Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Fuzzy Gain Scheduling PI Controller Based PSS for SMIBS

Jayaudhaya J[1], S. Sandosh[2], I. Sundari[3], Ramash Kumar K[4*]

[1]*Department of Electronics and Communication Engineering, R.M.D. Engineering College, Chennai, India, jju.eee@rmd.ac.in*
[2]*School of Computer Science and Engineering, VIT Chennai Campus, India, sandosh.s@vit.ac.in*
[3]*Department of Electrical and Electronics Engineering, Rajiv Gandhi College of Engineering and Technology, Pondicherry, India, sunharsan@gmail.com*
[4*]*Department of Electrical and Electronics Engineering, Dr.N.G.P. Institute of Technology, Coimbatore, India, ramash1210@yahoo.co.in*

This article deals a new technique to improving performance of the Power System Stabilizers (PSS) with a Fuzzy Gain Scheduling Proportional Integral Controller (FGSPIC) in a Single Machine Infinite Bus System (SMIBS). SMIBS is chosen due to its simplicity, which aids in understanding the PSS's impact. The Conventional PSS (CPSS) often causes excessive damping and oscillations during both transient and dynamic operating conditions. To address this, an FGSPIC-based PSS is developed to enrich SMIBS transient and dynamic stability. The efficacy of controller is confirmed via computer simulations in MATLAB/Simulink, comparing its performance with that of a traditional proportional derivative controller (PDC) under various operating conditions. The results establish the greater enactment of the designed controller.

Keywords: PSS, FGSPIC, SMIBS, PD controller, MATLAB.

1. Introduction

The need for consistent power supply and the control of electro-mechanical oscillations in complex power systems have led to the development of power system stabilizers (PSS) since the mid-1940s. However, conventional PSS (CPSS) has shown limitations in addressing the complex and time-varying environment of power systems, which pose significant challenges to power engineers [1-2]. Power systems, being highly non-linear, repeatedly parade small frequency fluctuations owing to inadequate damping instigated by unfavorable operational situations that will lead to synchronism loss. PSS is crucial in mitigating these fluctuations and improving whole stability.

CPSS, entailing of lead-lag controls derived from linear models expressive the power system in specific working conditions, has been used to damp oscillations despite load disturbances

[3]. However, this linear model-based approach has not consistently delivered expected results across an extensive range of working conditions [4-5]. While Proportional integral (PI) control for PSS in power systems has been widely implemented, it may not achieve high performance and can become unstable during significant load variations [6-7].

Alternative approaches, such as the variable structure control for SMIBS, have been explored but have shown limitations in transient overshoot and dynamic performance [8-10]. SMC also requires extensive information on the model state, which can be challenging to obtain.

In contrast, the gain scheduling-based controller approach allows for rapid variation of controller parameters without the need for parameter evaluation [11-12]. This approach is relatively easy to implement compared to automatic tuning or parameter adaptation methods. However, inrush response can be unstable due to sharp changes in model parameters, and it is difficult to achieve accurate linear time-invariant models under discrete working conditions [13-15].

To address these challenges, a FGSPIC is designed in article for SMIBS. The FGSPIC aims to enhance dynamic and transient stability by designing rules for the proportional integral parameters. Computer simulations using MATLAB/Simulink are used to validate the controller's performance under different operating conditions, comparing it with conventional controllers.

