' X_e M} - \frac{V_d}{X_e M}\right)\right]$$

$$c = \left(\frac{1}{T_{d0}'} + \frac{\left(x_d - x_d'\right) I_d}{T_{d0}' E_q'}\right)$$

$$d = \frac{K_E}{T_E E_q'}\left(V_{ref} - V_T\right)$$

So:

$$\dot{X} = AX + Bu \tag{6}$$

where:

$$X = \left[\delta \quad \omega \quad E_q' \quad E_{fd}'\right]^T;$$

$$A = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ 0 & a & -b & 0 \\ 0 & 0 & -c & \frac{1}{T_0'} \\ 0 & 0 & d & -\frac{1}{T_E} \end{bmatrix}; B = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \frac{K_E}{T_E} \end{bmatrix}$$

Matrix A of system in Eq. (6) contain ω , δ so that the system in Eq. (6) is non linear. It is not possible to design the output feedback controller directly, therefore the system was changed in fuzzy system in order to get the piecewise linear system.

III. Design of Proposed Control

In this research, the output feedback controller was designed without and with fuzzy. In both cases, the output feedback gain was determined by using the pole placement method and the Routh-Hurwitz method. The performances of $\delta, \omega, E_q, E_{fd}$ for system without control, with control and with fuzzy controller were compared.

III.1. Fuzzy Output Feedback Controller

In this paper, P, Q, X_e were taken as fuzzy parameters, by using the Takagi – Sugeno Fuzzy Model [12], $P \in \left[P^- \quad P^+\right]$; $Q \in \left[Q^- \quad Q^+\right]$ and $X_e \in \left[X_e^- \quad X_e^+\right]$ were taken and the fuzzy rules were obtained as follows:

Rule 1

$IF.....P(t) is..P^- AND...Q(t) is..Q^- AND...X_e(t) is..X_e^-$

$THEN$

$\dot{x}(t) = A_1 x(t) + Bu(t)$

$y(t) = Cx(t)$

Rule 2

$IF.....P(t) is..P^- AND...Q(t) is..Q^- AND...X_e(t) is..X_e^+$

$THEN$

$\dot{x}(t) = A_2 x(t) + Bu(t)$

$y(t) = Cx(t)$

Rule 8

$IF.....P(t) is..P^+ AND...Q(t) is..Q^+ AND...X_e(t) is..X_e^+$

$THEN$

$\dot{x}(t) = A_8 x(t) + Bu(t)$

$y(t) = Cx(t)$

The member function of P, Q and X_e as follows:

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

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

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

Supposing that:

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

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

then the state space equation (Eq. (6)) can be written as a fuzzy model:

$$\dot{x} = \sum_{i=1}^{8} h_i \left(A_i x_i + Bu\right) \tag{7}$$

with output:

$$y = Cx \tag{8}$$

The output feedback controller was designed based on Eq. (7) and Eq. (8).

The output feedback controller is determined by using pole placement and Routh Hurwitz methods.

Define the output controller as follows:

$$u = -\sum_{j=1}^{8} K_j y_j = -\sum_{j=1}^{8} K_j C x_j \tag{9}$$

so that, the state space system is obtained:

$$\dot{x} = \sum_{i=1}^{8} \sum_{j=1}^{8} h_i \left(A_i - BK_j C_j\right) x_i \tag{10}$$

System Eq. (6) is stable if system Eq. (10) is stable or all eigen values of matrix:

$$h_i \left(A_i - BK_j C_j\right)$$

have a negative real part, that means that the system in Eq. (5) has poles on the left half plane.

In this paper, the output system is $y = \omega$, so we have the output equation $y = \begin{bmatrix}0 & 1 & 0 & 0\end{bmatrix} x$ or matrix $C = \begin{bmatrix}0 & 1 & 0 & 0\end{bmatrix}$ and the polynomial characteristic of matrix $A_i - BK_j C$ is

$$\begin{gathered}\lambda^4 + \left(c_i + \frac{1}{T_E} - a_i\right)\lambda^3 + \\ \left(\frac{c_i}{T_E} - \frac{d_i}{T_0'} - a_{1i} c_{1i} - a_i \frac{1}{T_E}\right)\lambda^2 - \\ \left(\frac{c_i a_{1i}}{T_E} - \frac{d_i a_i}{T_0'} + b_i \frac{1}{T_0'} \frac{K_E}{T_E} K_j\right)\lambda = 0\end{gathered} \tag{11}$$

The SMIB system (Eq. (6)) is stable if the solution of polynomial characteristic (Eq. (11)) have negative real part or $Re(\lambda) \le 0$. So, it was determined the output feedback gain, K_j such that $Re(\lambda) \le 0$.

