

## **Robust Tuning of Power System Stabilizers Using Coefficient Diagram Method**

**Vasu Puligundla<sup>1</sup> and Jayanta Pal<sup>2</sup>**

*<sup>1,2</sup>Indian Institute of Technology, Kharagpur, India*  
*E-mail: <sup>1</sup>vaasu1101@gmail.com, <sup>2</sup>jpal@ee.iitkgp.ernet.in*

### **Abstract**

In this paper, robust design and tuning of power system stabilizers (PSS) is considered. The objective is to tune PID-PSS so that closed-loop response of a single machine connected to an infinite bus system (SMIB) is made stable over a wider range of operating points while maintaining the desired damping. The Coefficient Diagram Method (CDM) is used for choosing the coefficients of the target characteristic polynomial of the closed loop system based on performance criteria; such as equivalent time constant, stability indices and stability limits. Standard Manabe form is used for choosing the stability indices. The parametric uncertainties are handled by adding a pre-filter that increases the degree of the CDM based controller (PID-PSS) by one. Genetic Algorithm and pole coloring technique are then used for tuning the pre-filter by minimizing the shift in the closed-loop poles due to perturbations. The robustness of the designed feedback controller for SMIB is verified by using the Kharitonov Theorem and the Zero-exclusion condition.

**Index Terms:** Power System Stabilizers, Power system dynamic stability, Coefficient Diagram Method, Genetic Algorithm, Robust control.

### **1. Introduction**

There has been considerable effort for solving the problem of low frequency oscillations leading to instability of power systems. These modes of oscillations are characterized by low mechanical natural frequencies in the range of 0.3-2.0 Hz. To

damp out the oscillations, power system stabilizers (PSS) are used to inject a supplementary signal at the voltage reference input of the automatic voltage regulator (AVR). Conventionally a single-input single-output feedback controller is used as PSS. As an input signal to a conventional PSS, anyone of the three signals i.e., machine shaft speed, ac bus frequency or accelerating power can be used. Most commonly used input signal is the machine shaft speed [10].

Many research papers have been published in this area [2, 8, 9]. The PSS design normally uses classical control theory and is based on a model of the power system linearized at some operating point. Properly tuned, a PSS can considerably enhance the dynamic performance of a power system.

Some work in the area of designing self-tuning, adaptive and robust PSS [2, 8] has been reported for achieving better control over wide range of load variations. However, the complexity and/or real-time computational requirement of such controller preclude their use in actual power plants.

Changes in transmission networks, generation and load patterns results in changes in operating conditions of power systems. Thus, the small signal dynamic behavior of a power system is varied, which can be expressed as a parametric uncertainty in the small signal linearized model of the system. In this work, we design a robust PSS so that adequate damping can be provided over a wide range of operating conditions. This work was motivated by some papers [2, 8, 9], where the quantitative feedback theory (QFT) [8], LMI technique [2] and Optimization Techniques [9] have been used for designing a robust PSS.

In this paper coefficient diagram method [3], an algebraic design approach (or polynomial method), is used. The time-domain performance of a system is closely related with its poles or characteristic polynomial. The characteristic polynomial can be defined from stability and response specification, but it is very difficult to choose it with guarantee of robustness. The CDM standard form [3] is used for choosing the target closed loop characteristic polynomial. Although the CDM results in pretty robust controllers, if there are large uncertainties in the system CDM itself may not be enough to satisfy robust stability and performance requirements. The CDM design method is extended to handle all possible parametric uncertainties with satisfactory performance by increasing the degree of the controller offered by the CDM by one. A pole-zero pair is introduced to create extra design freedoms and then a pole-coloring technique [4] to guarantee robust pole assignment. The pole-zero pair is tuned using Genetic Algorithm by minimizing the shift in the closed-loop poles due to perturbations.

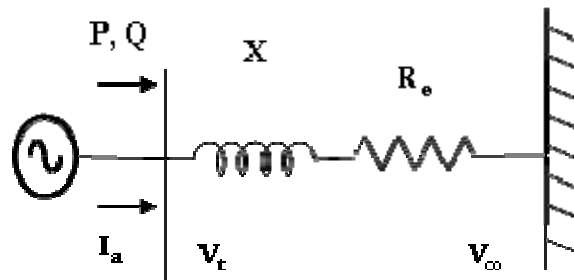
## 2. Problem Statement

By varying the operating conditions over a range which includes almost all practical operating conditions for the generator and by varying lengths of transmission lines includes very weak to very strong transmission systems, so the operating conditions are chosen in the intervals  $P[0.4 \ 1.0]$ ,  $Q[-0.2 \ 0.5]$  and  $X[0.2,0.7]$ .

