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Design of Firefly Based Power System Stabilizer Based on Pseudo Spectrum Analysis

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Abstract: To improve the dynamic stability of power systems, by increasing the damping torque of the synchronous machine, it is necessary to use the power system stabilizers to enhance the damping during low frequency oscillations. In this article, an attempt has been made to design the parameters of power system stabilizer by using the Firefly Algorithm applied to the single machine infinite bus system to an amenable form. The stability enhancement has been compared with Genetic Algorithm stabilizer for different operating conditions. The results show that the designed power system stabilizer based on Firefly Algorithm gives a good dynamic response when compared to Genetic Algorithm power system stabilizer. The Pseudo Spectrum analysis is also presented which is evident about the enhanced stability of the system with the proposed Algorithm.

Key words: Power system stabilizer (PSS), Firefly Algorithm (FFY), Genetic Algorithm (GA), dynamic response of power systems, Pseudo Spectrum Analysis, single machine infinite bus.

1. Introduction

The stability of synchronous machine's operation has received a great deal of attention in the past and will also receive importance in the future. For economic system design with larger unit sizes and higher per unit reactance generating and transmission equipment designs, more emphasis and reliance is being placed on controls to provide the required compensating effects with which to offset the reductions in stability margins inherent from these trends in the design of the equipment [1,2,4]. In concurrent with these trends over the years considerable efforts have been placed on the enhancement of the dynamic stability of power systems. The modern voltage regulators and excitation systems with high speed response and high ceiling voltage can be used to improve the transient stability by increasing the synchronizing torque of the machine and their effects on the damping torque are rather small.

In the cases where the system operates with negative damping characteristics the voltage regulator usually improves the situation by increasing the negative damping and hence instability may result in the system [1- 3].

To reduce this undesirable effect and to improve the system dynamic performance it is useful to introduce additional stabilizing signals to increase the damping torque of the synchronous machine. Several approaches have reported in the literature to provide the required damping torque for improving the dynamic stability. One of the approaches is conventional power system stabilizer a lead/lag network using the speed or power as input to generate an additional stabilizing signal [4-6] is employed and its parameters were designed by using different techniques, another is to employ a linear optimal stabilizer using the theory of linear optimal regulators [7-12] and so on.

The power system is highly complex and non linear with finite number of plants which resembles continuously changing operating conditions. The conventional PSS which is designed at a particular operating point cannot successfully damp out the low frequency oscillations under wide range of operating conditions.

Literature [13, 14, 15, 25] shows that the power system stabilizers designed based on the evolutionary techniques like GA, BFOA, ACO, PSO etc. can guarantee the better performance in improving the dynamic stability of the system.

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Genetic algorithm, a parameter search technique, utilizes the genetic operators to find near optimal solutions [25]. The firefly algorithm is also used to find the parameters of the power system stabilizer. For different loading conditions the stability of the system is guaranteed if the power system stabilizers are designed by using the firefly algorithm. However, the genetic algorithm based design of power system stabilizers will only perform well for some operating points. The system considered for the study is a single machine connected to infinite bus and lag/lead type power system stabilizer.

The dynamic stability [23] of the system has been tested for multi operating conditions from normal to heavy loading by using the two approaches conditions and the results are compared.

2. System Model

The line diagram for the single machine connected to infinite bus system is shown in Figure.1. The linearised model of this system including the voltage regulator and exciter is shown in Figure. 2 [4,5,6,18]. The linearised incremental model of this system may be found in references [12,19,20,21,22]. The linearised equations for the given linearized incremental model of synchronous machine (Figure.2) with an exciter and stabilizer are as follows:

$$\Delta V_t = K_5 \Delta\delta + K_6 \Delta e_q' \tag{1}$$

$$\Delta\omega = \frac{1}{Ms} - \Delta T_e \tag{2}$$

$$\Delta T_e = k_2 \Delta e_q' + k_1 \Delta\delta \tag{3}$$

$$\Delta e_{FD} = \frac{K_A}{1+sT_A}\left(\Delta V_{REF} - \Delta V_F + U - \Delta V_t\right) \tag{4}$$