Here, the output feedback controller K_j, is determined by using Pole Placement and Routh Hurwitz methods.

III.2. Pole Placement Method

The state space system (Eq. (6)) is not controllable then it is not possible to apply "the place" toolbox in Matlab to determine the output feedback controller, K_j. Suppose, in pole placement method, the desired poles of system are $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ then satisfied:

$$(\lambda - \lambda_1)(\lambda - \lambda_2)(\lambda - \lambda_3)(\lambda - \lambda_4) = 0$$

or:

$$\begin{aligned}
&\lambda^4 + (\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4)\lambda^3 + \\
&(\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_1\lambda_4 + \lambda_2\lambda_3 + \lambda_2\lambda_4 + \lambda_3\lambda_4)\lambda^2 + \\
&(\lambda_1\lambda_2\lambda_3 + \lambda_1\lambda_2\lambda_4 + \lambda_2\lambda_3\lambda_4 + \lambda_1\lambda_3\lambda_4)\lambda + \\
&(\lambda_1\lambda_2\lambda_3 + \lambda_1\lambda_2\lambda_4 + \lambda_2\lambda_3\lambda_4)\lambda + \lambda_1\lambda_3\lambda_4 = 0
\end{aligned}$$

So, the poles $\lambda_1, \lambda_2, \lambda_3, \lambda_4$ must be satisfied Eq. (12)-(15):

$$\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 = -\left(c_{1i} + \frac{1}{T_E} - a_{1i} \right) \tag{12}$$

$$\begin{aligned}
&\lambda_1\lambda_2 + \lambda_1\lambda_3 + \lambda_1\lambda_4 + \lambda_2\lambda_3 + \lambda_2\lambda_4 + \lambda_3\lambda_4 = \\
&\left(\frac{c_i}{T_E^{'}} - \frac{d_i}{T_0^{'}} - c_i a_i - \frac{a_i}{T_E} \right)
\end{aligned} \tag{13}$$

$$\begin{aligned}
&\lambda_1\lambda_2\lambda_3 + \lambda_1\lambda_2\lambda_4 + \lambda_2\lambda_3\lambda_4 + \lambda_1\lambda_3\lambda_4 = \\
&\left(a_i c_i \frac{1}{T_E^{'}} - a_1 \frac{d_1}{T_0^{'}} + b_i \frac{K_E}{T_E} K_j \frac{1}{T_0^{'}} \right)
\end{aligned} \tag{14}$$

$$\lambda_1\lambda_2\lambda_3\lambda_4 = 0 \tag{15}$$

Eq. (15) shows that one of Eigen values or poles is zero. Supposing to choose $\lambda_4 = 0$ and substituting it to Eq. (12), it is possible to obtain:

$$\lambda_3 = -\left(c_i + \frac{1}{T_E} - a_i + \lambda_1 + \lambda_2 \right) \tag{16}$$

by substituting Eq. (16) to Eq. (13) and $\lambda_4 = 0$, it is possible to obtain:

$$\begin{aligned}
&\lambda_1\lambda_2 - (\lambda_1 + \lambda_2)\left(c_i + \frac{1}{T_E} - a_i + \lambda_1 + \lambda_2 \right) = \\
&\left(\frac{c_i}{T_E^{'}} - \frac{d_i}{T_0^{'}} - c_{1i} a_{1i} - \frac{a_i}{T_E} \right)
\end{aligned} \tag{17}$$