By taking a step difference of 0.1 in the values of P, Q and X, totally 336 combinations are obtained which corresponds to 336 operating points. Using the Heffron-Philips linearized model [6] of a single machine connected to an infinite bus (SMIB) system, 336 linearized models of the plant is constructed. The problem considered in [2], [8] is to design a feedback controller that maintains a damping ratio of at least 0.1 and real parts of all closed-loop poles less than -0.5 simultaneously for all operating points.

**2.1 Power system model**

The Heffron-Philips linearized model [6] of a single machine connected to an infinite bus (SMIB) system is considered in this work. Fig.1 shows the line diagram of a synchronous machine connected to an infinite bus through a transmission line having resistance and reactance X



**Fig. 1:** Line diagram of single machine connected to infinite bus.

The detailed derivation and assumptions are given in [7]. System data and state space representation are given in appendix.

**2.2 PSS structure**

*Case1:* A simple PID-PSS is considered, when parameters are tuned using standard CDM only. The transfer function of PSS as:

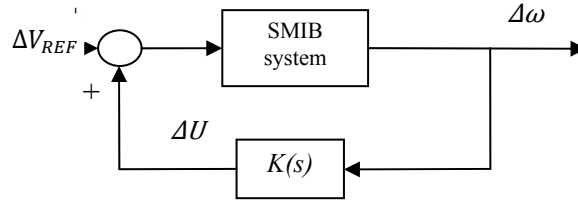
$$\text{—————} \tag{1}$$

*Case2:* A PID amended with a pole-zero pair is considered when CDM & pole-coloring are used. The transfer function of PSS as:

$$\text{— — — — —} \tag{2}$$

The input to PSS is the machine shaft speed,  $\Delta\omega$  and the output is  $\Delta U$ , i.e.

$$\Delta U = K(s) \Delta\omega$$



**Fig. 2:** Closed loop configuration of single-machine system.

The parameters of PSS viz.  $k_d$ ,  $k_p$ ,  $k_i$ ,  $a$  and  $b$  are tuned through combination of CDM, GA and pole-coloring techniques to meet the desired objectives.

### 3. Method

#### 3.1 Concept of CDM

In CDM, the controllers are designed based on the stability index known as  $\gamma_i$  and the equivalent time constant known as  $\tau$  which are synthesized from the characteristic polynomial of the closed-loop transfer function.

$$P(s) = a_n s^n + \dots + a_1 s + a_0 = \sum_{i=0}^n a_i s^i \quad (3)$$

From the characteristic polynomial  $P(s)$  given in eq. (3), the stability index  $\gamma_i$  and the equivalent time constant  $\tau$  are respectively described in general term as the following equations [3]

$$\gamma_i = \frac{a_i^2}{a_{i+1} a_{i-1}}, i = 1 \sim n - 1 \quad (4)$$

$$\tau = \frac{a_1}{a_0} \quad (5)$$

In order to meet the specifications, the equivalent time constant  $\tau$  and the stability index  $\gamma_i$  are normally chosen as

$$\tau = \frac{t_s}{2.5} \sim \frac{t_s}{3}$$

$$\gamma_i > 1.5\gamma_i^*$$

Where  $t_s$  is the specified settling time and  $\gamma_i^*$  is the stability limit defined as

$$\gamma_i^* = \frac{1}{\gamma_{i+1}} + \frac{1}{\gamma_{i-1}}, i = 1 \sim n - 1, \gamma_n = \gamma_0 = \infty$$

In general the stability index is recommended as

$$\gamma_{n-1} \sim \gamma_2 = 2, \gamma_1 = 2.5 \quad (6)$$

known as standard stability index.

Finally the characteristic polynomial known as the desired characteristic polynomial can be expressed as

$$P(s) = a_0 \left[ \left\{ \sum_{i=2}^n \left( \prod_{j=1}^{i-1} \frac{1}{\gamma_{i-j}^j} \right) (\tau s)^i \right\} + \tau s + 1 \right]$$

$$= a_n s^n + \dots + a_1 s + a_0,$$

Where,  $a_n, a_{n-1}, \dots, a_0$  are the coefficients of the desired characteristic polynomial.