2. Model of SMIBS

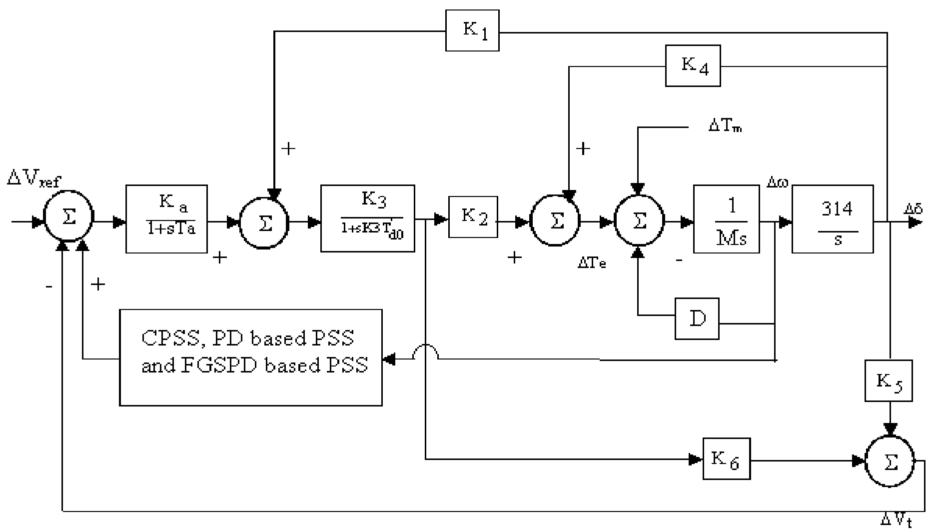


Fig. 1. Linearized model of SMIBS

In this study, a SMIBS is chosen for the performance analysis as shown in Fig.1. A machine connected to huge model via a transmission line will be abridged to a SMIBS through utilizing the equivalent of the transmission circuit (thevenin’s) exterior machine. On account of virtual size of the system to which the machine is generating power, diminuendos linked with machine will root almost no modification in the potential and frequency of the voltage (thevenin's) like endless bus voltage. The $Z_{th} = (R_e + jX_e)$. The machine is engraved as the 4th order model. The double axis machine illustration with a field network in the direct axis except refusal damper windings is well thought-out for the analysis. Mathematical expression representing constant mode functioning of a constant speed generator associated to an unlimited bus via an exterior reactance may be linearized on at all fussy working point has been reported in [1-2] and the final form of the model is engraved as (1)

$$\dot{X} = AX + BU \qquad (1)$$

Where,

$$X = [\ \Delta\delta\ \ \Delta\omega\ \ \Delta E_q'\ \ \Delta E_{fd}\ ]^T \qquad (2)$$

$$A=\begin{bmatrix} 0 & 314 & 0 & 0 \\ -D/M & -K_1/M & -K_2/M & 0 \\ -K_4 & 0 & -1/K_3T'_{do} & -1/T'_{do} \\ -(K_A/T_A)K_5 & 0 & -(K_A/T_A)K_6 & 1/T_A \end{bmatrix} \qquad (3)$$

$$B=\begin{bmatrix} 0 & 0 & 0 & \dfrac{K_A}{T_A} \end{bmatrix}^T \qquad (4)$$

(A – System matrix, B-control matrix, U-control signal or PSS output).

A. CPSS

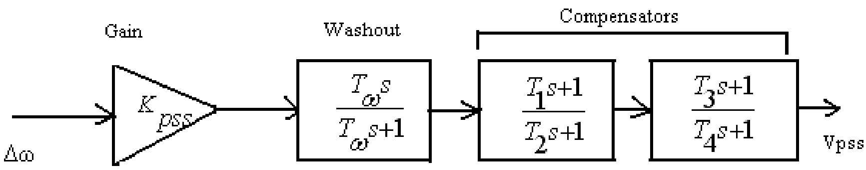


Fig. 2. Model of CPSS

Here, exciter considered only having K_A and T_A. Generally, model of the PSS consists of stabilizer gain (K_{PSS}), wasout function, and a phase compensator (lag/lead network) is depicted in Fig.2. The washout function perform identical a filter with T_w = 1 - 10 s, more adequate to pass signals allied with fluctuations in the input signals to permit unaffected. Compensators give the suitable phase lead to compensate for the phase lag amid the input and output signals. The traditional PSS is illustrate in fig. 2 and its corresponding transfer function can be expressed as (5)

$$V_{pss}(s) = K_{pss}\left(\frac{T_\omega s}{T_\omega s+1}\right).\left(\frac{T_1 s+1}{T_2 s+1}\right).\left(\frac{T_3 s+1}{T_4 s+1}\right).\ \Delta\omega \qquad (5)$$

In this paper design case, T_w=10s is pre-specified. The gain (K_{PSS}=7.4) and time constants (T_1=0.32s, T_2=0.105s, T_3=0.32s, and T_4=0.105s) are too computed. The PSS input signal is speed deviation (Δω) and output of the PSS is V_{PSS}.

B. Design PD based PSS

Fig. 3. Control block diagram of PD based PSS

A PD controller based PSS is used for providing the excellent damping oscillation of SMIBS as indicates in the Fig. 3. In this case, the PD controller based PSS output fix the V_{pss}. The PD controller parameters, proportional gain (K_p) and derivative time (T_d) are calculated using Zeigler – Nichols tuning method [16]. Using this method the values of K_p = 2 and derivative gain K_d = 28s.

