Sugeno Type Fuzzy-PID Hybrid Controller for Efficient Inter-area Power Oscillation Damping in Two Area Four Machine Power System by using MATLAB

[1]Sundeep Pradeep Kashyap, [2]Mr. Mahesh Singh, [3]Dr. R.N. Patel
[1]PG Scholar, [2]Sr. Assistant Professor, [3]Professor & Head
[1]Department of Electrical & Electronics Engineering
[1]SSGI (SSTC), Bhilai, India

***Abstract* - As a result of the increasing amount of energy transmission over a long distance, low frequency Inter-area oscillations have been becoming an increasingly important concern in the planning and operation of practical power systems. This undesirable phenomenon may cause very serious results, such as the loss of interconnects, load curtailments and even system blackouts. Abundant of power system stabilizers have been developed by the researchers in the past few years, but the area is still open for the efficient power stabilizer development which can efficiently able to handle the power oscillations without increasing the system controller system complexity. This paper presents a novel way to achieve fast and efficient damping of Inter-area oscillations and improve the dynamic stability of interconnected power systems by designing of an Sugeno type Fuzzy-PID hybrid controller for efficient Inter-area power oscillation damping in two area four machine power system. The most important point for using Sugeno type fuzzy inference over mamdani fuzzy inference is that it is much more suitable for linear PID like controllers. The implementation of the proposed work is with the Simulink of MATLAB 2012(b).This paper also present a complete comparative analysis of Inter-area power oscillation damping capabilities of proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) and conventional PID controller based power system stabilizer (PID-PSS) and with no controller (No-PSS) at line to ground (LG) fault condition. The obtained results shows that the Inter-area power oscillation damping capability of proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) is much higher than the conventional PID-controller based PSS. In addition to this the damping time required by proposed Sugeno type Fuzzy-PID hybrid controller.**

***Index term* - PID Controller, Power System Stabilizer (PSS), Multi area machine system, Power oscillation Damping, Sugeno type Fuzzy-PID hybrid controller, PID-PSS.**

I. INTRODUCTION

The power systems are complex non-linear systems, which are often subjected to low frequency oscillations. The application of power system stabilizers for improving dynamic stability of power systems and damping out the low frequency oscillations due to disturbances has received much attention recently. Power system is a highly nonlinear system and it is difficult to obtain exact mathematical model of the system. In recent years, adaptive self-tuning, variable structure, artificial neural network based PSS, fuzzy logic based PSS, have been proposed to provide optimum damping to the system oscillations under wide variations in operating conditions and system parameters. Low frequency oscillation problems are very difficult to solve because power systems are very large, complex and geographically distributed. Therefore, it is necessary to utilize most efficient optimization methods to take full advantages in simplifying the problem and its implementation [1-5].

This paper presents a novel way to achieve fast and efficient damping of Inter-area oscillations and improve the dynamic stability of interconnected power systems by designing of an Sugeno type Fuzzy-PID hybrid controller for efficient Inter-area power oscillation damping in two area four machine power system.

II. FOUR MACHINE TWO AREA SYSTEM

The test system present in MATLAB 2012(b) consists of two fully symmetrical areas linked together by two tie 230 KV lines of 220 Km length as shown in Fig.1. It was specifically designed to study low frequency electromechanical oscillations in large interconnected power systems. Despite its small size, it mimics very closely the behavior of typical system in actual operation. Each area is equipped with two identical round rotor generators rated 20 KV/900 MVA. The synchronous machines have identical parameters except for the inertias which are H = 6.5s in area 1 and H is = 6.175s in area 2. Thermal plants having identical speed regulators are further assumed at all locations, in addition to fast static exciter with a 200 gain. The load is represented as constant impedance and spilt between the areas [1, 11, and 12].

