

## Robust Power System Stabilizer Design Based on $H_{\infty}/\mu$

**Firas Ahmed Aldurze**

dr.firasaldurze@uomosul.edu.iq

Mechatronics Engineering Department, Collage of Engineering, University of Mosul

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### ABSTRACT

In this article,  $H_{\infty}/\mu$  controller is relied on to control the power system stabilizer(PSS) using state space approach for a single machine infinite bus (SMIB) system. Design a robust feedback controller for the system using the  $H_{\infty}/\mu$  technology supported by the Matlab / Simulink. The  $H_{\infty}/\mu$  design method leads to a robust controller with a fixed structure and fixed parameters. The uncertainties of the model are taken into account when specifying the weights. The controller demeanor obtained was analyzed through the input represented by the step response and the output response of the power system (PS) in the case of normal operation and then the system with changed parameters. The suggested controller proved its effectiveness by maintaining the stability of the system with acceptable limits of disturbances.

### Keywords:

Robust control,  $H_{\infty}/\mu$  controller, PSS ,Uncertain parameters.

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Email: [alrafidain\\_engjournal1@uomosul.edu.iq](mailto:alrafidain_engjournal1@uomosul.edu.iq)

### 1. INTRODUCTION

Stabilizers for power systems have been used for many years to dampen electromechanical vibrations. It works through the generator excitation system, which generates an electrical torque corresponding to the generated speed difference [1]. However, it is easy to implement the stabilizers of the (PS), since their function mainly depends on the vibration modes, if it is in local mode or between zones [2]. Vibrations from the low frequency cause the system to become unstable and reduce its performance, so (PSS) is utilized to generate a control signal to mitigate the impact of these vibrations. It is also the (PSS) responsible for maintaining the stability of the system in the event of changing machine parameters resulting from the change in load in different operating conditions. The conventional power system stabilizer(CPSS) for electrical systems is used in the existing electrical system and has contributed to improve the dynamic stability of electrical systems [3]. Since power systems are non-linear systems and parameters of

(CPSS) operate on a linear (PS) around the nominal operating point of that(CPSS) cannot provide a guaranteed performance of the (PS) in the practical work environment [4].

The vastly used (CPSS) is prepared utilize the phase compensation theory in the frequency domain and is put in as a lead-lag compensator.[5].

Many researchers have been contributed their efforts on the tuning techniques of PSS parameters. These techniques include robust control [6], optimization methods [7] and artificial intelligence approaches such as fuzzy logic [8], fuzzy sliding mode control techniques [9 ],neuro-fuzzy [10]. Genetic Algorithm (GA) [11] and Particle Swarm Optimization (PSO) [12].

In this paper, a robust controller was developed that uses  $H_{\infty}/\mu$  control of the (PSS) to dampen vibrations in the (SMIB) system. The settling time (ts) is treated as a major performance norm to reduce oscillations for time-domain specifications. The design requirements and

constraint limits are initially set when the goal is to dampen vibrations while minimizing (ts).

2. SYSTEM DESCRIPTION

The linearized model of the studied (PS) consisted of (SMIB). This is shown in a functional diagram, as shown in Figure 1, it can be expressed state space formulation as follows [13].

$$\Delta \dot{\delta} = \omega_0 \Delta \omega \dots\dots\dots 1$$

$$\Delta \dot{\omega} = \frac{1}{M} (-K_1 \Delta \delta - D \Delta \omega - K_2 \Delta E' q + \Delta T_m) \dots\dots\dots 2$$

$$\Delta \dot{E}' q = \frac{1}{T'_{do}} \left( -K_4 \Delta \delta - \frac{\Delta E' q}{K_3} + \Delta E_{FD} \right) \dots\dots\dots 3$$

$$\Delta \dot{E}_{FD} = \frac{1}{T_A} (-K_A K_5 \Delta \delta - K_A K_6 \Delta E' q - \Delta E_{FD} + K_A \Delta V_{ref}) \dots\dots\dots 4$$