C. Design FGSPIC based PSS

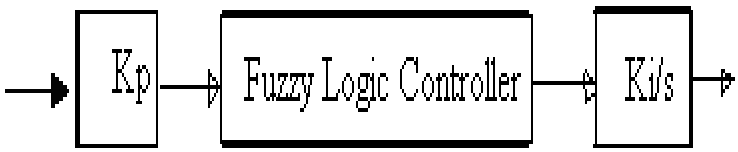
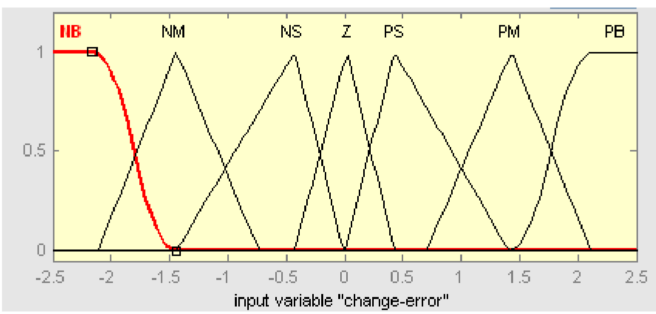


Fig. 4. Structure of FGSPIC based PSS

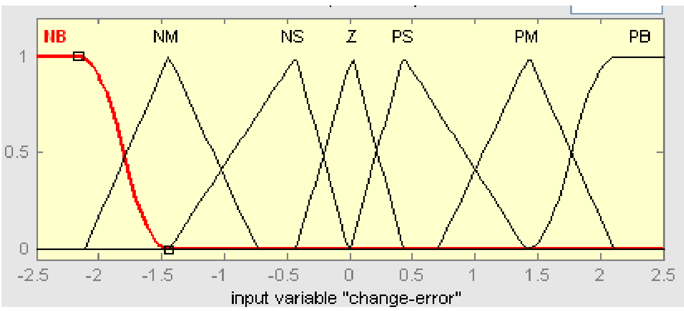
Fig. 4 depicts the structure of FGSPIC based PSS. It is widely recognized that a Fuzzy Logic Controller (FLC) primarily comprises fuzzification, knowledge base, and defuzzification processes. In this FGSPIC study, the actual value of the controller output V_{pss} is computed by (6).

$$d(k) = d(k-1) + d(k)' \tag{6}$$

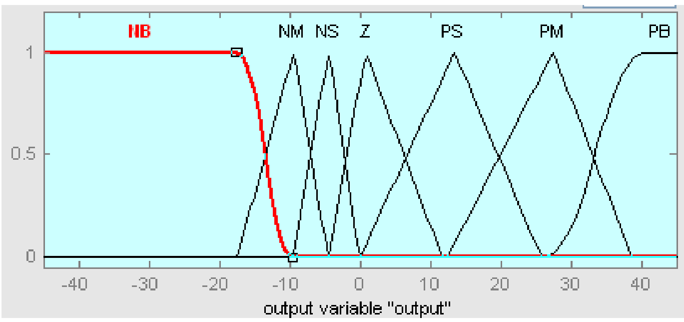
Where, d(k)- output, d(k-1) - (k-1)th instant output and d(k)'-incremental change in output.



(a)



(b)



(c)

Fig. 5. Membership function of FGSPIC based PSS, (a) error input (Δω), (b) change in error input (Δω'), (c) Kp, Ki (output-Vpss)

FLC utilizes speed error input (Δω), change in speed error input (Δω'), and output V_{pss}, represented by conventional triangular shapes with 50% overlapping as shown in Fig.5. The fuzzy variables 'error', 'change in error', and output are classified into seven sets: negative big (NB), negative medium (NM), negative small (NS), zero (Z), positive big (PB), positive medium (PM), and positive small (PS). These sets are based on empirical knowledge gained from simulations on SMIBS in open-loop operation.

The linguistic rules for the FLC are outlined in Table I, which have been derived from experience. Table I illustrates the rules for the FGSPIC. The defuzzification process employs the center of gravity method.