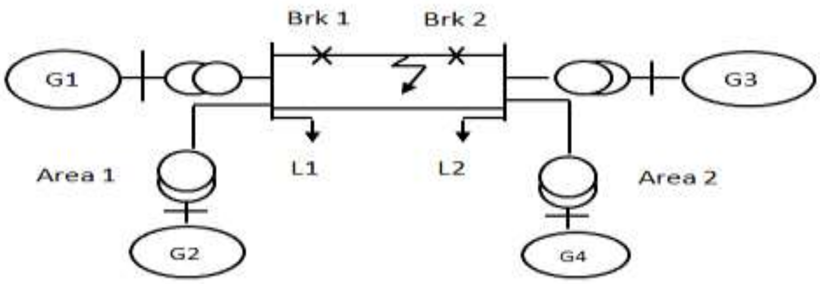


Fig. 1 Two Area Four-Machine power system for Stability Analysis

Now the actual simulation model implemented for analysis of the PID-PSS and proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) for Inter-area power oscillation stability is shown in fig.2. Fig.3. Shows the internal structure of area-1 of the implemented power study testing system and fig. 4 Depicts the Internal configuration of Turbine and regular consisting the conventional PID controller and proposed sugeno type fuzzy PID hybrid controller.Fig.5 shows the internal configuration of output signals. Fig. 6 shows the internal configuration of system data.

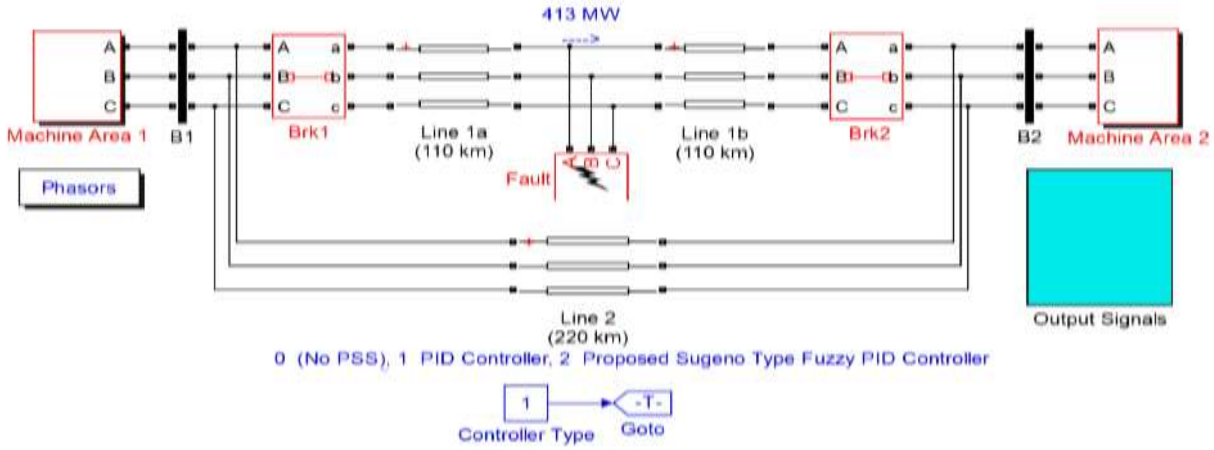
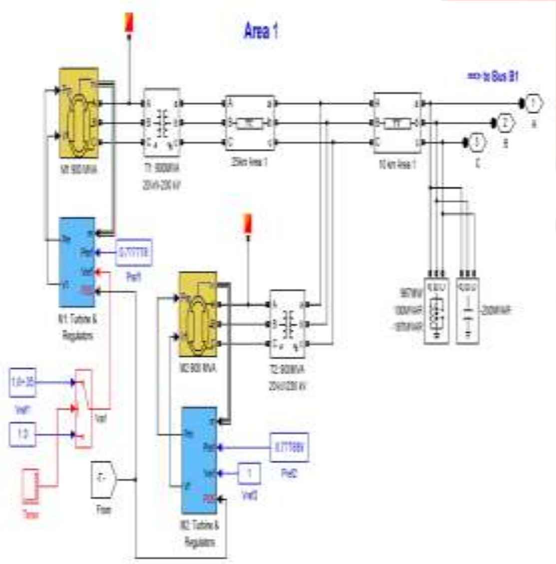


Fig.2 Actual simulation model implemented with PID-PSS and proposed Hybrid-PSS for Inter-area power oscillation stability Analysis.