In a matrix form as follows:

$$\dot{X}(t) = Ax(t) + Bu(t) \dots\dots\dots 5$$

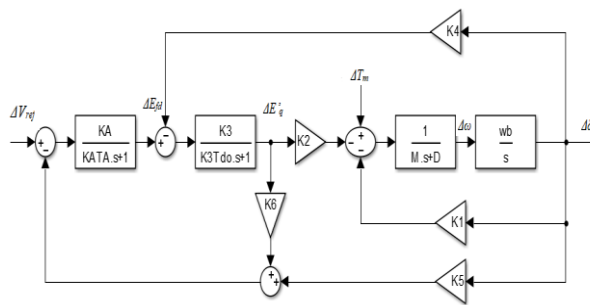


Fig. 1 Block diagram of (PS) model

Where,

$$\begin{bmatrix} \Delta \dot{\delta} \\ \Delta \dot{\omega} \\ \Delta \dot{E}' q \\ \Delta \dot{E}_{FD} \end{bmatrix} = \begin{bmatrix} 0 & \omega_0 & 0 & 0 \\ -k_1 & -D & -k_2 & 0 \\ M & M & M & 0 \\ T'_{do} & 0 & -1 & 1 \\ -k_A k_5 & 0 & -k_A k_6 & -1 \\ T_A & T_A & T_A & T_A \end{bmatrix} \times \begin{bmatrix} \Delta \delta \\ \Delta \omega \\ \Delta E' q \\ \Delta E_{FD} \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \\ M \\ 0 \end{bmatrix} \times [\Delta T_m] \dots\dots (6)$$

- Where:
- $\delta$ : torque angle
- $\omega$ : angular velocity (speed)
- $E'q$ : the internal tension of the machine
- $E_{FD}$ : the excitation voltage
- $K_A$  and  $T_A$  : are the gain and time constant of the excitation system
- $T'_{do}$ : is the transition time constant for open-circuit
- $\Delta$  : a small deviation around the operating point
- $D$  : is the torque coefficient d 'depreciation and
- $K1$  to  $K6$  are constant.
- A detailed block diagram model of the (PS) is shown in Figure 1.

3. DESCRIPTION AND REPRESENTATION OF THE SYSTEM UNCERTAINTY IN THE INTERCONNECTION MATRIX

Two physical parameters ( $T_A$ ,  $T'_{do}$ ) can be taken into account. these parameters are mostly unknown. Is being added  $\delta\Delta$  to the parameters ( $T_A$ ,  $T'_{do}$ ) to exemplify the uncertainty parameters.

where  $\delta$  is the weight of the parameter's uncertainty and  $\Delta$  is 1 or -1. Figure 2 shows the procedure with which the uncertainty parameter ( $T'_{do}$ ) is entered. The perturbations entered are  $\delta\Delta T_A$ ,  $\delta\Delta T'_{do}$ .. the  $(1+\delta\Delta)$  can be added to the ( $T_A$ ,  $T'_{do}$ ) parameters to display the fluctuations in the uncertainty as shown in Figure 3.

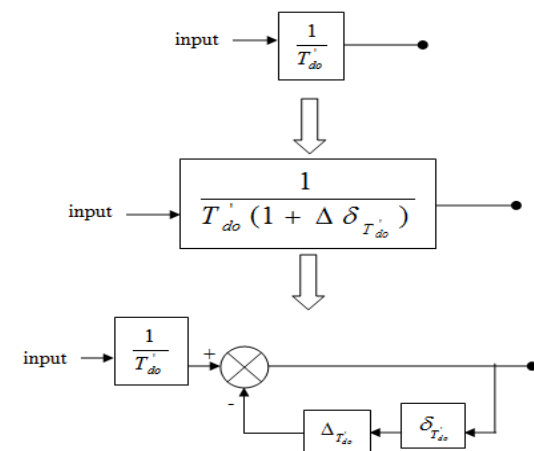


Fig. 2 The functional diagram shows the procedure that enters the uncertainty element ( $T'_{do}$ ).