**3.2 Pole coloring [4]:**

Consider the simple case of a third-order system where the nominal poles and perturbed poles for a fixed  $q$  (perturbations) are given in Fig1. Here, assume that big points represent perturbed poles and small points represent nominal poles corresponds to which of the perturbed poles is called ‘pole coloring’.

**3.3 Graphical approach for checking robustness [5]**

Consider a real general polynomial  $p(s)$  of degree ‘ $n$ ’ as given below:

$$p(s) = a_n s^n + a_{n-1} s^{n-1} + \dots + a_1 s + a_0 \tag{7}$$

The polynomial  $p(s)$  is said to be an interval polynomial if each coefficient is independent of the other and varies within an interval having a lower and upper bound [5]: i.e.  $a_i = [a_i^-, a_i^+], i = 0, 1, 2, \dots, n$ , such an uncertain polynomial is said to have an independent uncertainty structure.

Kharitonov Theorem: The interval polynomial  $p(s)$  is robustly stable if and only if the following four Kharitonov polynomials:

$$K_1(s) = a_0^+ + a_1^+ s + a_2^- s^2 + a_3^- s^3 + a_4^+ s^4 + a_5^+ s^5 + \dots$$

$$K_2(s) = a_0^- + a_1^- s + a_2^+ s^2 + a_3^+ s^3 + a_4^- s^4 + a_5^- s^5 + \dots$$

$$K_3(s) = a_0^- + a_1^+ s + a_2^+ s^2 + a_3^- s^3 + a_4^- s^4 + a_5^+ s^5 + \dots$$

$$K_4(s) = a_0^+ + a_1^- s + a_2^- s^2 + a_3^+ s^3 + a_4^+ s^4 + a_5^- s^5 + \dots \tag{8}$$

are stable [5].

Given the interval polynomial  $p(s, a)$  as defined in eq. (7) and a fixed frequency  $\omega = \omega_0$ , one can describe a set of possible values that  $p(j\omega_0, a)$  can assume as  $a$  varies over the box  $Q$  which can be shown as:

$$p(j\omega_0, Q) = \{ p(j\omega_0, a) : a \in Q \}$$

Then,  $p(j\omega_0, Q)$  can be termed as the Kharitonov rectangle [5] at frequency  $\omega = \omega_0$  with vertices which are obtained by evaluating the four Kharitonov polynomials,  $K_i(s), i=1, 2, 3, 4$ , as defined in eq. (8), at  $s = j\omega_0$ . The rectangularity is proved in [5]. By varying the frequency from  $\omega = 0$ , and with  $\omega$  increasing in discrete steps, results in the

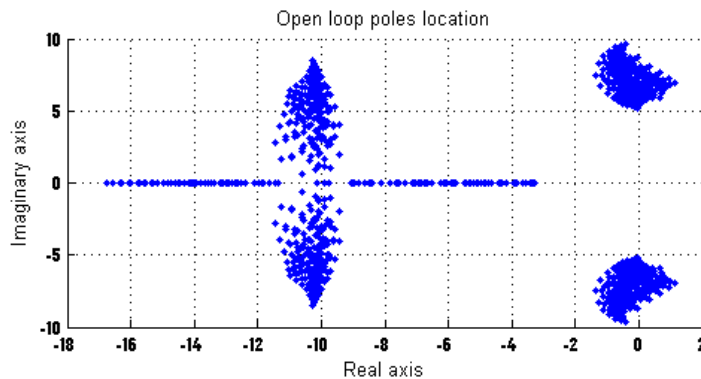
motion of the Kharitonov rectangle with the rectangle moving around the complex plane with vertices  $K_i(j\omega)$ . The dimensions (size) of this rectangle vary with the frequency  $\omega$ .

**Zero Exclusion Condition:** Suppose that an interval polynomial family  $p(s)$  has invariant degree and at least one stable member, the  $p(s)$  is robustly stable if and only if  $s=0$  is excluded from the Kharitonov rectangle at all non-negative frequencies [5]; i.e.  $0 \notin p(j\omega, Q)$

The zero exclusion condition suggests a simple graphical procedure for checking robust stability. By watching the motion of Kharitonov rectangle  $p(j\omega, Q)$  as  $\omega$  varies from 0 to  $+\infty$ , one can easily determine by inspection if the Zero Exclusion condition is satisfied. If it is satisfied, then one can say that the polynomial family  $p(s)$  is robustly stable.