$$\Delta V_F = \frac{sK_F}{1+sT_F}\Delta e_{FD} \tag{5}$$

$$\Delta V_S = K_s \frac{1+sT_1}{1+sT_2}\Delta\omega \tag{6}$$

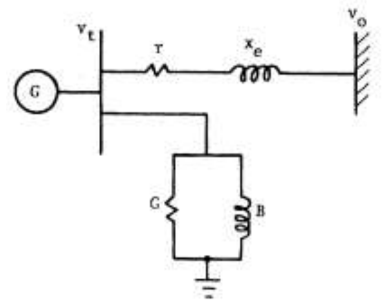

Figure 1. line diagram for single machine connected to infinite bus

3. Power System Stabilizer [16,17]

The stabilization problem is to design a stabilizer which provides an additional stabilizing signal to increase the damping torque of the system. The design of parameters of power system stabilizer is based on the genetic algorithm and firefly algorithms. To formulate the problem using search algorithm, a set of parameters will be first selected. Considering a lead circuit, the transfer function of the power system stabilizer is given as:

$$G_p(s) = \frac{K_s(1+sT_1)}{(1+sT_2)} \tag{7}$$

4. Proposed Method

The tuning of the parameters of a power system stabilizer for different operating points means that power system stabiliser must stabilize the family of N number of plants:

$$\dot{x} = A_k x + B_k u \text{ where } k = 1,2 ,..., N \qquad (8)$$

where $x(t) \in R^n$ is the state vector and $u(t)$ is thecontrolling signal. The necessary condition for the set of plants in equation (7) to be simultaneously
operated with the stabilizing signal is that Eigen values of the closed-loop system lie in the left side of the complex s-plane.

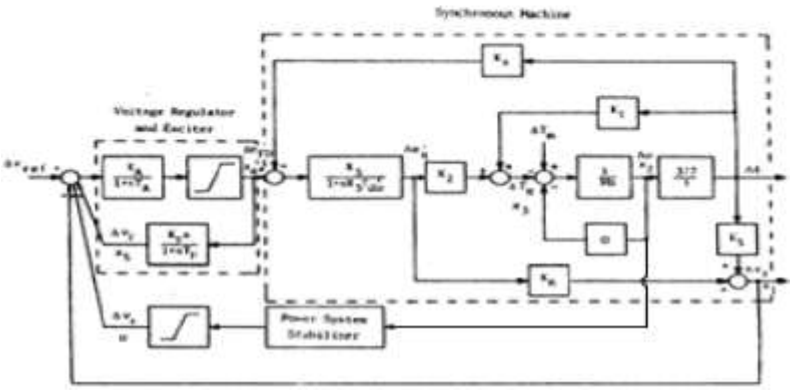

Figure 2. Linearised model of synchronous machine with an exciter and stabilizer.

From this condition the following approach for determining the parameters K_s and T_1 *and* T_2 of the power system stabilizer is proposed.

The fitness function for selection of K_s, T_1 and T_2 is

$$J = \max \mathrm{Re}(\lambda_{k,i}),\ k = 1 ,..., N,\ ,i = 1 ,..., N \qquad (8)$$

where $\lambda_{k,i}$ is the i^{th} closed-loop eigen value of the k^{th} plant. The resulting parameters of the stabilizer K_s, T_1 and T_2 by using firefly algorithm will stabilize the collection of plants. The existence of a solution is verified numerically by minimizing J. The optimization problem is solved accurately by using genetic algorithms [25] and firefly algorithms.

5. Genetic Algorithm

Genetic algorithm is an optimization approach is based on the mechanics of natural selection and natural genetics. The search procedure is similar to the natural revolution of biological creature in which successive generations of organisms are given birth and raised until they are able to breed. Only the fittest organisms will survive to reproduce while the weakest organisms will be eliminated [25]. The basic process of Genetic Algorithm is summarized in Figure 3.

6. Fire Fly Algorithm

The flashing light of fireflies in the summer sky in the tropical regions is the key process. There are about two thousand firefly species and most of the fireflies produce short flashes. The pattern of flashes is unique for a particular species. The flashing light is produced by a process of bioluminescence. Two fundamental functions of flashes are to attract mating partners and to attract potential prey[24].

The flashing light can be formulated in such a way that it is associated with objective function to be optimized, which makes it possible to formulate new optimization algorithms. The brightness of a firefly is determined by landscape of the objective function.

6.Case study

The single machine infinite bus system is considered with following data represented in the 'K' constants as [12]:

K_1= 0.55	K_A= 130	D = 0
K_2= 1.16	T_A= 0.05	$e_{FD,MAX}$ = 7.3
K_3= 0.66	T'_{do}= 0.05	$e_{FD,MIN}$ = -7.3
K_4= 0.67	M = 9.26	u_{MAX} = 0.12
K_5= -0.09	K_F= 0.03	u_{MIN} = -0.12
K_6= 0.82	T_F= 1.0	

The corresponding state equations can be written in the form

$$\dot{x} = Ax + Bu \tag{9}$$

where $x = [\Delta V_t \;\; \Delta\omega \; \Delta T_e \;\; \Delta e_{FD} \;\; \Delta V_F]^T$ (10)

is the state vector.