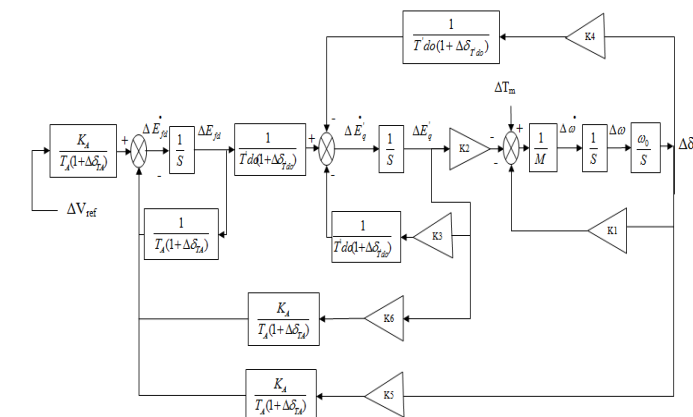


Fig. 3 Uncertainty parameters of (PS) block diagram .

4. THEORY OF SYNTHESIS  $H_{\infty} / \mu$

The  $H_{\infty}/\mu$  control synthesis method contains three stages: first is  $H_{\infty}$  optimal control synthesis



is calculated based on the synthesis configuration, which consists of a state-space model, second:  $\mu$ -analysis, third: a D-scale, which are nested in an iterative scheme [14].

**4.1 Singular value structure and  $\mu$ - synthesis**

Using linear fractional transformations (LFTs) the general structure is built for  $\mu$ -analysis and synthesis as shown in a diagram in Figure 4 [15].it is shown all interconnection of inputs, outputs and a controller with disturbance and reorganized according to this diagram. For analysis, the controller K is acquired in the structure plant P to form the interconnected matrix structure shown in " Figure 4-a".

$$\Delta \approx \{diag(\delta_i \times I_{r_i}, \dots, \delta \times I_{r_s}, \Delta_i, \dots, \Delta_F), \delta_i \in C, \Delta_i \in C^{m_i \times m_s}\} \dots\dots\dots(7)$$

$$\Delta = \{\Delta \in \Delta / \bar{\sigma}(\Delta) \leq 1 \}$$

to define singular structure value  $\mu$  for complex matrix,  $M \in C^{m \times n}$ , as:

$$\mu_{\Delta}(M) = \frac{1}{\min\{\bar{\sigma}(\Delta) : \Delta \in \Delta, \det(I - M\Delta) = zero\}} \dots\dots\dots(8)$$

Thus,  $\mu$  is a measure of the smallest structure that gives rise to the instability of the feedback-loop constant matrix shown in "Fig.4-b".Given a required uncertainty level, the objective of this design is to look for a control law, which can minimize the  $\mu$  level closed-loop system and secure the stability of the system for all prospective uncertainty attributive.

The performance and stability conditions of a system in the presence of a structured uncertainty in relation to the  $\mu$  are given by:

**1. Robust stability**

$$F_u(M, \Delta) \dots stable \dots (\forall \Delta \in B\Delta)$$

$$iff \sup_{\omega} \mu(M_{11}(j\omega)) \leq 1 \dots\dots\dots(9)$$

**2. Robust performance**

$$F_u(M, \Delta) \dots stable \dots and \|F_u(M, \Delta)\|_{\infty} \leq 1$$

$$iff \sup_{\omega} \mu(M_{11}(j\omega)) \leq 1 \dots\dots\dots(10)$$

The control error  $e'$  can be expressed as the following LFT.

$$\acute{e} = F_L(P, K)\acute{v} = [P_{11} + P_{12}K(I - P_{22}K)^{-1}P_{12}]\acute{v}$$