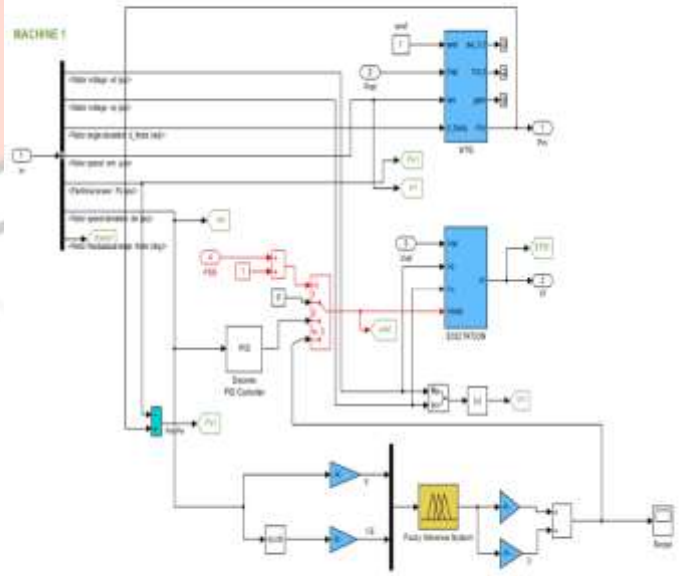


Fig.3 Internal configuration of area 1(subsystem) & Fig.4 Internal configuration of Turbine and regulator With PID-controller and proposed sugeno type fuzzy PID Hybrid controller

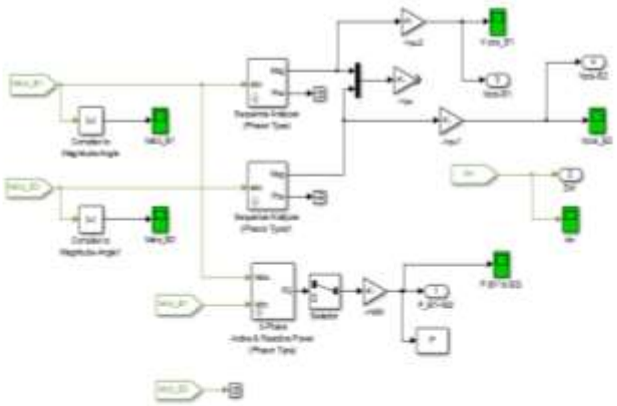


Fig.5 Internal configuration of Output signals (sub system) & Fig.6 Internal configuration of System data (sub system)

III. PROPOSED SUGENO TYPE FUZZY PID CONTROLLER

The PID Controller

Due to their simple structure and robust performance, proportional-integral-derivative (PID) controllers are the most commonly used controllers in industrial process control. The transfer function of **a** PID controller has following form:

$$G(s) = K_p + \frac{K_i}{s} + K_d s \qquad \ldots(3.1)$$

Where K_p, K_i and K_d are called the proportional, integral, and derivative gains, respectively.

Analysis of a Fuzzy Controller

Consider a product-sum type fuzzy controller with two inputs and one crisp output (MISO). Let the inputs to the fuzzy controller be the error e and the rate of change of the error e˙, and the output of the fuzzy controller (that is the input to the controlled process) be u. If an analysis of this controller is made, it can be seen that it behaves approximately like a PD controller. We can therefore consider it as a time-varying parameter PD controller. Such a controller is named as a PD type fuzzy controller (PDFC) in the literature. It is well known that if the controlled system is type "0", a P or PD type controller cannot eliminate the steady-state error. Although the use of an integral term in the controller (such as PI controller) can take care of the steady-state error, it can deteriorate the transient characteristics by slowing the response. However, with a PID-type fuzzy controller fast rise times and small overshoots as well as short settling times can be achieved with no steady-state error.

PID Type Fuzzy Control

In order to design a PID type fuzzy controller (PIDFC), one can design a fuzzy controller with three inputs, error, and the change rate of error and the integration of the error. Handling the three variables is however, in practice, quite difficult. Besides, adding another input to the controller will increase the number of rules exponentially. This requires more computational effort, leading to larger execution time. Because of the drawbacks mentioned above, a PID type fuzzy controller consisting of only the error and the rate of change of error is used in the proposed method. This allows PD and PI type fuzzy controllers to work in parallel. An equivalent structure is shown in Fig. 7, where β and α are the weights of PI and PD type controllers, respectively. Similarly, K and Kd are the scaling factors for e and e˙, respectively. As the α/β ratio becomes larger, the effect of the derivative control increases with respect to the integral control.

