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Controller Design SMIB By Direct Feedback Linearization

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Abstract — **Single machine infinite bus is a non linear dynamic system. To design the controller of non linear dynamic system is not easy. Usually, we linearize the system and after that design the controller as linear dynamic system. In this paper, we studied the controller design of single machine infinite bus (SMIB) by using a direct feedback linearization (DFL). This method is different with linearization method by Taylor series approximation. Here, we did simulation by Matlab program. From this simulation, we know that DFL method can be applied to design the controller of SMIB.**

Keywords—**SMIB, DFL, design controller**

1. Introduction

Controller design is a method to determined of feedback gain such that the system become closed loop system and has the desired pole. Usually, the controller design is done to make the system stable or place the pole in the left half plane. Design controller, usually is applied in the linear dynamic system, so that for non linear dynamic system, we must linearize before we design the controller.

In this paper, we design the controller of power system with single machine infinite bus (SMIB) by using direct feedback linearization (DFL). The DFL method consist of two steps: the first one is compensator linearization of non linear state feedback variable DFL (output) which change the non linear system become linear system with new input, and the second is optimal control design non linear [1]. Before we applied the DFL method, we derive the mathematical model of power system with SMIB.

2. Dynamic Model of SMIB

Single machine infinite bus is a simple model of power system [2]. 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.

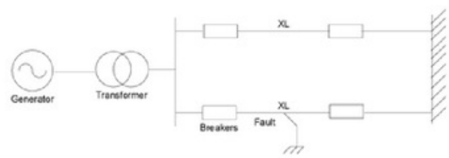

Figure 1. SMIB power system

Mathematical model of this system, consist of mechanic equation, power electric equation and electrical equation. The mathematical model [1] are:
Mechanical equation is

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

$$\dot{\omega} = \frac{\omega_0}{2H}\left[P_m - \frac{D}{\omega_0}\omega - P_e\right] \tag{2}$$

Electric power dynamic

$$\dot{E}_q' = \frac{1}{T_{d0}'}\left[E_f - E_q\right] \tag{3}$$

Electrical equation

$$E_q = E_q' + (x_d - x_d')I_d \tag{4}$$

$$E_f = k_e u \tag{5}$$

$$P_e = \frac{E_q' V_s}{x_{d\varepsilon}'} Sin\delta \tag{6}$$

$$I_d = \frac{E_q' - V_s\, Cos\delta}{x_{d\varepsilon}} = \frac{E_q' - V_s\, Cos\delta}{x_{d\varepsilon}'} \tag{7}$$

$$I_q = \frac{V_s}{x'_{d\varepsilon}} Sin\delta \tag{8}$$

$$Q = \frac{E'_q V_s}{x'_{d\varepsilon}} Cos\delta - \frac{V_s^2}{x'_{d\alpha}} \tag{9}$$

Equation (1) –(8) are SMIB mathematical model. Where δ is rotor angel, ω is a rotor velocity, ω_0 reference velocity, p_m, p_e, is mechanical power input and active power delivery, respectively. D is a damping power coefficient, E'_q, E_q, E_f is internal transient power, x'_d, x_d is a transient reactance and synchronize transient. I_d, I_q is stator current in direction d and q, k_c, u is excitation amplifier from gain and control input. V_s, V_t is a infinite voltage and power terminal voltage. Q is a reactive power delivery .

The DFL method is beginning by differentiate the active power delivery P_e Eq. (6) respect to time, we get

$$\dot{P}_e = \frac{V_s}{x'_{d\varepsilon}} Sin\delta \ \frac{d}{dt} E'_q + \frac{E'_q V_s}{x'_{d\varepsilon}} \frac{d}{dt} Sin\delta$$

or

$$\dot{P}_e = \frac{V_s}{x'_{d\varepsilon}} Sin\delta \ \dot{E}'_q + \frac{E'_q V_s}{x'_{d\varepsilon}} \ Cos\delta \ \dot{\delta} \tag{10}$$

Substitute Eq. (3, 8,9) into Eq. (10), the equation (10) become

$$\dot{P}_e = \frac{I_q}{T'_{d0}} \left[k_c u - E'_q - (x_d - x'_d) I_d \right] + \left(Q + \frac{V_s^2}{x'_{d\alpha}} \right) \Delta\omega \tag{11}$$