Ideally, the value of the controller K is calculated as follows

$$\|F_L(P, K)\|_{\mu} \text{ less than or equal } 1$$

However, since there is no efficient mechanism to get this K directly, the D-scale matrix is calculated indirectly.

$$\min_K \inf_D \|DF_L(P, K)D^{-1}\|_{\infty} \leq 1 \dots\dots\dots(11)$$

$$D = \{diag(d_1I, d_2I, \dots, d_0I) \uparrow d_i \in R\}$$

During the minimization process, the fixation of D or K is specifically referred to as iteration D-K. It has no practical meaning and can be widespread [16].

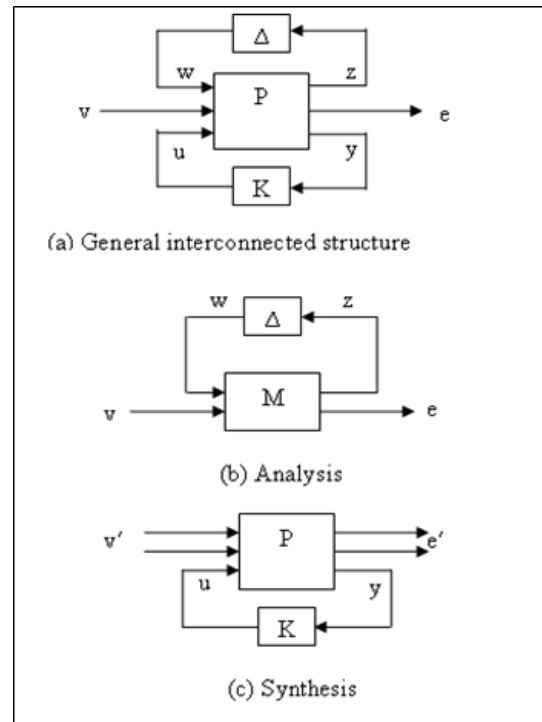


Fig. 4  $\mu$ -analysis and synthesis structure

The goal of designing a controller in a model of an interconnected (PS) is to dampen the angular velocity deviation. Therefore, the angular velocity (speed) deviation ( $\Delta\omega$ ) of power system is treated as controller inputs. The state-space model will be separated from the uncertainty as follows:

$$P_0 = \begin{cases} \dot{x} = A_0x + B_0u_1 + B_1w \\ Z = C_zx + D_zu_1 \\ y = Cx \\ w = \Delta z \end{cases} \dots\dots\dots(12)$$

Where the matrix  $\Delta$  is given by :

$$\Delta = \{diag(\delta_1 \times I_2, \dots, \delta_2 \times I_2, \delta_i), \delta_i \in R, \|\Delta\| \text{ less than or equal } 1\}$$

The figuration of the controller design based on  $\mu$  is shown in Figure 5. In this diagram,  $P_0$  is the interconnection between the nominal installation and all parametric uncertainties. In order to take into account the modeling error, a parameter of uncertainty ( $W_c$ ) was added as an

input to the system. Whereas, (Wp) represents the system performance specifications [17].

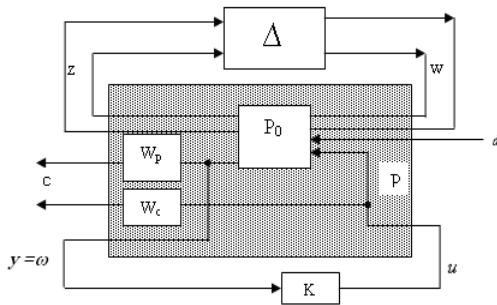


Fig. 5 The figuration of the controller design based on  $\mu$ .

**4.2. Uncertain system robust performance**

At this stage, some parameters such as Wc and Wp are added to the system as improved parameters, as shown in Figure 6. where, Wc and Wp are represent input and output uncertainties weight.