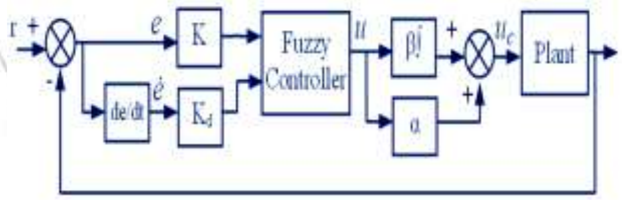


Fig. 7 Block diagram of the PID type fuzzy control system

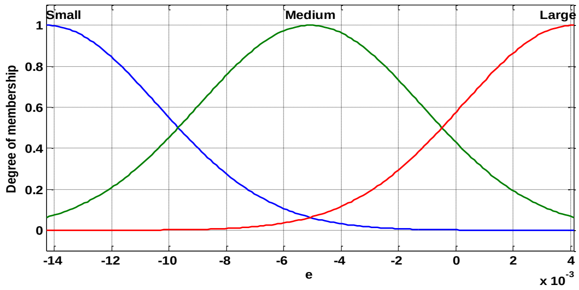
The output of the controller can be expressed as,

$$u_c = \propto u + \beta \int u dt \qquad \ldots (3.2)$$

This controller is called as PID type fuzzy controller (PIDFC).

Development of Proposed Sugeno Type Fuzzy PID Type Controller

During the development of fuzzy controller two variables, error (e) which is the rotor speed deviation (in pu) has been used as first input variable for designing of fuzzy controller. On the same time the rate of change of error signal ($\dot{e}$) has been taken as the second input variable for the fuzzy controller. The membership functions of error (e), change rate of error ($\dot{e}$)are shown in Fig.8 and Fig.9, are chosen as triangular membership functions. On the other hand, since the proposed fuzzy-PID controller uses Sugeno type fuzzy inference the control signal (u) is selected as linear as shown in figure 10.



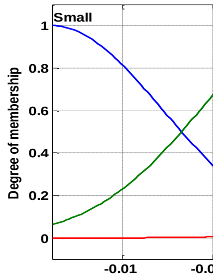


Fig. 8 The membership functions of error (e) & Fig. 9 The membership functions of rate of change of error($\dot{e}$)

Parameter	Generator
Xd	1.8
Xd’	0.3
Xd’’	0.25
Xq	1.7
Xq’	0.55
Xq’’	0.25
Xt	0.2
Tdo	8
Tdo’	0.03
Tq	0.4
Tq’	0.05

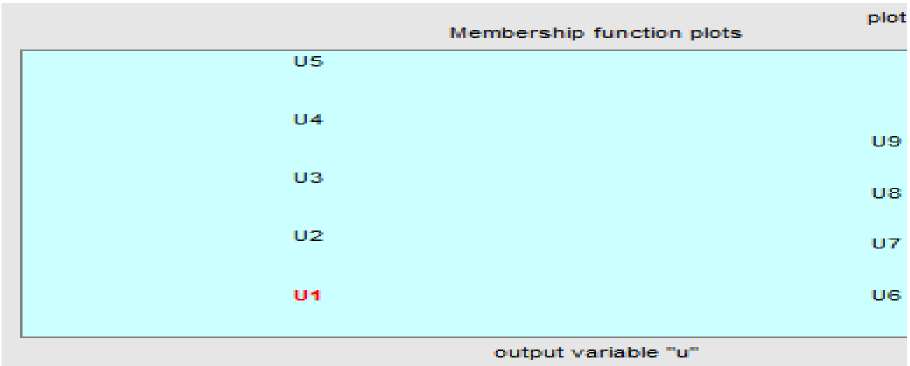


Fig. 10 Output control signal u as a linear function

Finally the rule base designed and employed for the fuzzy PID type controller aregiven as