Eq. (17) can be written as quadratic form in λ_1, to obtain:

$$\begin{aligned}
&\lambda_1^2 + \left(c_i + \frac{1}{T_E} - a_i + \lambda_2 \right)\lambda_1 + \lambda_2^2 + \left(c_i + \frac{1}{T_E} - a_i \right)\lambda_2 + \\
&\left(\frac{c_i}{T_E^{'}} - \frac{d_i}{T_0^{'}} - c_i a_i - \frac{a_i}{T_E} \right) = 0
\end{aligned}$$

or:

$$\begin{aligned}
\lambda_1 = &-\frac{1}{2}\left(c_i + \frac{1}{T_E} - a_i + \lambda_2 \right) \pm \\
&\frac{1}{2}\sqrt{\left(c_i + \frac{1}{T_E} - a_i + \lambda_2 \right)^2 - 4\left(\lambda_2^2 + \left(c_i + \frac{1}{T_E} - a_i \right)\lambda_2 + \left(\frac{c_i}{T_E^{'}} - \frac{d_i}{T_0^{'}} - c_i a_i - \frac{a_i}{T_E} \right) \right)}
\end{aligned} \tag{18}$$

Supposing to have $\lambda_2 < 0$, the system is stable if:

$$c_i + \frac{1}{T_E} - a_i + \lambda_2 > 0 \rightarrow |\lambda_2| < c_i + \frac{1}{T_E} - a_i \tag{19}$$

Therefore, it is possible to choose λ_2 so that Eq. (19) is satisfied, and λ_1, λ_3 can be choosen as Eq. (18) and Eq. (16). The output feedback gain by pole placement method can be obtained from Eq. (10):

$$K_i = \left(\lambda_1\lambda_2\lambda_3 - a_i c_i \frac{1}{T_E^{'}} + a_{1i} \frac{d_i}{T_0^{'}} \right) \frac{T_0^{'} T_E}{b_i K_E} \tag{20}$$

where $a_i c_i, d_i$ are the parameters, which contain P, Q, X_e.

III.3. Routh-Hurwitz Method

In Routh Hurwitz method, the Eigen values or poles of system were not chosen, but the output feedback controller $K_{R-H,i}$ was determined based on the Routh-Hurwitz table. The Routh Hurwitz table can be built based on the polynomial characteristic in Eq. (11), and based on the Routh-Hurwitz criteria, the SMIB system (Eq. (6)) is stable if:

$$\left(c_i + \frac{1}{T_E} - a_i \right) > 0 \tag{21}$$

$$\left(\frac{c_i}{T_E^{'}} - \frac{d_i}{T_0^{'}} - c_i a_i - \frac{1}{T_E^{'}} a_i \right) + \frac{\left(a_i c_i \frac{1}{T_E^{'}} - a_i \frac{d_i}{T_0^{'}} + b_i \frac{K_E}{T_E} \frac{1}{T_0^{'}} K_j \right)}{\left(c_i + \frac{1}{T_E} - a_i \right)} > 0 \tag{22}$$

$$-\left(a_i c_i \frac{1}{T_E^{'}} - a_i \frac{d_i}{T_0^{'}} + b_i \frac{K_E}{T_E} \frac{1}{T_0^{'}} K_j \right) > 0 \tag{23}$$

and the output feedback gain by Routh Hurwitz method is obtained:

$$K_i < \left(a_i \frac{d_i}{T_0^{'}} - a_i c_i \frac{1}{T_E^{'}} \right) \frac{T_E T_0^{'}}{b_i K_E} \tag{24}$$

where a_i, c_i, d_i are the parameters, which contain P, Q, X_e.

IV. Simulation and Discussion

In this simulation the parameters were taken from [4]:

$$\omega_0 = 0.2;\ T_m = 8;\ x_q = 1.2$$
$$x_d^{'} = 1.8;\ M = 13;\ K_E = 20$$
$$T_E = 0.001;\ T_{d0}^{'} = 8$$

with initial conditions $\delta = 0.3; \omega = 0.2; E_q = 0.2$ and $E_{fd} = 0.1$. In pole placement method, from Eq. (19), it was obtained:

$$\lambda_2 = -\alpha \left(c_i + \frac{1}{T_E} - a_i \right); 0 < \alpha < 1$$

and the output feedback gain:

$$K_{ipole} = \left(\lambda_1 \lambda_2 \lambda_3 + a_i \frac{d_i}{T_0^{'}} - a_i c_i \frac{1}{T_E^{'}} \right) \frac{T_0^{'} T_E}{b_i K_E}$$

and from Eq. (24), the output feedback gain of Routh Hurwitz method is:

$$K_{iR-H} = \beta \left(a_i \frac{d_i}{T_0^{'}} - a_i c_i \frac{1}{T_E^{'}} \right) \cdot \frac{T_E T_0^{'}}{b_i K_E}$$
$$0 < \beta < 1$$