We arrange Eq. (11), and we get

$$\dot{P}_e = -\frac{I_q}{T'_{d0}} E'_q + \frac{I_q}{T'_{d0}} \left[k_c u - (x_d - x'_d) I_d \right] + \frac{T'_{d0}}{T'_{d0}} \left(Q + \frac{V_s^2}{x'_{d\alpha}} \right) \Delta\omega$$

$$\dot{P}_e = -\frac{V_s}{x'_{d\varepsilon}} E'_q \ Sin\delta \frac{1}{T'_{d0}} + \frac{1}{T'_{d0}} \left\{ \frac{T'_{d0}}{T'_{d0}} I_q \left[k_c u - (x_d - x'_d) I_d \right] + T'_{d0} \left(Q + \frac{V_s^2}{x'_{d\alpha}} \right) \Delta\omega \right\}$$

And finally we have

$$\dot{P}_e = -\frac{1}{T'_{d0}} (P_e - P_m) + \frac{1}{T'_{d0}} \left\{ \frac{T'_{d0}}{T'_{d0}} I_q \left[k_c u - (x_d - x'_d) I_d \right] + T'_{d0} \left(Q + \frac{V_s^2}{x'_{d\alpha}} \right) \Delta\omega - P_m \right\} \tag{12}$$

Define

$\Delta\delta = \delta - \delta_0 \ ; \Delta\omega = \omega - \omega_0 \ ; \Delta P_e = P_e - P_m$,

from Eq. (1),(2) and (12) we have the linear dynamic system of SMIB with input v_f :

$$\Delta\dot{\delta} = \Delta\omega$$
$$\Delta\dot{\omega} = \frac{-D}{2H} \Delta\omega - \frac{\omega_0}{2H} \Delta P_e \tag{13}$$
$$\Delta\dot{P}_e = \frac{-1}{T'_{do}} \Delta P_e + \frac{1}{T'_{do}} v_f$$

Where

$$v_f = I_q \left[k_c u - (x_d - x'_d) I_d \right] + T'_{d0} \left(Q + \frac{V_s^2}{x'_{d\alpha}} \right) \Delta\omega - P_m$$

Equation (13) can be written as state space system

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{P}_e \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & \frac{-D}{2H} & \frac{-\omega_0}{2H} \\ 0 & 0 & \frac{1}{T'_{do}} \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta P_e \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \frac{1}{T'_{do}} \end{bmatrix} \left[v_f \right] \tag{14}$$

Now, the problem is design a controller such that system (14) stable asymptotical.

3. Control Design Law DFL

Define an input system [1]:

$$u = \frac{1}{k_c I_q} \left[v_f - T'_{d0} \left(Q + \frac{V_s^2}{x'_{d\varepsilon}} \right) \Delta\omega - P_m \right]$$

$$+\frac{1}{k_c}(x_d - x_d^{'})I_d \qquad (15)$$

for $I_q \neq 0$ in $0^0 < \delta < 180^0$.

In the system Eq.(14) $\Delta\delta$, $\Delta\omega$, and ΔP_e are desired converge to.

Suppose

$$v_f = \begin{bmatrix} f_1 & f_2 & f_3 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta P_e \end{bmatrix} \qquad (16)$$

Where $F = [f_1, f_2, f_3]$ is feedback gain, then system (14) become

$$\begin{bmatrix} \Delta\dot{\delta} \\ \Delta\dot{\omega} \\ \Delta\dot{P}_e \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 \\ 0 & \frac{-D}{2H} & \frac{-\omega_0}{2H} \\ -\frac{1}{T_{do}^{'}} f_1 & -\frac{1}{T_{do}^{'}} f_2 & \frac{1}{T_{do}^{'}}(1 - f_3) \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta\omega \\ \Delta P_e \end{bmatrix} \qquad (17)$$

Therefore, we must determine feedback gain $F = [f_1, f_2, f_3]$ such that system (17) asymptotical stable [3].

Here we use pole assignment method to determine feedback gain F.

After we obtained $\Delta\delta, \Delta\omega, \Delta P_e$ then we substitute those value in Eq. (16) to get new input v_f, and then this value is substitute to Eq. (15) to get the real input u.

4. Simulation Result

To make a simulation, we take the parameter from [3]:

$x_d = 1.863$, $x_d^{'} = 0.257$, $x_t = 0.127$, $T_{do}^{'} = 6.9$, $H = 4$, $D = 5$, $x_{ad} = 1.712$, $x_l = 0.4853$, $k_c = 1$, $\omega_0 = 314.159$

For pole placement method, we take some poles and we obtain the feedback gain by using Matlab function (place) [3]. Figure 2. Shows system SMIB without input controller system is unstable.