1. If (e is Small) and (edot is Small) then (u is U1) (1)
2. If (e is Small) and (edot is Medium) then (u is U2) (1)
3. If (e is Small) and (edot is Large) then (u is U3) (1)
4. If (e is Medium) and (edot is Small) then (u is U4) (1)
5. If (e is Medium) and (edot is Medium) then (u is U5) (1)
6. If (e is Medium) and (edot is Large) then (u is U6) (1)
7. If (e is Large) and (edot is Small) then (u is U7) (1)
8. If (e is Large) and (edot is Medium) then (u is U8) (1)
9. If (e is Large) and (edot is Large) then (u is U9) (1)

IV. SIMULATION RESULTS

Performance of the PID-PSS and proposed Hybrid-PSS was evaluated by applying a large disturbance caused by line to ground fault applied at the middle of one tie line for 0.2 sec duration. Fault may be applied at 1 sec. and cleared after 1.2 sec by opening the breakers, with one tie-line the system can reach a stable operating point in steady state. The Parameters of PID-PSS used in test generators are given in Table 1. Each generator parameters are based on data in Table 2.

Parameter	Kp	Kl	Kd
G1	30	10	0.001
G2	10.50	0.67	0.45
G3	10.50	0.67	0.45
G4	10.50	0.67	0.45

Table 1: Parameter of PID controller

Table 2: Parameters of the generator

To investigate the Inter-area power oscillation damping performance of No controller, PID controller and proposed sugeno type fuzzy PID Hybrid controller with two-area four-machine test system, the line to ground (LG) fault was considered in the simulation studies. A line-ground fault of 0.2sec duration is simulated at line-1. Fault may be applied at 1 sec. and cleared after 1.2 sec Fig. 11 and Fig. 12, Fig.13, Fig.14 Shows the compared system response under with Sugeno type fuzzy PID hybrid controller, with PID controller and without any controller.