In this paper, the simulation for several values of α, β were done and the performance of fuzzy output feedback controller SMIB between by pole placement method and Routh-Hurwitz method were compared. From these simulations, the performances of SMIB without control, with control without fuzzy and control with fuzzy were also presented. Figures 2-9 represent the performance of SMIB for $P = 1.8; Q = 0.2; Xe = 1.8$ and $\alpha = 0.2, \beta = 0.2$. The interval of fuzzy number is

$$P \in [0.2 \quad 2]; Q \in [-0.2 \quad 0.4]; Xe \in [-0.2 \quad 2]$$

Figures 2-3 represent the performance of SMIB with control but not with fuzzy controller. SMIB with control is more stable than without the controller. The output feedback controller by pole placement method is represented in Figure 2. The performance δ is stable and tends to 0.3002, the performance ω is stable and tends to -0.1 in time $t = 100 \times 0.001$ s. The performance E_q has overshoot until 400 and stable with settling time $t = 120 \times 0.001$ s, and the overshoot of E_{fd} is 3×10^6 and stable with settling time $t = 120 \times 0.001$ s.

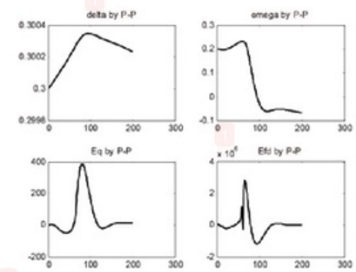

Fig. 2. SMIB Performance with Control by Pole Placement

The output feedback controller by Routh-Hurwitz method is represented on Figure 3. The performance of δ tends to 0.304, ω tends to 1.5 in time $t = 100 \times 0.001$ s. E_q has overshoot until 80, and the overshoot of E_{fd} is 15×10^4. E_{fd} tends to -3×10^4 with settling time $t = 180 \times 0.001$ s.

Fuzzy output feedback controller was also applied to SMIB. Figure 4 represents the performance of system with fuzzy output feedback controller by using pole placement methods and the performance by using Routh-Hurwitz method is represented on Figure 5.

Figures 5-6 show that, in Fuzzy output feedback controller, the performance of δ using pole placement method (Fig. 5) is almost the same between that and the performance by using Routh-Hurwitz method (Fig. 6). When using pole placement method, ω has overshoot until 0.5 and stable tends to zero (Fig. 5), but by using Routh Hurwitz method, there is no overshoot and ω tends to 0.3 (Fig. 6).