#### 4. Controller Design

A family of 336 linearized models of the plants is constructed for grid of operating points as  $P, Q$  and  $X_e$  vary independently in steps of 0.1 over the interval  $[0.4, 1.0]$ ,  $[-0.2, 0.5]$  and  $[0.2, 0.7]$  respectively. The reference terminal voltage is kept as  $\Delta V_{REF}=0.05$  and moment of inertia is calculated as  $M=2H$ . Open loop poles location: when  $P, Q$ , and  $X_e$  are varied independently in steps of 0.1 over the interval  $[0.4, 1.0]$ ,  $[-0.2, 0.5]$  and  $[0.2, 0.7]$  are shown in Fig.3.



**Fig. 3:** Open loop poles locations for all chosen perturbations.

##### 4.1 Designing a robust PID-PSS:

Step1: Let the light loading condition  $P=0.4$ ,  $Q=-0.2$  and  $X=0.2$  be the nominal operating point, then corresponding transfer function will be

$$G_{light}(s) = \frac{-44.3s}{s^4 + 21.1s^3 + 170.6s^2 + 1102.3s + 4371}$$

Step2: Choose controller to be designed as PID

Step3: Obtain the closed loop characteristic polynomial in terms of unknown controller parameters-

$$P(s) = s^4 + 21.1s^3 + (170.6s^2 + 44.3k_d)s^2 + (1102.3 + 44.3k_p)s + (4371 + 44.3k_i)$$

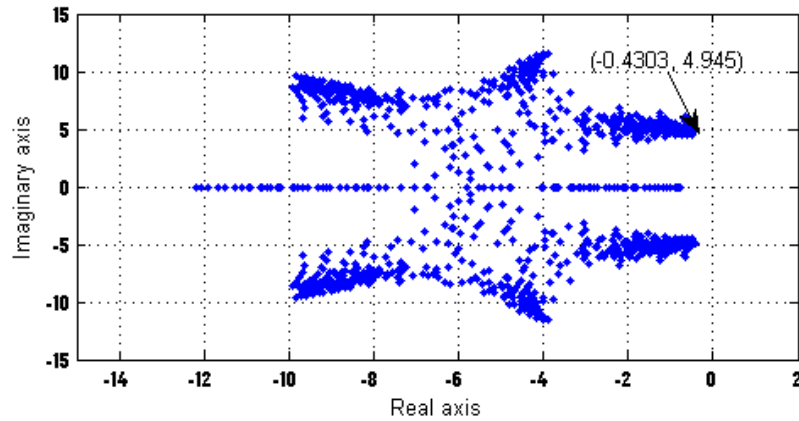
$$a_i = [a_5 \ a_4 \ a_3 \ a_2 \ a_1 \ a_0] = [1 \ 21.1 \ (170.6s^2 + 44.3k_d) \ (1102.3 + 44.3k_p) \ (4371 + 44.3k_i)] \quad (9)$$

Step4: Choose the stability indices according to the CDM standard form Eq. (6)

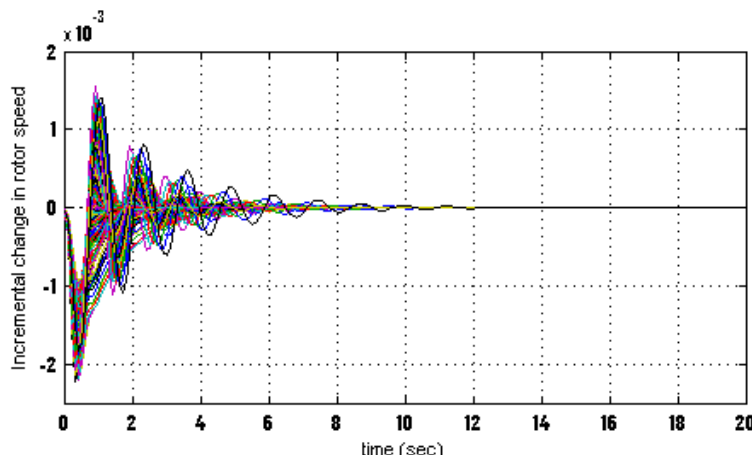
As we have taken  $\gamma_1$  from standard form, stability conditions are satisfied,  $\gamma_2 > \gamma_2^*$

Or from R-H criterion  $a_2 > \left(\frac{a_1}{a_3}\right) a_4 + \left(\frac{a_3}{a_1}\right) a_0$  is also satisfied.