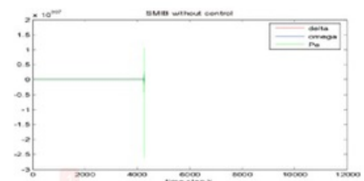

Figure 2. SMIB without control

Case 1. For case 1, we take pole=[-1;-2;-0.5] and by Matlab program, we get feedback gain
F=[-0.1763 -1.3002 20.8375].
For this feedback gain, the performance of SMIB is stable (Figure 3a), the new input v_f is shown in Figure (3b) and the real input control u in Figure (3c).

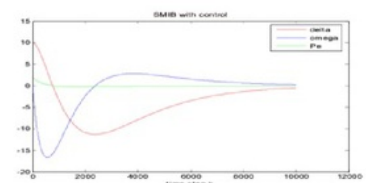

Figure 3a. SMIB with control input

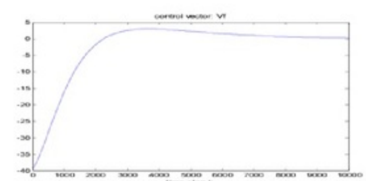

Figure 3b. The new input v_f

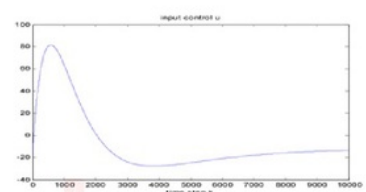

Figure 3c. control input u

Case 2: For case 2, we take pole=[-5;-10;-3]; and by Matlab program we get feedback gain F=[-26.4402 -15.8313 120.8875]

In this case the system is stable, the state of system, new input v_f and control input u, are represented in Figure (4a),(4b),(4c).

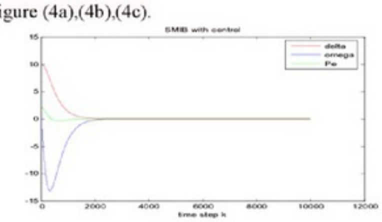

Figure 4a. SMIB with control input

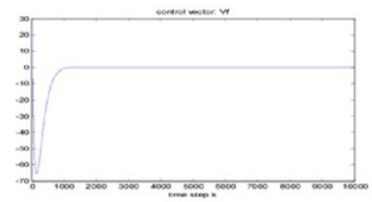

Figure 4b. The new input v_f

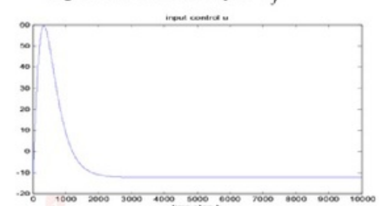

Figure 4c. Control input u

Case 3. For pole=[0;-1;-2]; and we get F=[0.0000 -1.0909 17.3875]; The SMIB system is unstable. The performance, the new input and control input are represented Figure (5a),(5b), and (5c)

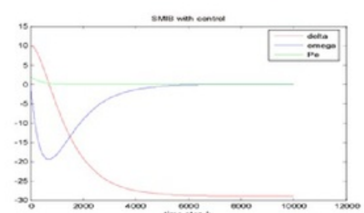

Figure 5a. SMIB system with control

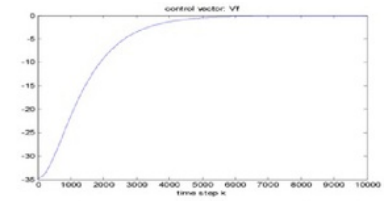

Figure 5b. Control input v_f

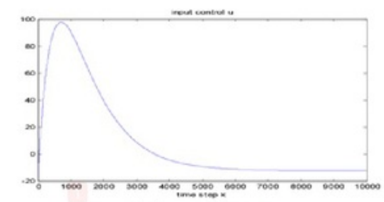

Figure 5c. Control input u

From those figures, we know that the SMIB system without control input is unstable. The case 3, feedback gain F=[0.0000 -1.0909 17.3875] is an example of system with control input u(t), but system is still unstable. This is happen because control feedback system Eq.(17) has pole zero.

5. CONCLUDING REMARK

From our analyze and simulation we conclude that

a. The DFL method can be applied to design the controller of SMIB
b. The feedback gain of linear system is determined by function in Matlab
c. The second case, F=[-26.4402 -15.8313 120.8875] give a good performance, the state is stable with smooth performance, without oscillation.

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