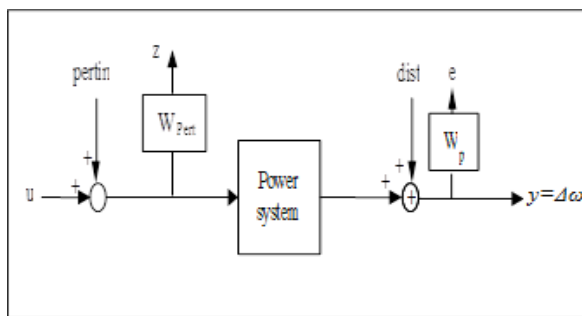


Fig. 6 Input output uncertainty representation

**5. Design procedure H $\infty$ / $\mu$  Algorithm**

The H $\infty$ / $\mu$  controller design using  $\mu$ -synthesis can be summarized in the following steps:

1. Forming the interconnection matrix. This step includes linearization of the non-linear model.
2. H $\infty$ -synthesis. When the interconnection matrix has been defined, an H $\infty$  controller is designed. This involves the solution of two Riccati equations iterated over a scalar parameter in a one dimensional search. The result is a controller K. When the plant matrix P is closed-loop with the controller K results in a closed-loop system matrix M.
3.  $\mu$ -analysis. In this step  $\mu$ -analysis of the closed loop system matrix M is carried out. the structured singular values of M is calculated[18].
4. Rational approximation of D $_s$ -scaling. In this step, the D $_s$ -scaling calculated in the  $\mu$ -analysis (step3) is approximated by rational transfer functions.

5. D $_s$ -K iteration. The interconnection matrix P is improved with the coherent transport utilities. H $\infty$ -synthesis,  $\mu$ -analysis and D $_s$ -scaling approximations are repeated until no longer changes occur in it.

6. Changing weights. If D $_s$  and K have converged but the requirements are not fulfilled, then the weights must be changed. The design objectives must be stopped and a new D $_s$ -K iteration must be done.  $\mu$ -analysis can be used to know which design objectives are driving the problem.

The algorithm steps are given in the flowchart shown in Figure (7).