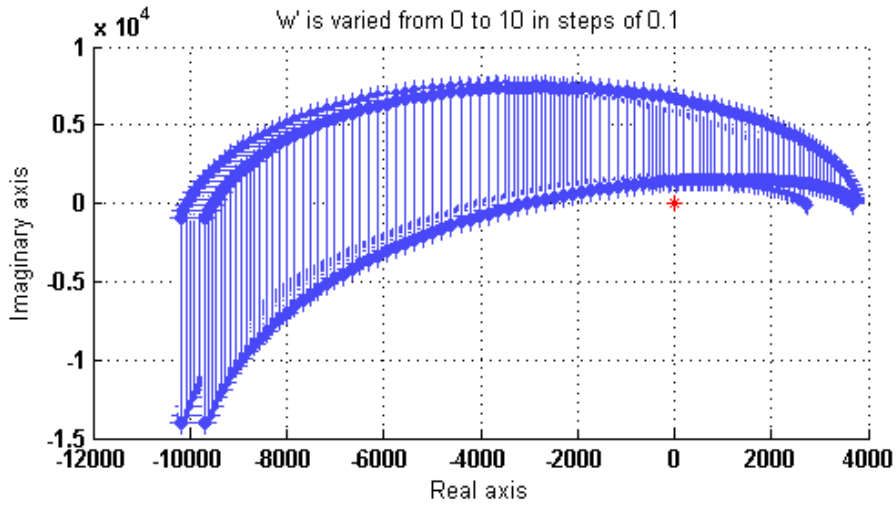
Step5: From equations (4), (6) & (9),  $k_d=1.1916$ ,  $k_p = 1.7636$ ,  $k_i = -42.3410$ .



**Fig.4a.:** Closed-loop poles location. Most dominant pole at -0.43, minimum damping ratio offered 5o.



**Fig. 4b:** Closed loop system response to a 5% disturbance step at all 336 operating points with  $k_d = 1.1916$ ,  $k_p = 1.7636$ ,  $k_i = -42.3410$ .



**Fig. 4c:** The Kharitonov Rectangles satisfying zero exclusion condition.

The interval characteristic polynomial of the closed loop system becomes:

$$G_{\text{interval}}^1 = [1,1]s^4 + [20.66, 21.13]s^3 + [229.22, 233.84]s^2 + [708.82, 1974.81]s + [2726.75, 3686.83].$$

For this values of  $k_d$ ,  $k_p$ , and  $k_i$  closed loop poles location, closed-loop system response to 5% disturbance step, and Kharitonov rectangles are shown in figures 4a, 4b and 4c respectively

The heavy loading condition,  $P=1.0$ ,  $Q=0.5$ ,  $X=0.7$  be the nominal operating point

$$G_{\text{heavy}}(s) = \frac{-37.23s}{s^4 + 20.66s^3 + 168.69s^2 + 569.62s + 5798.4}$$

Repeating steps 2 to 5, we finally obtain:  $k_d=1.2020$ ,  $k_p=14.3134$ ,  $k_i=-94.5537$ .

By observing the pole locations in Fig.5, we can say that the controller designed with nominal operating condition as heavy loading condition is not robust. It was already mentioned that CDM does not always guarantee robustness. To get the flexibility in choosing any operating point as our nominal operating condition, we include a pre-filter (Eq. 2) and search for the unknown parameters  $a$  &  $b$  by using GA such that the stability indices (standard CDM) are  $[2 \ 2 \ \dots \ 2.5]$ .

This will give the robustness if the pole-zero pair is properly tuned. Out of 336 operating points we can choose anyone as the nominal operating point for designing the controller and we can attain robustness by proper tuning of pre-filter.



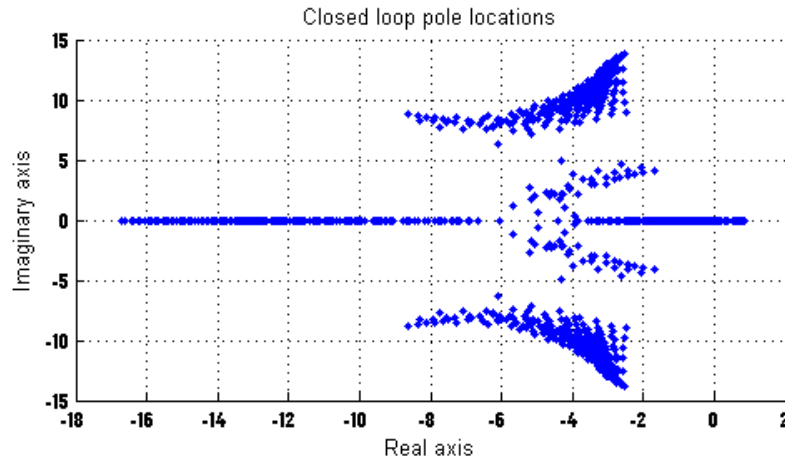


Fig. 5: Closed-loop poles location shows that the controller is not robustly stable.