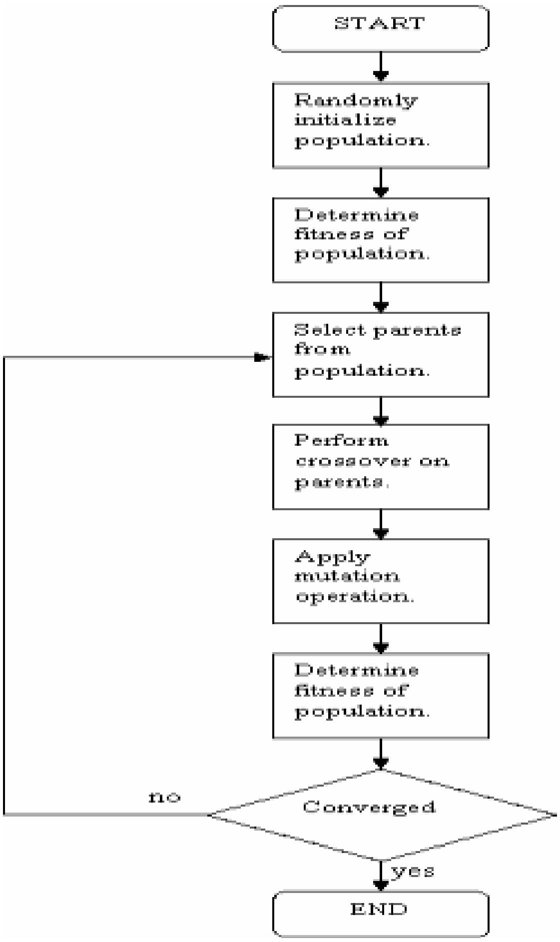

Figure 3. Genetic Algorithm flowchart

$$A = \begin{bmatrix} -0.0108 & -33.93 & -0.1305 & 0.1057 & 0 \\ 0 & 0 & -0.108 & 0 & 0 \\ -0.0153 & 207.35 & -0.1846 & 0.1495 & 0 \\ -2600 & 0 & 0 & -20 & -2600 \\ -78 & 0 & 0 & -0.6 & -79 \end{bmatrix}$$

$$B = [0 \quad 0 \quad 0 \quad 2600 \quad 78]^T$$

With power system stabiliser state equations are written in the form by increasing the size from 5x5 to 7x7.

$$\dot{x} = A_k x + B_k u$$

$$A_k = \begin{bmatrix} -0.0108 & -33.93 & -0.1305 & -0.105 & 0 & 0 \\ 0 & 0 & -0.107 & 0 & 0 & 0 \\ -0.015 & 207.35 & -0.184 & 0.149 & 0 & 0 \\ -2600 & 0 & 0 & -20 & -2600 & 2600 \\ -78 & 0 & 0 & -0.6 & -79 & 78 \\ 0 & \frac{K_s}{T_2} & \frac{-0.107*T_1}{T_2} & 0 & 0 & \frac{-1}{T_2} \end{bmatrix}$$

$$B_k = [0 \quad 0 \quad 0 \quad 2600 \quad 78 \quad 2600]^T$$

The variables Ks, T_1 and T_2 are determined using proposed method and Genetic Algorithm approach . The results are compared.

For the Genetic Algorithm approach the population size is considered as 20, the length of each chromosome is 46 and the number of generations is 100.

For the Firefly Algorithm approach 3500 generations are run to get the fittest power system stabilizer parameters.

The designed parameter values of power system stabilizer are as follows:

GA PSS	K_s=6.61	T_1=7.54	T_2=0.08
FF PSS	K_s= 15.11	T_1=0.985	T_2=0.06

The stability of the considered system for various operating conditions from the light load conditions to the heavy load conditions is tested by observing the Eigen values of the system. The Eigen values of the system are analyzed by using the pseudo spectrum analysis and are presented for two operating conditions 0.5+j0 and 1-j0.5 in listed in table 1 and table 2 respectively.