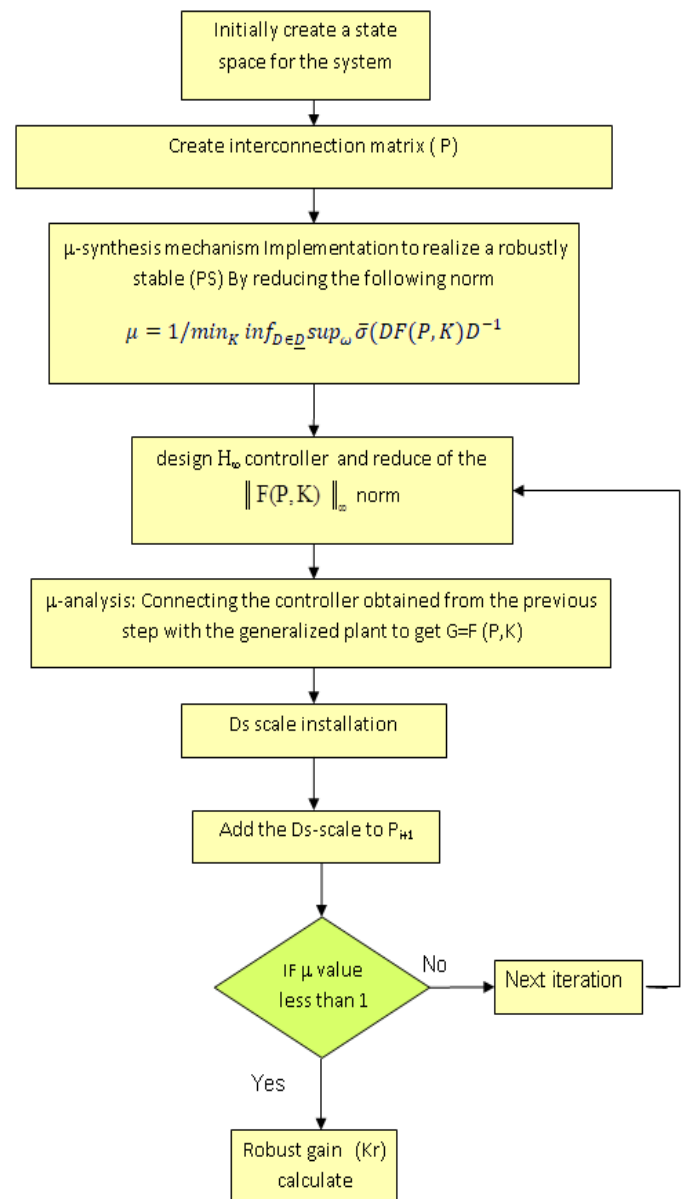


Fig. 7 H $\infty$ / $\mu$  synthesis algorithm flowchart

6. SIMULATION AND RESULTS

Using the MATLAB / SIMULINK program, the proposed  $H_\infty/\mu$  controller performance has been tested by performing multiple simulation tests and comparing them to a CPSS system to check if the proposed controller is better and more robust than the CPSS or not. For comparison, simulation tests of the reaction to the speed deviation depending on the nominal condition and the variation of the uncertainty parameters of the (PS) were carried out. Figure 8 shows the control of the speed deviation responses of the CPSS power system and the  $H_\infty/\mu$  controller. Based on the simulation results, the  $H_\infty/\mu$  controller offers the best performance compared to the CPSS.

In order to be a high performance  $H_\infty/\mu$  controller, it must be strong and robust during the change in the parameters ( $T_A$ ,  $T'_{do}$ ) examined by simulations by changing one parameter at a time, while the other parameters remain unchanged.

Figures 9 and 10 show the responses of (PS) based on  $H_\infty/\mu$  controller when  $T_A$  and  $T'_{do}$  are incremented by 30% and 50% of the main value. Figures 11 and 12 show the responses of (PS) based on  $H_\infty/\mu$  controller when  $T_A$  and  $T'_{do}$  are changed from the main value by -30% and -50%.

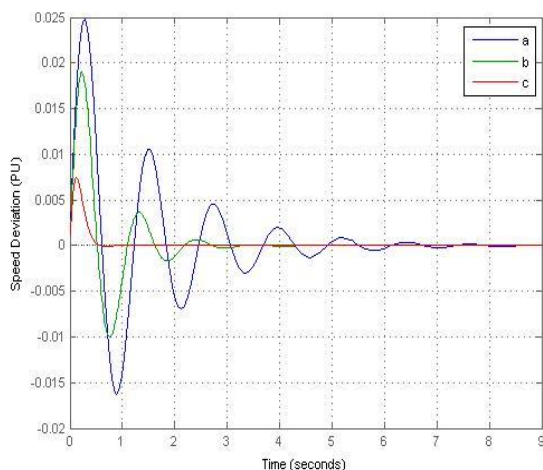


Fig. 8 Speed deviation power system responses a- No-PSS b- CPSS c-The system with  $H_\infty/\mu$  controller

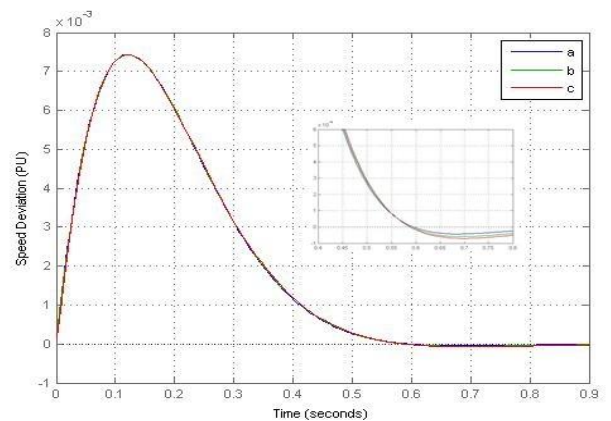


Fig. 9 The responses of speed deviation with  $H_\infty/\mu$  controller a-  $\delta T_A=0\%$  b-  $\delta T_A=30\%$  c-  $\delta T_A=50\%$