#### 4.2 Fitness calculation for GA

1. Using the nominal transfer function (with no perturbations), for a particular value of a and b (supplied by GA) find the values of  $k_d$ ,  $k_p$  &  $k_i$  by using equations (4), (6) and characteristic polynomial. Find the roots of closed loop characteristic polynomial
2. By making perturbation in P, Q and X obtain the open loop transfer function from equations mentioned in appendix. Find the closed loop transfer function, with the same controller designed at nominal operating point, which gives perturbed pole locations.
3. Using the pole coloring technique, calculate the distance between the corresponding nominal poles and the perturbed poles let sum of the distances be  $d_{ij}$  (distance corresponding to  $i^{\text{th}}$  perturbation and  $j^{\text{th}}$  iteration)
4. Repeat the steps 2 & 3 for 336 times, add all

$$d'_{ij}, D_j = \sum_{i=1}^{336} d_{ij}, (D_j \text{ is to be minimised}).$$

#### 4.3 Robust PSS (PID and a pre-filter)

Step1: Let the heavy loading condition  $P=1.0$ ,  $Q=0.5$ ,  $X=0.7$ , be the nominal operating point

$$G_{heavy}(s) = \frac{-37.23s}{s^4 + 20.66s^3 + 168.69s^2 + 569.62s + 5798.4}$$

Step2: Choose controller to be designed as in Eq. (2)

Step3: Obtain closed-loop Characteristic polynomial coefficients:

$$\begin{aligned} a_5 &= 1; \\ a_4 &= 20.66 + b; \\ a_3 &= 20.66b + 168.69 + 37.23k_d \end{aligned}$$

$$a_2 = 168.69b + 569.62 + 37.23ak_d + 37.23k_p$$

$$a_1 = 569.62b + 5798.4 + 37.23ak_p + 37.23k_i$$

$$a_0 = 5798.4b + 37.23ak_i$$

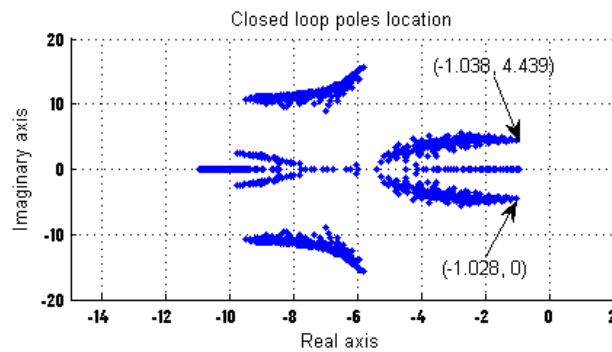
Step4: Choose the stability indices according to the standard CDM as in Eq. (6)

Step5: From equations (4), (6) and step3, we can get the values of  $k_d$ ,  $k_p$  &  $k_i$ , for every given values of  $a$  and  $b$ . Using GA tune  $a$  and  $b$  by minimizing  $D_j$ .

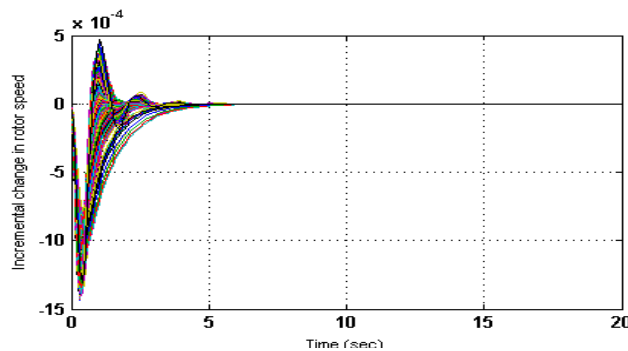
$$k_d = 2.93, k_p = 15.54, k_i = -36.23, a = 9.51, b = 11.36.$$

The interval characteristic polynomial of the closed loop system becomes:

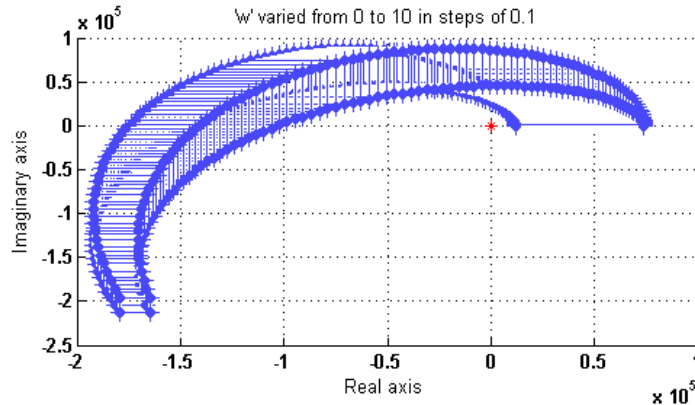
$$G_{\text{interval}}^I = [1, 1]s^5 + [32.02, 32.49]s^4 + [502.97, 605.57]s^3 + [5123.73, 5645.31]s^2 + [19024.95, 31328.33]s + [12350.93, 74198.11].$$



**Fig. 6a:** Closed-loop poles location. Most dominant pole is at -1.028, minimum damping ratio offered is 13.160.



**Fig. 6b:** Closed loop system response to a 5% disturbance step at all 336 operating points with  $k_d = 2.93$ ,  $k_p = 15.54$ ,  $k_i = -36.23$ ,  $a = 9.51$ ,  $b = 11.36$ .



**Fig.6c:** The Kharitonov Rectangles satisfying zero exclusion condition

In table-1 we can find robust PSS designed at different operating points (light, average, heavy and worst loading conditions) as our nominal operating condition, which are satisfying all the closed loop requirements as mentioned in the problem.

**Table 1:** Robust PSS Designed by Choosing Different Operating Points as Nominal Operating Conditions

Loading Condition: [P,Q,X]	PSS [k <sub>d</sub> , k <sub>p</sub> , k <sub>i</sub> , a, b]	Most Dominant Pole	Min. Damping Ratio (factor)
Light: [0.4, -0.2, 0.2]	[3.58, 20.75, -42.75, 7.41, 14.54]	-0.77	9.67° (0.17)
Average: [0.7, 0.15, 0.45]	[3.08, 15.60, -61.17, 7.66, 14.66]	-0.67	8.57° (0.15)
Heavy: [1.0, 0.5, 0.7]	[2.93, 15.54, -36.23, 9.51, 11.36]	-1.03	13.16° (0.23)
Worst: [1.0, 0.0, 0.7]	[3.18, 6.33, -45.38, 10.81, 12.15]	-0.71	9.61° (0.17)

In all the cases most dominant pole is always less than -0.5, and the minimum damping factor offered is always greater than 0.1. Thus the performance requirements are achieved.

### 5. Conclusions

The resultant controller is: Implementable, Low Order, All Stabilizing and Robust. Only output feedback is used and all given closed loop specifications are satisfied.

Using CDM and GA robust PSS can be designed by choosing any operating point (in the specified range) as our nominal operating condition. The method is flexible to

choose nominal operating point, where the plant is running most of the time, at which we desire better performance.

## 6. Appendix

### 6.1 Open loop state space representation:

The state equation of a single machine connected with infinite bus (SMIB) system may be derived from the linearized transfer function model (Fig.2) as:

$$\dot{x} = Ax + bu$$

$$\Delta\omega = c_1x$$

$$\Delta V_t = c_2x$$

Where,

$$A = \begin{bmatrix} 0 & \omega_r & 0 & 0 \\ -\frac{k_1}{2H} & -\frac{D}{2H} & -\frac{k_2}{2H} & 0 \\ -\frac{k_4}{\tau'_{d0}} & 0 & -\frac{1}{k_3\tau'_{d0}} & \frac{1}{\tau'_{d0}} \\ -\frac{K_a k_5}{T_a} & 0 & -\frac{K_a k_6}{T_a} & -\frac{1}{T_a} \end{bmatrix}$$

$$b = \left[ 0 \quad 0 \quad 0 \quad \frac{K_a}{T_a} \right]^t$$

$$c_1 = [0 \quad 1 \quad 0 \quad 0]$$

$$c_2 = [k_5 \quad 0 \quad k_6 \quad 0]$$

State vector  $x$  is defined as,  $x = [\Delta\delta \quad \Delta\omega \quad \Delta E'_q \quad \Delta E_{fd}]^t$

Where  $\Delta\delta$ ,  $\Delta\omega$ ,  $\Delta E'_q$  and  $\Delta E_{fd}$  are the incremental changes in rotor speed, rotor angle, voltage proportional to field flux linkage and field voltage respectively.  $k_i$ ,  $i=1, 2, \dots, 6$  are the k-parameters whose value depends on the operating conditions.