Table 1. Eigen values for the operating condition 0.5+j0

Without PSS	With GA PSS	With FFY PSS
-95.78+.000i	-95.99 + 0.00i	-96.62+ 0.00i
0.006+ 4.90i	-15.40+ 0.00i	-8.07+ 0.00i
0.006- 4.90i	-0.46+ 4.90i	-2.45+ 3.68i
-1.71+ 0.44i	-0.46- 4.90i	-2.45- 3.68i
-1.71- 0.44i	-1.76+ 0.45i	-4.53+ 0.00i
----	-1.76- 0.45i	-1.70+ 0.00i
----	-0.50+0.00i	-0.50+ 0.00i

Table 2. Eigen values for the operating condition 1-j0.5

Without PSS	With GA PSS	With FFY PSS
-96.13+ 0.00i	-96.54+ 0.00i	-97.76+0.00i
0.07+ 5.88i	-14.17+ 0.00i	-6.27+ 9.63i
0.07- 5.88i	-0.92+ 6.04i	-6.27- 9.63i
-1.60+ 0.67i	-0.92- 6.04i	-1.77+ 1.80i
-1.60- 0.67i	-1.64+ 0.73i	-1.77- 1.80i
----	-1.64-0.73i	-1.97+ 0.00i
----	-0.50+ 0.00i	-0.50+ 0.00i

From Figure 4 to Figure.6 the pseudo spectrum analysis of the Eigen values for the operating condition 0.5+j0 has been presented and from the Figure. 7 to Figure.8 the pseudo spectrum analysis of the Eigen values for the operating condition 1-j0.5 has been presented.

It is observed that the Eigen values of the both the operating conditions assured more stability for the firefly based PSS design and the Eigen values of the ten operating conditions are also analyzed similarly and tabulated in table 3.

Table 3. Eigen values for the ten operating conditions varying from light load to heavy load

S.No	Operating point	Without PSS	With GA PSS	With FFY PSS
01	0.1+j0	-95.7492 + 0.0000i -0.0122 + 4.8729i -0.0122 - 4.8729i -1.7111 + 0.3972i -1.7111 - 0.3972i	-95.8244 + 0.0000i -16.2266 + 0.0000i -0.1764 + 4.8786i -0.1764 - 4.8786i -1.7288 + 0.3991i -1.7288 - 0.3991i -0.5012 + 0.0000i	-96.0556 + 0.0000i -14.6648 + 0.0000i -0.7135 + 4.7821i -0.7135 - 4.7821i -1.8562 + 0.2960i -1.8562 - 0.2960i -0.5025 + 0.0000i
02	0.1+j0.1	-95.7495 + 0.0000i -0.0128 + 4.6781i -0.0128 - 4.6781i -1.7103 + 0.3981i -1.7103 - 0.3981i	-95.8251 + 0.0000i -16.2212 + 0.0000i -0.1779 + 4.6796i -0.1779 - 4.6796i -1.7295 + 0.4002i -1.7295 - 0.4002i -0.5013 + 0.0000i	-96.0576 + 0.0000i -14.6350 + 0.0000i -0.7134 + 4.5606i -0.7134 - 4.5606i -1.8701 + 0.2808i -1.8701 - 0.2808i -0.5027 + 0.0000i
03	0.5+j0	-95.7877 + 0.0000i 0.0069 + 4.9021i 0.0069 - 4.9021i -1.7109 + 0.4451i -1.7109 - 0.4451i	-95.9956 + 0.0000i -15.4024 + 0.0000i -0.4675 + 4.9075i -0.4675 - 4.9075i -1.7631 + 0.4555i -1.7631 - 0.4555i -0.5031 + 0.0000i	-96.6269 + 0.0000i -8.0772 + 0.0000i -2.4526 + 3.6811i -2.4526 - 3.6811i -4.5395 + 0.0000i -1.7068 + 0.0000i -0.5067 + 0.0000i
04	0.5-j0.2	-95.8019 + 0.0000i -0.0164 + 5.2525i -0.0164 - 5.2525i -1.6805 + 0.4976i -1.6805 - 0.4976i	-96.0227 + 0.0000i -15.3391 + 0.0000i -0.5250 + 5.2847i -0.5250 - 5.2847i -1.7238 + 0.5162i -1.7238 - 0.5162i -0.5030 + 0.0000i	-96.6926 + 0.0000i -7.6594 + 0.0000i -3.0781 + 4.3037i -3.0781 - 4.3037i -3.5134 + 0.0000i -1.8343 + 0.0000i -0.5063 + 0.0000i
05	0.5+j0.5	-95.7671 + 0.0000i 0.0781 + 3.3111i 0.0781 - 3.3111i -1.7924 + 0.2398i -1.7924 - 0.2398i	-95.9537 + 0.0000i -15.4753 + 0.0000i -0.2991 + 3.2079i -0.2991 - 3.2079i -1.9146 + 0.0773i -1.9146 - 0.0773i -0.5059 + 0.0000i	-96.5214 + 0.0000i -8.1291 + 2.0833i -8.1291 - 2.0833i -0.7926 + 2.2148i -0.7926 - 2.2148i -0.5124 + 0.0000i -1.4853 + 0.0000i
06	0.7+j0.3	-95.8164 + 0.0000i 0.1255 + 4.0543i 0.1255 - 4.0543i -1.8151 + 0.2295i -1.8151 - 0.2295i	-96.0643 + 0.0000i -15.0842 + 0.0000i -0.4129 + 3.9735i -0.4129 - 3.9735i -2.0078 + 0.0000i	-96.8145 + 0.0000i -7.6232 + 5.0174i -7.6232 - 5.0174i -1.1453 + 2.4097i -1.1453 - 2.4097i