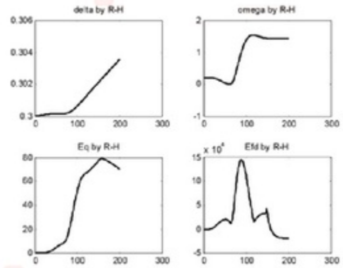

Fig. 3. SMIB Performance Control by Routh Hurwitz

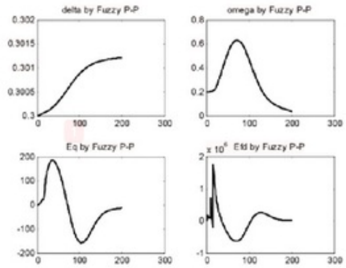

Fig. 4. SMIB Performance with Fuzzy Controller by Pole Placement

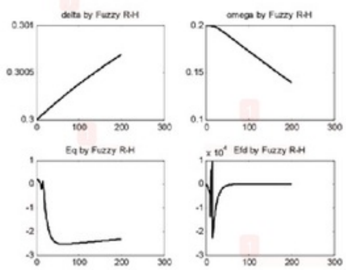

Fig. 5. SMIB Performance Fuzzy Control by Routh Hurwitz

By using pole placement method, E_q has overshoot until -500 and it is stable after time $t = 100 \times 0.001$ s (Fig. 5), but by using Routh Hurwitz method, there is no overshooting and E_q tends to 5 (Fig. 6). The performance E_{fd} has overshooting -6×10^6 in the beginning but after that it is stable and tends to zero (Fig. 5) by using pole placement method, and by Routh-Hurwitz method, E_{fd} has smaller overshooting (5×10^4 (Fig. 6)) than when using pole placement method.

For the same interval of fuzzy parameters:

$$P \in [0.2 \quad 2]; Q \in [-0.2 \quad 0.4]; Xe \in [-0.2 \quad 2]$$

other simulations were also done, by taking $\alpha = 0.02$ and $\beta = 0.2$. The performances of δ, ω, E_q and E_{fd} for all simulation are represented in Figures 6-9. In this simulation, "control R-H" is the system with control by Routh Hurwitz method without fuzzy, "control P-P" is the system with control using the Pole Placement method without fuzzy, "control fuzzy R-H" is the system with fuzzy control by Routh Hurwitz method and control fuzzy P-P" is the system with fuzzy control using the Pole Placement method.

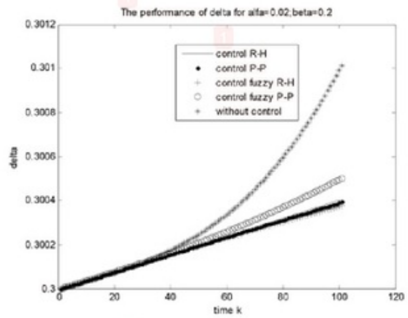

Fig. 6. The Performance of δ

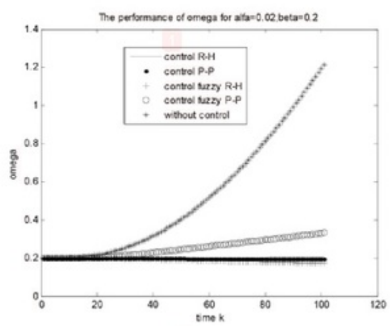

Fig. 7. The Performance of ω

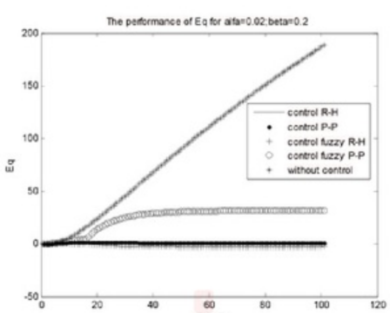

Fig. 8. The Performance of E_q

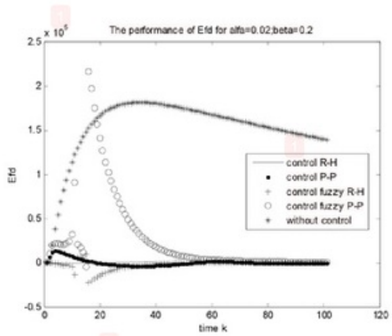

Fig. 9. The Performance of E_{fd}

Figures 6-9, show that δ, ω have almost the same performance for all output feedback controllers, either with fuzzy or without fuzzy, using pole placement or Routh-Hurwitz. The performance of E_q and E_{fd} on output feedback fuzzy controllers using pole placement is worst than with other controller methods.

In the next simulation, $P \in [0.2 \quad 2]; Q \in [-0.2 \quad 0.4]; X_e \in [-0.2 \quad 2]$ and $P = 0.8; Q = 0.2; X_e = 0.8$ for $\alpha = 0.02; \beta = 0.2$ were chosen. The performances are represented in Figures 10-13. Different values of P, Q, X_e give different performances results. Design output feedback controller using Routh Hurwitz with or without fuzzy have almost the same result, and have better performance compare to the pole placement method. The fuzzy output feedback controllers using the pole placement method has worst performance. There are overshooting on E_q and E_{fd}.