### 6.2 Equations for k-parameters [7]

$$k_1 = K_t V_\infty \left[ E_{qa} \{ R_e \sin(\delta - \alpha) + (X_e + x'_d) \cos(\delta - \alpha) \} \right. \\ \left. + I_q (x_q - x'_d) \{ (X_e + x_q) \sin(\delta - \alpha) - R_e \cos(\delta - \alpha) \} \right]$$

$$k_2 = K_t \left\{ R_e E_{qa} + I_q \left( R_e^2 + (X_e + x_q)^2 \right) \right\}$$

$$k_3 = \left( 1 + \left( K_t (x_q - x'_d) (X_e + x_q) \right) \right)^{-1}$$

$$k_4 = K_t V_\infty (x_d - x'_d) \{ (X_e + x_q) \sin(\delta - \alpha) - R_e \cos(\delta - \alpha) \}$$

$$k_5 = \frac{K_t V_\infty}{V_t} [V_q x'_d \{R_e \cos(\delta - \alpha) - (X_e + x_q) \sin(\delta - \alpha)\} - V_d x_q \{R_e \sin(\delta - \alpha) + (X_e + x'_d) \cos(\delta - \alpha)\}]$$

$$k_6 = \frac{V_q}{V_t} (1 - K_t (X_e + x_q) x'_d) - \frac{K_t V_d}{V_t} R_e x_q$$

Where

$$K_t = \frac{1}{R_e^2 + (X_e + x'_d)(X_e + x_q)}$$

System parameter values [2]

**Table 2:** System Parameters.

$H$	$\omega_r$	$K_a$	$T_a$	$R_e$	$r$	$\Delta V_t$	$D$
3.25	314.15	50	0.05	0	0	1	0
$x_d$	$x_q$	$x'_d$	$\tau'_{d0}$				
2.0	1.91	0.224	4.18				

## References

- [1] Keel, L.H. and Bhattacharyya, S.P., “Robust, Fragile or Optimal?” *IEEE Trans. Automat. Contr.*, vol. 42, no. 8, pp 1098-1105, August 1997.
- [2] Herbert Werner, Petr Korba, and Tai Chen Yang., “Robust Tuning of Power System Stabilizers Using LMI-Techniques”, *IEEE Trans. On Control Systems Technology*, vol.11, no.1, January 2003.
- [3] S. Manabe. “The Coefficient Diagram Method”, *The 4<sup>th</sup> IFAC Symposium on Automatic Cont. in Aerospace*, Seoul, Korea, pp. 199-210, Aug. 1998.
- [4] M. T. Soylemez and N Munro, Robust Pole assignment in uncertain systems, *Proc. IEE: Control Theory and Applications*, 144(3), pp 217-224.
- [5] Barmish, B. R., “*New Tools for Robustness of Linear Systems*”, Macmillan Publishing Company, New York, 1994.
- [6] Heffron, W. G. and Philips, R. A., “Effect of a modern amplidyne voltage regulator on under-excited operation of large turbine generators”, *AIEE Transactions*, 71: 692-697, 1972.
- [7] Anderson, P.M and Fouad, A.A., “*Power system control and stability*”, Second Edition, A Wiley InterScience Publication, John Wiley and Sons Inc.
- [8] Rao, P.S. and Sen, I., “Robust tuning of power system stabilizers using QFT”, *IEEE Trans. Control Systems Technology*, vol. 7, no. 4, pp. 478-486, July 1999.

- [9] T.K Sunil Kumar and Jayanta Pal., “Robust tuning of power system stabilizers using Optimization Techniques”, *IEEE international Conference*, pages: 1143-1148, on 12-17 Dec 2006.
- [10] E.V. Larsen and D. A Swann, “Applying power system stabilizers (three parts),” *IEEE Trans. Power Apparatus Syst.*, vol. PAS-100, pp. 3017-3046, 1981.