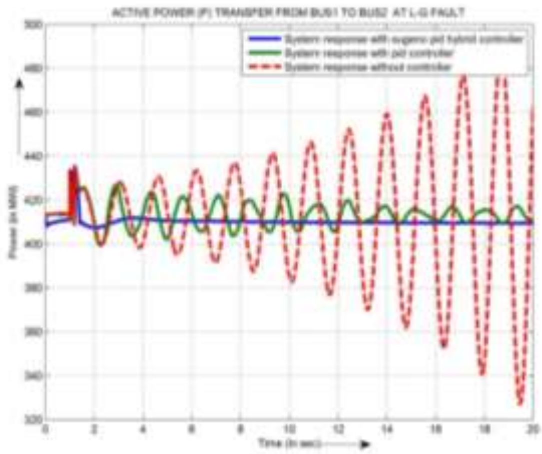


Fig.11 Active power transfer from B1 to B2 at LG fault

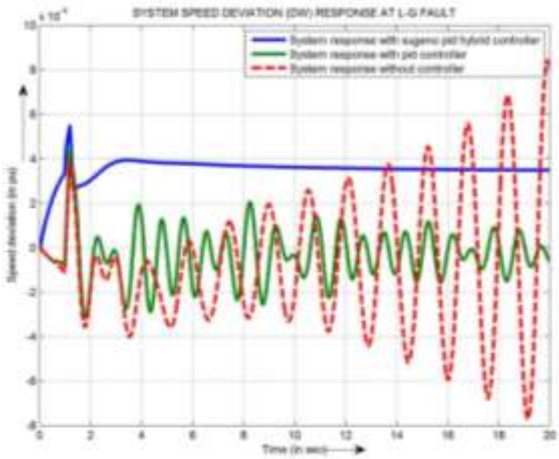


Fig.12 System speed deviation at LG fault

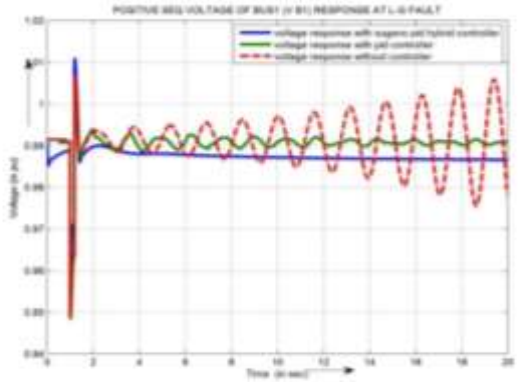


Fig.13 Positive sequence voltage of bus1 at LG fault

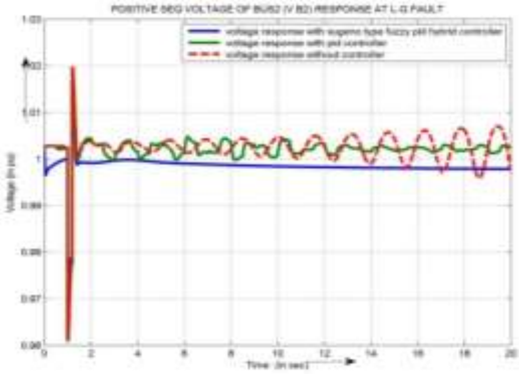


Fig.14 Positive sequence voltage of bus2 at LG fault

V. CONCLUSION

This work forwarded a novel way to achieve fast and efficient damping of Inter-area power oscillations. By the development of the project work an improved dynamic stability of interconnected power systems has been achieved by designing of an Sugeno type Fuzzy-PID hybrid controller for efficient Inter-area power oscillation damping in two area four machine power system. The basic aim was to exploit unique advantage of the fuzzy based advance control structure.

After the successful implementation of the proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS), a complete testing process have been performed by generating line to ground fault. The detail description and discussion about the testing results for proposed work and conventional PID-PSS have been given separately in the results section.

This paper also presents a complete comparative analysis of Inter-area power oscillation damping capabilities of proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS), conventional PID controller based power system stabilizer (PID-PSS) and without any controller. The obtained results shows that the Inter-area power oscillation damping capability of proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) is much higher than the conventional PID-PSS.

In addition to this the results also indicates that, the proposed Sugeno type Fuzzy-PID hybrid controller based power system stabilizer (Hybrid-PSS) takes only 4 sec to completely damp the Inter-area power oscillations, whereas PID-PSS takes even more than 14 sec to control the power oscillations.

VI. REFERENCES

[1] Prabha Kundur, Power System Stability and Control, McGraw-Hill, Inc, 1994.

[2] Junbo Zhang; Chung, C.Y.; Shuqing Zhang; Yingduo Han, "Practical Wide Area Damping Controller Design Based on Ambient Signal Analysis," Power Systems, IEEE Transactions on , vol.28, no.2, pp.1687,1696, May 2013.

[3] Hussein, T.; Shamekh, A., "Direct Adaptive Fuzzy Power System Stabilizer for a Multi-machine System," Computer Modeling and Simulation (UKSim), 2013 UKSim 15th International Conference on , vol., no., pp.33,38, 10-12 April 2013.

[4] Qudaih, Y.S.; Mitani, Yasunori; Mohamed, T.H., "Wide-Area Power System Oscillation Damping Using Robust Control Technique," Power and Energy Engineering Conference (APPEEC), 2012 Asia-Pacific , vol., no., pp.1,4, 27-29 March 2012.