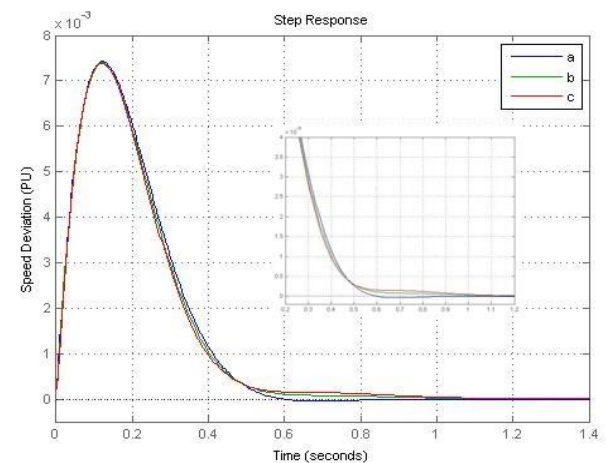


Fig. 10 The responses of speed deviation with  $H_\infty/\mu$  controller a-  $\delta T'_{do}=0\%$  b-  $\delta T'_{do}=30\%$  c-  $\delta T'_{do}=50\%$

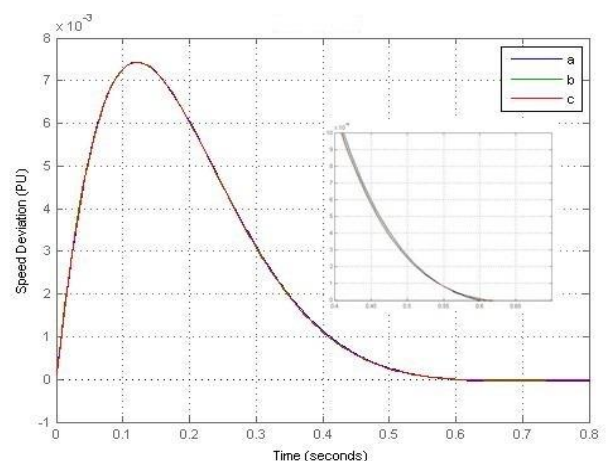


Fig. 11 The responses of speed deviation with  $H_\infty/\mu$  controller a-  $\delta T_A=0\%$  b-  $\delta T_A=-30\%$  c-  $\delta T_A=-50\%$

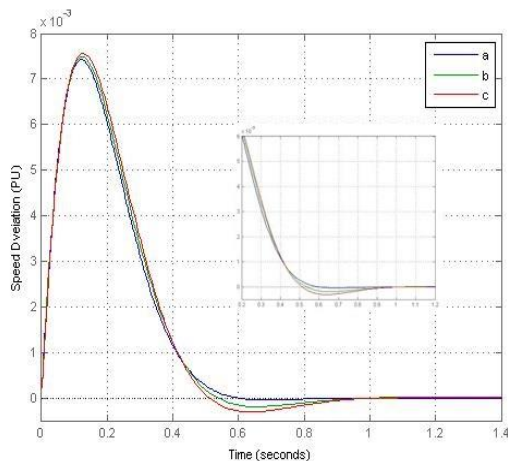


Fig.12.The responses of speed deviation with  $H_{\infty}/\mu$  controller a-  $\delta_{T_{do}}=0\%$  b-  $\delta_{T_{do}}=-30\%$  c-  $\delta_{T_{do}}=-50\%$

Table (1) shows the effect of changing each parameter alone on the system performance for each  $H_{\infty}/\mu$  controller and CPSS with the rest of the parameters remain constant . According to Table 1, the controller  $H_{\infty}/\mu$  has the fastest (ts) of 0.528 seconds, whereas the CPSS has the slowest (ts) of 2.58 seconds. For the overshoot percentage, the K controller has a percentage overshoot value of 0.743%, while the CPSS has a percentage overshoot value of 1.9% (Figure 8). It is obvious that changing the uncertainty of the  $T_A$  parameter has little effect on the behavior of the model. Figure 9 and Figure 10. While the parameter  $T_{do}$  (Figure 12) changes the behavior of the model compared to other parameters.