			-1.8752 + 0.0000i -0.5051 + 0.0000i	-0.5108 + 0.0000i -1.5000 + 0.0000i
07	1+j0	-95.9685 + 0.0000i 0.2165 + 4.8365i 0.2165 - 4.8365i -1.8301 + 0.2910i -1.8301 - 0.2910i	-96.3168 + 0.0000i -14.4386 + 0.0000i -0.5809 + 4.8077i -0.5809 - 4.8077i -0.5049 + 0.0000i -1.9701 + 0.1676i -1.9701 - 0.1676i	-97.3617 + 0.0000i -7.1145 + 8.0000i -7.1145 - 8.0000i -1.3664 + 2.3513i -1.3664 - 2.3513i -0.5103 + 0.0000i -1.5284 + 0.0000i
08	0.952+j0.02	-95.9426 + 0.0000i 0.1888 + 4.8034i 0.1888 - 4.8034i -1.8154 + 0.3191i -1.8154 - 0.3191i	-96.2771 + 0.0000i -14.5345 + 0.0000i -0.5776 + 4.7743i -0.5776 - 4.7743i -0.5048 + 0.0000i -1.9453 + 0.2411i -1.9453 - 0.2411i	-97.2817 + 0.0000i -7.1156 + 7.6513i -7.1156 - 7.6513i -1.4004 + 2.3599i -1.4004 - 2.3599i -0.5101 + 0.0000i -1.5386 + 0.0000i
09	1+j0.2	-95.9275 + 0.0000i 0.2981 + 4.2484i 0.2981 - 4.2484i -2.2757 + 0.0000i -1.5887 + 0.0000i	-96.2577 + 0.0000i -14.5025 + 0.0000i -0.4030 + 4.1471i -0.4030 - 4.1471i -2.7146 + 0.0000i -0.5056 + 0.0000i -1.5758 + 0.0000i	-97.2496 + 0.0000i -7.5833 + 7.5519i -7.5833 - 7.5519i -1.0015 + 2.3279i -1.0015 - 2.3279i -0.5120 + 0.0000i -1.4314 + 0.0000i
10	1-j0.5	-96.1343 + 0.0000i 0.0717 + 5.8809i 0.0717 - 5.8809i -1.6024 + 0.6732i -1.6024 - 0.6732i	-96.5433 + 0.0000i -14.1761 + 0.0000i -0.9227 + 6.0410i -0.9227 - 6.0410i -1.6466 + 0.7322i -1.6466 - 0.7322i -0.5044 + 0.0000i	-97.7640 + 0.0000i -6.2787 + 9.6356i -6.2787 - 9.6356i -1.7759 + 1.8074i -1.7759 - 1.8074i -1.9799 + 0.0000i -0.5092 + 0.0000i

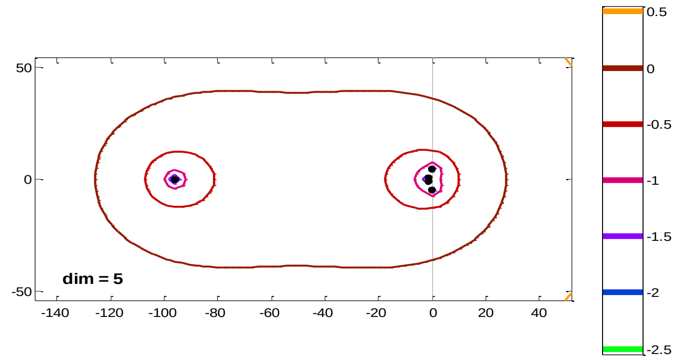

Figure 4. The pseudo spectrum representation without stabilizer for the operating point 0.5+j0