For the same interval of fuzzy parameters, $P \in [0.2 \quad 2]; Q \in [-0.2 \quad 0.4]; X_e \in [-0.2 \quad 2]$ with $P = 1.2; Q = 0.1; X_e = 1.2$ for $\alpha = 0.02; \beta = 0.2$, the performances are represented on Figures 14-17. For different values of P, Q, X_e, there are different performances results.

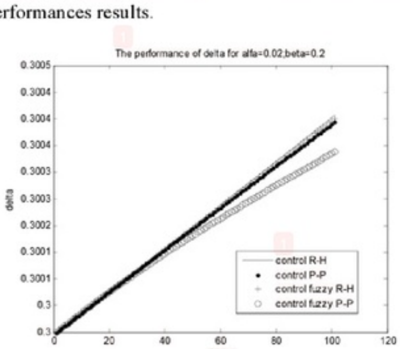

Fig. 10. The Performance of δ

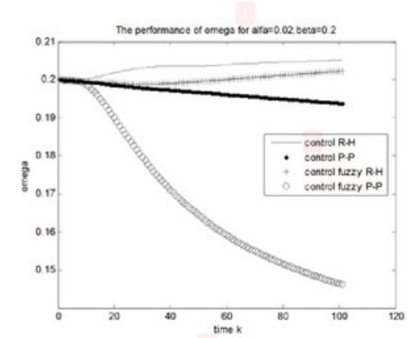

Fig. 11. The Performance of ω

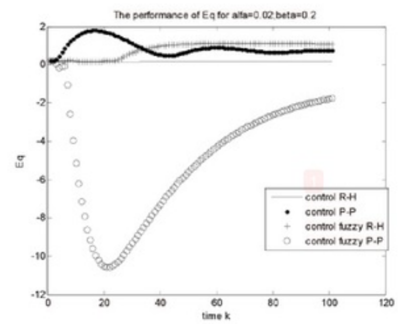

Fig. 12. The Performance of E_q

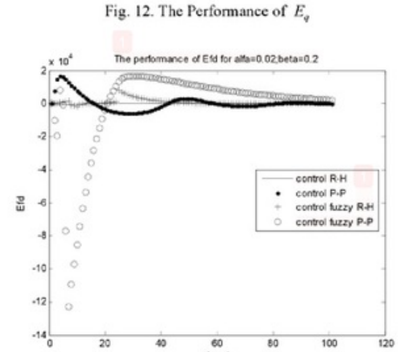

Fig. 13. The Performance of E_{fd}

Design output feedback controller using the Routh Hurwitz with or without fuzzy have almost the same result, and better performance compare to the pole placement method. The fuzzy output feedback controller using pole placement method has the worst performance. There is overshooting on E_{fd}. Finally, simulation were done with different parameters fuzzy interval $P \in [-0.2 \quad 2.2]; Q \in [-0.4 \quad 0.8]; X_e \in [-0.4 \quad 2.2]$ and

$P = 1.8; Q = 0.2; X_e = 1.8$ for $\alpha = 0.02; \beta = 0.2$.

The results are represented on Figures 18-21. This simulation shows that the designing fuzzy output feedback controller can be done using Routh-Hurwitz method and pole placement method. The output feedback gain obtained by using the Routh-Hurwitz method gives better results than by using the pole placement method. The performance of system obtained by using Fuzzy Routh-Hurwitz has also better performance than using Fuzzy pole placement.