Table 1. Rule Base Table of Fgspic Based Pss Using 49 Rules

e /ce	**NB**	**NM**	**NS**	**Z**	**PS**	**PM**	**PB**
NB	Z	Z	Z	Z	PB	PB	PB
NM	PS	PS	PS	PS	PS	PS	PS
NS	PS	PS	PS	PS	PS	PS	PS
Z	NM	NB	PM	PM	PS	PM	PM
PS	NB	NB	Z	PS	PM	PM	PB
PM	NS	Z	PS	PB	Z	PB	PB
PB	Z	PS	PM	PB	Z	Z	Z

3. Simulation Results and Discussions

This part is to deliberate results of various controllers based PSS for SMIBS as well as without PSS. The performances of complete model using different controllers are validated at different states (i.e. start-up transient and mechanical input variations) through computer simulation with help of the MATLAB/Simulink. The specification of simulation model is performed on the SMIBS (refer the Appendix A) [17]. Figs. 6 and 7 show the simulation results of speed deviations as well as rotor angle deviations of the system using various controllers and no connection of PSS. From this figures, it is clearly showed that the speed ad rotor angle deviations of given power system has instability (i.e. created huge damping oscillations) without connection of PSS, whereas the FGSPIC based PSS for same system has generated null transient overshoots and quick settling time in comparison with PD based PSS and CPSS. Figs. 8 and 9 show the simulation results of speed deviations as well as rotor angle deviations of system with various controllers for mechanical step change input from 0.05 p.u to 0.08 p.u at 10s. From this figures, it is found that the speed ad rotor angle deviations of given power system using designed controller has negligible transient overshoots and quick settling time in comparison with PD based PSS and CPSS.

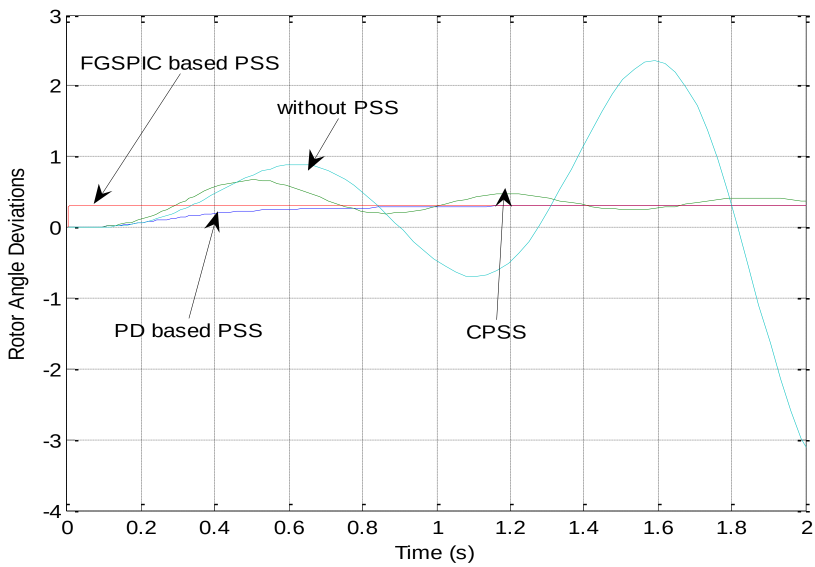


Fig. 6. Responses of rotor angle deviation of SMIBS using various controller based PSS and without PSS

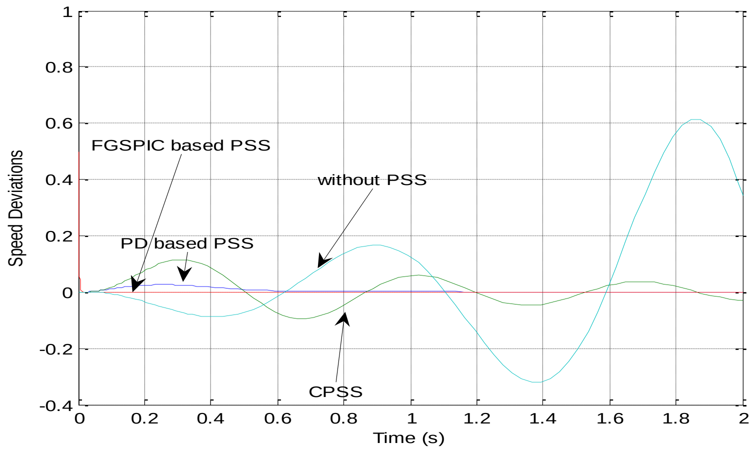


Fig. 7. Results of speed deviation of SMIBS with controls based PSS and without PSS