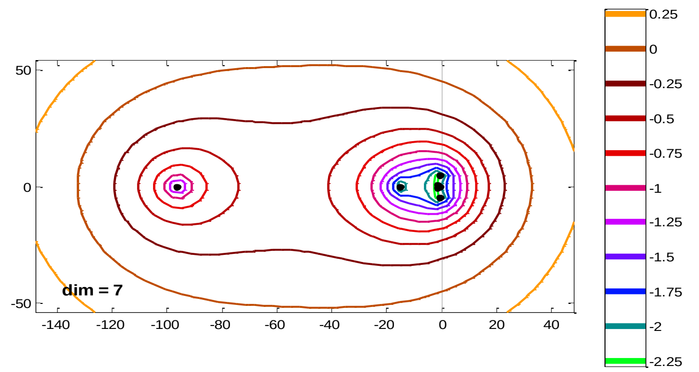

Figure 5. The pseudo spectrum representation with GA based stabilizer for the operating point 0.5+j0

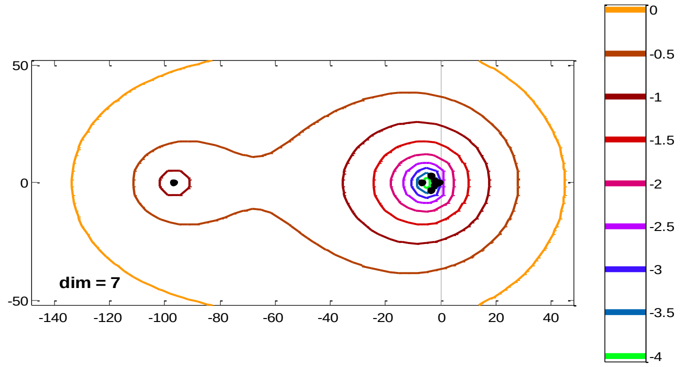

Figure 6. The pseudo spectrum representation with Firefly based stabilizer for the operating point 0.5+j0

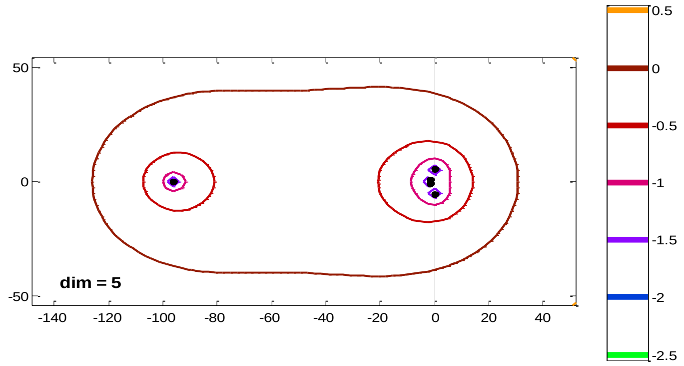

Figure 7. The pseudo spectrum representation without stabilizer for the operating point 1-j0.5

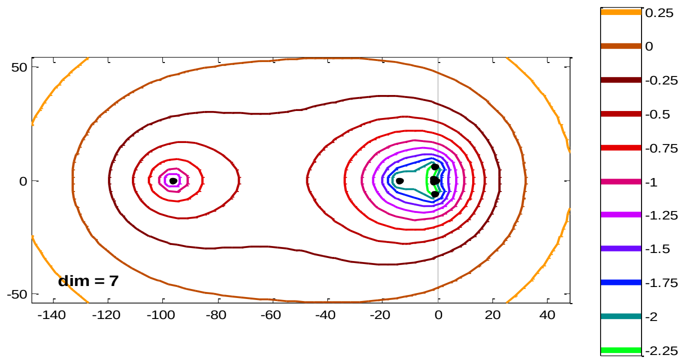

Figure 8. The pseudo spectrum representation with GA based stabilizer for the operating point 1-j0.5