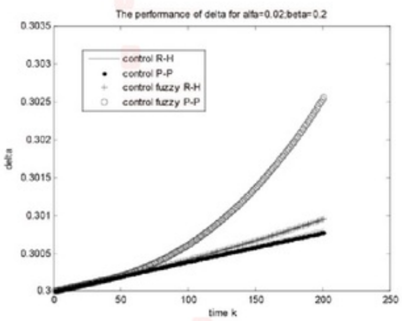

Fig. 14. The Performance of δ

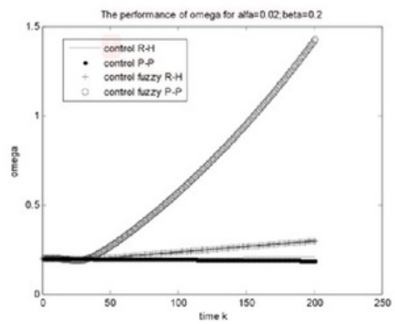

Fig. 15. The Performance of ω

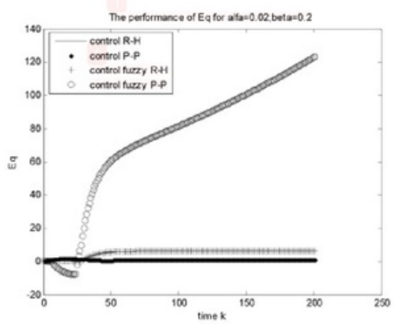

Fig. 16. The Performance of E_q

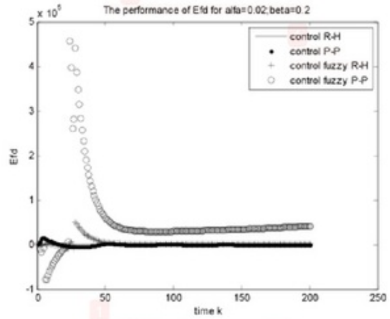

Fig. 17. The Performance of E_{fd}

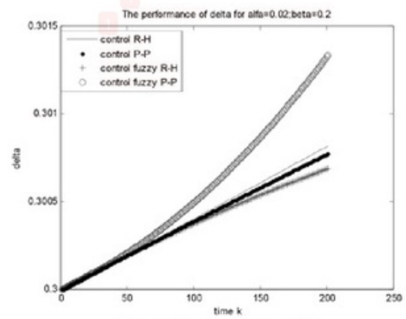

Fig. 18. The Performance of δ

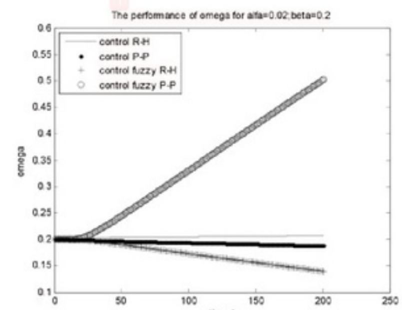

Fig. 19. The Performance of ω

V. Conclusion

As of the discussion in Section 3 and the simulation in Section 4, the conclusions are:

1. The system of SMIB is non linear, fuzzy Takagi-Sugeno control system was used to design the output feedback controller. Different state space system models were proposed.

2. The output feedback gain, K is obtained by using Pole Placement, Routh-Hurwitz, Fuzzy Pole Placement method and Fuzzy Routh-Hurwitz. Those methods are called Pole Placement output feedback controller, Routh-

Hurwitz output feedback controller, Fuzzy Pole Placement output feedback controller and Routh-Hurwitz output feedback controller.

3. The performance of SMIB by using the Routh-Hurwitz output feedback controller is almost the same than by using the Fuzzy Routh-Hurwitz output feedback controller. The performance of SMIB by using the Fuzzy Pole Placement output feedback controller is the worst.

4. The non linear system SMIB can be stabilized using Routh-Hurwitz, Pole Placement and Fuzzy Routh-Hurwitz output feedback controllers.

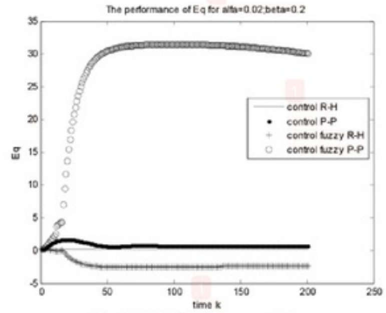

Fig. 20. The Performance of E_q

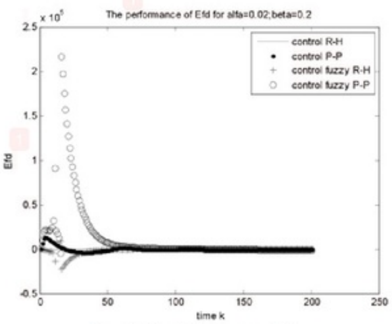

Fig. 21. The Performance of E_{fd}

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