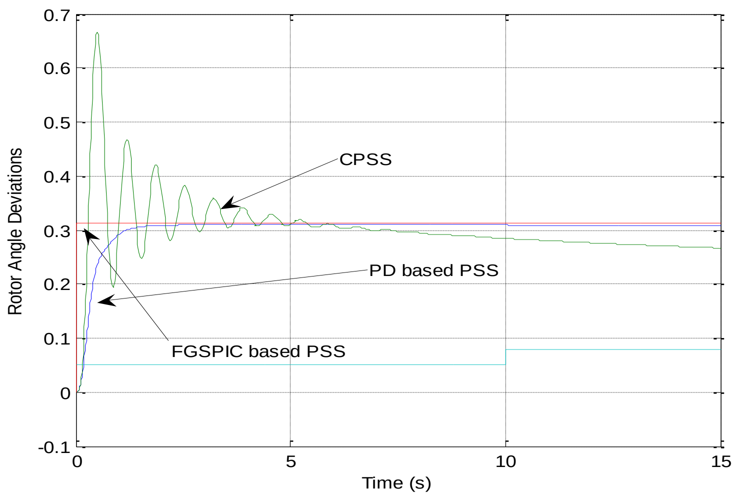


Fig. 8. Results of rotor angle deviation of SMIBS using controls based PSS when mechanical step input change from (0.05 to 0.08 p.u)

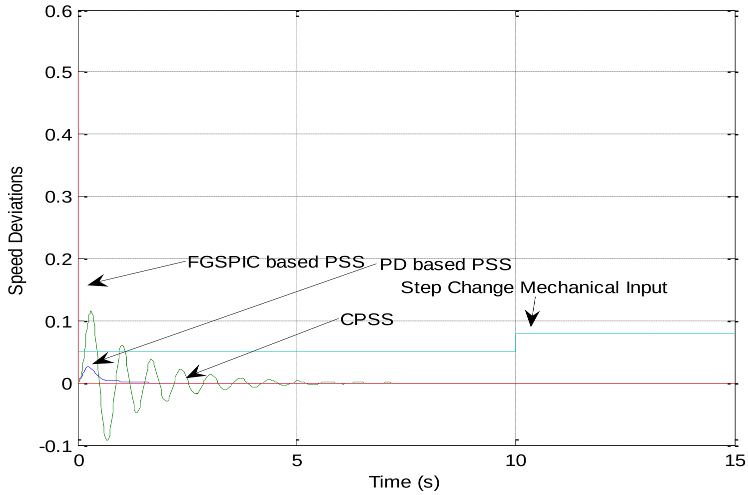


Fig. 9. Results of speed deviations of SMIBS with different controller based PSS when mechanical step input change from (0.05 to 0.08 p.u)

Table 2. Performance Analysis of Rotor Angle Deviations of System Using the Controllers

Types Controller	**Transient Region**		**Dynamic Region**	
	Peak Overshoots	**Settling Time**	**Peak Overshoots**	**Settling Time**
Without PSS	More Oscillations	Long setting time	More Oscillations	Long setting time
CPSS	0.68 (p.u)	5s	0.2 (p.u)	5s
PD based PSSS	null	0.8s	null	2s
FGSPIC based PSS	null	0.001s	null	0.002s

Table 3. Performance Analysis of Speed Deviations of System Using the Controllers

Types Controller	**Transient Region**		**Dynamic Region**	
	Peak Overshoots	**Settling Time**	**Peak Overshoots**	**Settling Time**
Without PSS	More Oscillations	Long setting time	More Oscillations	Long setting time
CPSS	0.68 (p.u)	5.5s	0.22 (p.u)	5s
PD based PSSS	null	0.8s	null	1.9s
FGSPIC based PSS	null	0.001s	null	0.001s

In summary, the TABLEs II and III were clearly indicated that the designed FGSPIC based PSS has performed well in all operating states in comparisons with other controllers.

4. Conclusion

In this article, the design of FGSPIC based PSS for SMIBS has been investigated successfully in software platform. The controller parameters are designed with help of the modelling of the system and then, fuzzy rules are generated based on the conventional controller values. Many results are presented to show that the designed FGSPIC based PSS have proficient damping oscillation in comparison with CPSS and PSS plus PD controller at different operating regions.