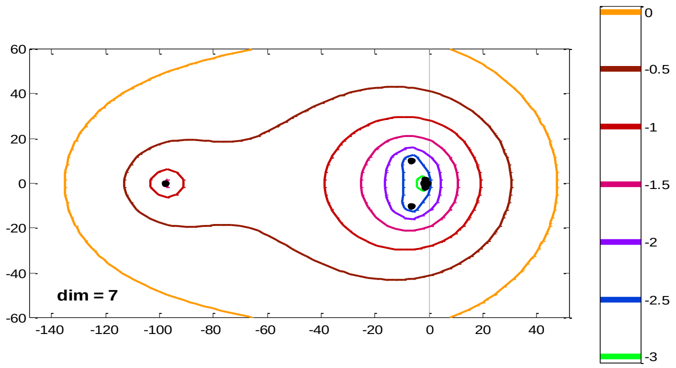

Figure 9. The pseudo spectrum representation with Firefly based stabilizer for the operating point 1-j0.5

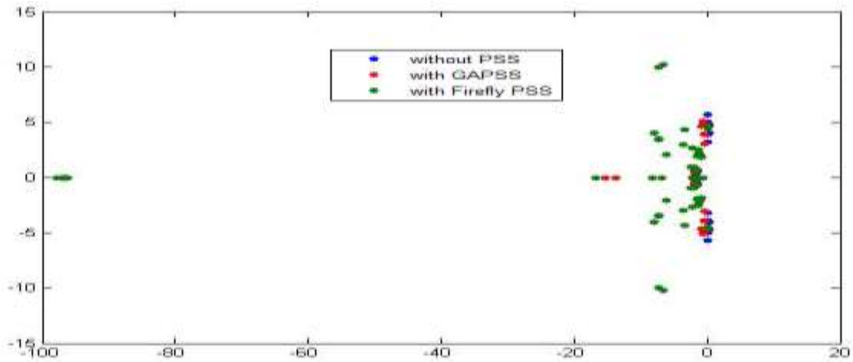

Figure 10. Representation of Eigen values in the S-plane without stabilizer, with GA based stabilizer and with Firefly based stabilizer for ten operating points.

From the results it is also observed that the performance of the proposed firefly based power system stabilizer gives the more stabilized Eigen values when compared with the genetic algorithm based power system stabilizer over wide range of operating conditions. Hence the dynamic stability of the synchronous machine is guaranteed for the more number of operating conditions by using the proposed power system stabilizer.

7. Conclusions

A novel technique for the design of parameters of power system stabilizer for single machine connected to infinite bus system has been proposed in this paper by using firefly algorithm approach. The results are compared with the genetic algorithm approach for the ten operating conditions include the light load and the heavy loading conditions. The results show that the designed parameters of power system stabilizer by using Firefly algorithm approach give a good dynamic stability when compared with the genetic algorithm approach.

Since it is independent design, subject to some conditions the proposed design approach can be extended to excitation systems with different dynamic characteristics. It is believed that from this analysis covering the conditions for the single machine case, the method can be extended for stabilizing machines in multimachine systems.

8. References

[1]. Abdul Mahabuba, AbdullahKhan "Identification of the Optimum Locations of Power System Stabilizers in a Multimachine Power System Using Second Order Eigenvalue Sensitivity Analysis" *Smart Grid and Renewable Energy*, 2013, 4, 35-42 Published Online February 2013.