Table 1:The effect of changing one of the parameters on the performance of the system, with the other parameters remaining constant for each time.

System	Change %	System with CPSS		System with $H_{\infty}/\mu$ controller	
		Overshoot %	Settling Time (ts) (sec)	Overshoot %	Settling Time (ts) (sec)
Without any change in parameter	0	1.9	2.58	0.743	0.528
$\delta_{T_A}$ and other parameter are constant	10	1.89	2.58	0.743	0.528
	30	1.87	2.58	0.743	0.528
	50	1.87	2.58	0.743	0.529
	-10	1.9	2.59	0.743	0.528
	-30	1.91	2.71	0.743	0.529
	-50	1.93	2.99	0.743	0.530
$\delta_{T_{do}}$ and other parameter are constant	10	1.89	2.59	0.741	0.536
	30	1.87	2.61	0.739	0.558
	50	1.87	2.65	0.738	0.641
	-10	1.96	2.68	0.744	0.520
	-30	2.01	3.4	0.747	0.746
	-50	2.15	4.1	0.749	0.804

### 7. CONCLUSION

In this work, the designed  $H_{\infty}/\mu$  controller deals with a (PS) model with the presence of uncertain parameters using Matlab Simulink. This controller is applied to control the speed deviation. The performance of both the designed  $H_{\infty}/\mu$  controller and CPSS was tested through simulation and it was found that the designed  $H_{\infty}/\mu$  controller maintains the stability of the power system in a manner Durable when changing uncertain parameters. It was concluded that the dominant had a high dynamic behavior of the power system with a rapid (ts) and very small overshoot compared to CPSS. The designed  $H_{\infty}/\mu$  controller can realize robustness and good performance.

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## تصميم مسيطر متين لمثبت نظام القدرة بالاعتماد على $H_{\infty} / \mu$

فiras احمد مجيد الدرزي

dr.firasaldurze@umosul.edu.iq

جامعة الموصل - كلية الهندسة - قسم هندسة الميكاترونكس

### المخلص

في هذا البحث ، يتم الاعتماد على المسيطر  $H_{\infty} / \mu$  للتحكم في مثبت نظام القدرة باستخدام نهج فضاء الحالة لنظام قدرة مكون من ماكينة احادية مربوطة الى عمومي لانهاهي. تم تصميم مسيطر متين ذو تغذية خلفية للنظام بالاعتماد على تقنية  $H_{\infty} / \mu$  باستخدام برامجيات و محاكاة ماتلاب. تؤدي طريقة تصميم  $H_{\infty} / \mu$  الى مسيطر متين ذات بنية ثابتة وعناصر ثابتة. تم الاخذ بنظر الاعتبار عدم دقة نموذج النظام عند تحديد الاوزان. تم تحليل سلوك المسيطر الذي تم الحصول عليه من خلال الإدخال المتمثل باستجابة الخطوة وكذلك استجابة الإخراج لنظام القدرة في حالة التشغيل الطبيعي وكذلك في حالة تشغيل النظام مع تغيير العناصر. أثبت المسيطر المقترح فعاليته من خلال الحفاظ على استقرار النظام مع حدود مقبولة للاضطرابات.

### الكلمات الداله :

السيطرة المتينة، المسيطر  $H_{\infty} / \mu$ ، مثبت نظام القدرة ، عناصر عدم الدقة .