References

1. E.V. Larsen, D.A. Swann, “Applying power system stabilizers, Part I, II, III,” IEEE Trans. on Power App. and Syst., PAS-100(1981), pp. 3017-304
2. F.P. deMello, C.A. Concordia, “Concept of synchronous machine stability as affected by excitation control,” IEEE Trans.PAS-103 (1969), pp. 316–329.
3. A.Kolabi, A, Sofalgar, S, Lotfi, T,Yousefi, M, “Comparing the Power system stabilizer based on sliding mode control with the fuzzy power system stabilizer for single machine infinite bus system (SMIB),” *Research Journal of Applied Sciences, Engineering and Technology* 2012, 5, pp. 16-22.
4. Jenica Ileana Corcau, Eleonor Stoenescu, “Fuzzy logic controller as a power system stabilizer,” International Journal of Circuits, Systems and Signal Processing 2007, 1, pp. 266-272
5. Tan Qian Yi, Gowrishankar Kasilingam, Raman Raguraman, “Effect of PID power system stabilizer for a synchronous machine in simulink environment,” *4th International Conference on Energy and Environment 2013*, Publisher: IOP pp. 1-4, DOI:10.1088/1755-1315/16/1/012025
6. N, Ravi, and SwanandKulkarni. 2023. “Smart Ways to Catch the Abutment DRCs at IP Level”. Journal of VLSI Circuits and Systems 6 (1):51-54. https://doi.org/10.31838/jvcs/06.01.08.
   Ghadir Radman and Youssef smaili, “Performance evaluation of PID power system stabilizer for synchronous generator”, *IEEE, 88CH2571-8/88/0000-0597$1.00*, pp.597-601, 1988
7. Rajabi, A, Ghazanfar, S, Bahram, K, Yosefi, M.R, “Analysis and design of PSS based on sliding mode control theory for SMIB,” *IPEC, ConferenceProceedings* 2010, pp. 994-999.
8. Vitthal Bandal, B. Bandyopadhyay, and A. M. Kulkarni, “Output Feedback Fuzzy Sliding Mode Control Technique Based Power System Stabilizer (PSS) For Single Machine Infinite Bus (SMIB) System”, *IEEE conference publication* 2005,pp 341–346
9. *Nechadi, E; Harmas, M.N, “Power system stabilizer based on global fuzzy sliding mode controller,” Balkan Journal of Electrical and Computer Engineering 2013, 1, pp. 78-84.*
10. *S. Brock, J. Deskur, K. Zawirski “Modified sliding-mode speed controller for servo drives,” in Proc. of IEEE Int. Symp. on Industrial Electronics, vol.2, pp.635-40, 1999.*
11. *I. Kocaarslan, G. Akalın, T. Erfidan, “Application of fuzzy reasoning to load–frequency control in two-area power system,” in: Proceedings of European Control Conference ECC’99, Karlsruhe, Germany, 31 August–3 September 1999, pp. 27–31.*
12. C.S. Chang, Weihui Fu, “Area load–frequency control using fuzzy gain scheduling of PI controllers,” Electr. Power Syst. Res. 42 (1997), pp. 145–152.

13. M.H. Hamza, P. Agathoklis, W.C. Chan, "A Combined Self-Tuning and Integral Controller for Load Frequency Control of Interconnected Power Systems," Regelungstechnik, Heft 7, Jahrgang 1982, pp. 226–2
14. Rajeev Gupta, B.Bandyopadhyay and A.M.Kulkarni, "Design of Decentralized Power System Stabilizers for Multimachine Power System using Model *Reduction"*, 5th Asian Control Conference, 2004
15. J. S. R. Jang et al., "Neuro Fuzzy and Soft Computing", Prentice Hall of India, 1997.
16. Katshika Ogata. Modern Control Engineering: Published by Prentice – Hall of India Private Limited, New Delhi, Third Edition, 1997
17. Pankaj Valand, Mayurdhvajsinh Gohil, Ankit Rabari, Jinal Prajapati, "A Novel approach for tuning of Power System Stabilizer (SMIB system) using Genetic Local Search Technique," IJSRD - International Journal for Scientific Research & Development| Vol. 1, Issue 11, 2014,pp. 2348- 2352.