[5] Babaei, E.; Golestaneh, F.; Shafiei, M.; Galvani, S., "Design an optimized power system stabilizer using NSGA-II based on fuzzy logic principle," Electrical and Computer Engineering (CCECE), 2011 24th Canadian Conference on , vol., no., pp.000683,000686, 8-11 May 2011.
[6] Alsafih, H. A.; Dunn, R. W., "Performance of Wide-Area based Fuzzy Logic Power System Stabilizer," Universities' Power Engineering Conference (UPEC), Proceedings of 2011 46th International , vol., no., pp.1,6, 5-8 Sept. 2011.
[7] Daryabeigi, E.; Moazzami, M.; Khodabakhshian, A.; Mazidi, M.H., "A new power system stabilizer design by using Smart Bacteria Foraging Algorithm," Electrical and Computer Engineering (CCECE), 2011 24th Canadian Conference on , vol., no., pp.000713,000716, 8-11 May 2011.
[8] Babaei, E.; Galvani, S.; AhmadiJirdehi, M., "Design of robust power system stabilizer based on PSO," Industrial Electronics & Applications, 2009. ISIEA 2009. IEEE Symposium on , vol.1, no., pp.325,330, 4-6 Oct. 2009.
[9] Hadidi, R.; Jeyasurya, B., "Reinforcement learning approach for controlling power system stabilizers," Electrical and Computer Engineering, Canadian Journal of , vol.34, no.3, pp.99,103, Summer 2009.
[10] Huaren Wu; Qi Wang; Xiaohui Li, "PMU-Based Wide Area Damping Control of Power Systems," Power System Technology and IEEE Power India Conference, 2008. POWERCON 2008. Joint International Conference on , vol., no., pp.1,4, 12-15 Oct. 2008.
[11] Athanasius, G.X.; Pota, H.R.; Subramanyam, P.V.B.; Ugrinovskii, V., "Robust power system stabilizer design using minimax control approach: Validation using Real-time Digital Simulation," Decision and Control, 2007 46th IEEE Conference on , vol., no., pp.2427,2432, 12-14 Dec. 2007.
[12] Hunjan, M.; Venayagamoorthy, G.K., "Adaptive Power System Stabilizers Using Artificial Immune System," Artificial Life, 2007. ALIFE '07. IEEE Symposium on, vol., no., pp.440, 447, 1-5 April 2007.
[13] Dobrescu, M.; Kamwa, I., "A new fuzzy logic power system stabilizer performances," Power Systems Conference and Exposition, 2004. IEEE PES, vol., no., pp.1056, 1061 vol.2, 10-13 Oct. 2004.
[14] V. Vittal, “Consequence and Impact of Electric Utility Industry Restructuring onTransient Stability and Small-Signal Stability Analysis”, Proceedings of the IEEE,Vol. 88, No. 2, Feb. 2000.
[15] M.Klien, G J Roger and P.kundur “A fundamental study of Inter-area Oscillation,” IEEE Trans, vol PWRS-6, No.3, pp914-921, Aug1991.
[16] M.Klien, G J Roger, S Murty and P.kundur “Analytical Investigation of factor Influence Power System Stability Performance,” paper 92WM016-6EC, Presented at the IEEE PES Winter meeting, New York, January 1992.
[17] Z. Wang, C. Y. Chung, and K. P. Wong, “Systematic approach to consider system contingencies in PSS design,” Electric Power Systems Research, vol.79, no 12, pp.1678-1688, Dec 2009.
[18] E. Babaei, S. Galvani, and M. Ahmadi Jirdehi, “Design of robust power system stabilizer based on PSO,” in Proc. ISIEA, 2009, Malaysia, vol.1,pp.325-330.
[19] T. K. Das, G. K. Venyagamoorthy, and U.O. Aliyu, “Bioinspired alogriyhms for the design of multiple optimal power system stabilizers: SPPSO and BFA, “IEEE Trans. Ind. Appl., vol.44,pp.1445-1457, Sep.2008.
[20] G. Rogers, Power System Oscillation. Kluwer, Norwell, MA.2000.
[21] M. E. EI-Hawary, Electrical Power Application of fuzzy system. New York: IEEE Press 1998.
[22] R. C. Bansal, “Bibliography on the fuzzy set theory applications in power system (1994-2001)”. IEEE Trans. Power System, vol.18(4), pp.1291-1299. Nov 2003.
[23] J. Lu, M.H. Nahrir, and D.A. Pierre, “A fuzzy logic-based adaptive power system stabilizer for multi-machine system”. Electric Power System Research, vol. 60(2), pp. 115-121, Sep 2001.
[24] N. Nallathambi, and P. N. Neelakantan, “Fuzzy logic based power system stabilizer”. E-Tech pp. 68-73. 2004.
[25] Singh, Mahesh, R. N. Patel, and Rajkumar Jhapte. "Performance comparison of optimized controller tuning techniques for voltage stability."2016 IEEE First International Conference on Control, Measurement and Instrumentation (CMI). IEEE, 2016.