[2]. Gurunath Gurrala, Graduate Student Member, IEEE, Indraneel Sen “Power System Stabilizers Design for Interconnected Power Systems” *IEEE transactions on power systems*, vol. 25, no. 2, may 2010.
[3]. Babaei, E.; Fac. of Electr. & Comput. Eng., Univ. of Tabriz, Tabriz, Iran; Galvani, S. ; Ahmadi Jirdehi, M. “Design of robust power system stabilizer based on PSO” Industrial Electronics & Applications, 2009. ISIEA 2009. *IEEE conference* (Volume: 1)pp325-330.
[4]. Vikhram, G.Y.R. ; Electr. & Electron. Eng., Thiagarajar Coll. of Eng., Madurai, India ; Latha, S. “Design of power system stabilizer for power system damping improvement using optimization based linear control design” *Power Electronics, Drives and Energy Systems (PEDES), 2012 IEEE International Conference* pp1-6.
[5]. F. P. Demello and C. Concordia, “Concepts of synchronous machine stability as affected by excitation control", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-88, pp.316-329, April 1969.
[6]. W. G. Heffron and R. A. Phillips, "Effect of modern amplidyne voltage regulators on underexcited operation of large turbine generators", *AIEE Transactions on Power Apparatus and Systems*, Vol. PAS-71, pp. 692-697, August 1952.
[7]. P. M. Anderson and A. A. Fouad, Power System Control and Stability, Chapter 8, Iowa State University Press, Ames, Iowa, 1977.
[8]. F.R. Schleif, H.D. Hunkins, G.E. Martin and E.E. Hattan, "Excitation control to improve power line stability", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-87, pp.1426-1434, June 1968.
[9]. P.L. Pandeno, A.N. Karas, K.R. Mc Clymontand W.Watson, "Effect of high-speed rectifier excitation systems on generator stability limits", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS- 87, pp. 190-201, January 1968.
[10]. F. R. Schleif, H.D. Hunkins, E. E. Hattan and W. B. Gish, "Control of rotating exciters for power system damping: Pilot applications and experience", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-88, pp. 1259-1266, August 1969.
[11]. Y. N. Yu, K. Vongsuriya and L. N.Wedman, "Application of an optimal control theory to a power system" *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-89, pp. 55-62, January 1970.
[12]. Y. N. Yu and C. Siggers, "Stabilization and optimal control signals for a power system", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-90, pp. 1469-1481, July/August 1971.
[13]. J. H. Anderson, "The control of a synchronous machine using optimal control theory", *Proc. EEE*, Vol.59, pp.25-35, January1971.
[14]. H. A. M. Moussa and Y. N. Yu, "Optimal power system stabilization through excitation and/or governor control", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-91, pp. 1166-1174, May/June 1972.
[15]. W.D. Humpage, J. R. Smith and G.J. Rogers, "Application of dynamic optimization to synchronous generator excitation controllers", *Proc IEE* Vol. 120, pp. 87-93, January 1973.
[16]. M. Hassan, 0. P. Malik, and G. S. Hope, “A fuzzy logic based stabilizer for a synchronous machine,” *IEEE Trans. EC*, vol. 6, no. 3, 1991, pp. 407-413.
[17]. A.B.Adbennonr and K.Lee, "A Decentralized Controller Design For a Power Plant Using Robust Local Controllers And Functional Mapping", *FEET-Energy Conversion*, Vol.11, No.2, pp. 394-400, June 1996.
[18]. D.E.Goldberg, "Genetic Algorithm in search, Optiiisation and Machine Learning", *Addison-Wesely, Reading MA*, 1989.
[19]. Y. N. Yu and H. A. M. Moussa, "Optimal Stabilization of a Multimachine System", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-91, pp.1174-1182, May/June 1972.

[20]. H.A.M. Moussa and Y. N. Yu, "Dynamic Interaction of Multi-Machine Power System and Excitation Control", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-93, pp. 1150-1158, July/ August 1974.
[21]. R. J. Fleming, M. A. Mohan and K. Parvatisam, "Selection of Parameters of Stabilizers in Multimachine Power Systems", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-100, pp.2329-2333, May 1981.
[22]. K.R. Padiyar, “Power System Dynamics Stability and Control", Second edition, BS Publications.
[23]. P.Kundur, “Power System Stability andcontrol”, Tata mecgrawhill, Text book.
[24]. Xin-She Yang “Nature-inspired Metaheuristic Algorithms” University of Cambridge, United Kingdom, Text book.
[25]. Mehran Rashidi, Farzan Rashidi, Hamid Moaavar, “Tuning of Power System Stabilizers via Genetic Algorithm for Stabilization of power Systems”, 2003 *IEEE Transactions* pp 4649-4654.

Nomenclature:
For the considered system:

A, A_K	System Matrices
B, B_K	Control Matrices
x	State Vector
u	Control Vector
K_s	Stabilizer gain
T_1, T_2	Phase compensator time constants

State Variables:

V_{ref}	Reference input voltage
V_T	Terminal Voltage
e_{FD}	Equivalent excitation voltage
e'_q	q-axis component of voltage behind transient reactance
V_F	Stabilizing transformer voltage
V_S	Stabilizer output
T_e	Energy conversion torque
T_M	Mechanical input
δ	Torque angle
ω	Angular velocity

System Parameters:

$r + jx_e$	Tie line impedance
G + jB	Terminal load admittance
K_A	Voltage regulator gain
T_A	Voltage regulator time constant
K_F	Stabilizing transformer gain
T_F	Stabilizing transformer time constant
K_1 to K_6	Constants of the linearised model of synchronous machine
T'_{d0}	d-axis transient open circuit time constant
M	Inertia coefficient, M = 2H
D	Damping coefficient

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