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Overview and Literature Survey of Power System Stabilizer In Power Systems

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Abstract:- Increasing interest has been seen in applying power system stabilizer to power systems problems from the number of publications on this topic in recent decade years. As a relatively new research topic a need is felt to pay more attention to the basic principles of the theory, identification of problems and design of Power System Stabilizer. This paper presents a survey of few decade publications on power system stabilizer theory to power systems and the basic procedures for PSS design methods to solve power systems problems.

I. INTRODUCTION

With the penetration of PSS into manufacturing and computer products, applications of PSS in power systems are beginning to receive attention from power systems researchers. PSS were first introduced in solving power systems long-range decision making problems in more than a decade ago. However, substantial interest in its applications to power areas is fairly recent. Different designing methods exist for many power systems operation. However, the mathematical formulations of real-world problems are derived under certain assumptions and even with these assumptions, the solutions of power systems problems is not trivial because there are many uncertainties in various power systems problems because power systems are large, complex, geographically widely distributed systems and influenced by unexpected events. These facts make it difficult to effectively design with many power systems problems through strict mathematical formulations alone. Therefore, different designing approaches were made and proved to be effective in various power system problems. With the advance of PSS and the achievements made in applications to other areas, it is beginning to receive power researchers' attention and it is felt that there is a need to develop alternative design method for more information on this subject. In this paper we aim to provide designing approach and a survey of the publications of PSS to power systems problems. The paper is organized as follows. Basics of PSS are explained in Section II. Historical and Evolution Perspective III. Overview Issues of PSS IV. PSS Design Concepts V.

II. BASICS OF POWER SYSTEM STABILIZER

A PSS is an additional control block used to enhance the system stability. This block is added to the AVR, and uses stabilizing feedback signals such as shaft speed, terminal frequency and/or power to change the input signal of the AVR. PSS consists of three basic blocks. The first block is the stabilizer Gain block, which determines the amount of damping. The second is the Washout block, which serves as a high-pass filter, with a time constant that allows the signal associated with oscillations in rotor speed to pass unchanged, but does not allow the steady state changes to modify the terminal voltages. The last one is the phase compensation block, which provides the desired phase-lead characteristic to compensate for the phase lag between the AVR input and the generator electrical. The PSS is designed to introduce an electrical torque in phase with the rotor speed variations. This is achieved by a supplementary stabilizing signal ΔVS applied to the automatic voltage regulator (AVR) of the generator. Basically, this controller is composed of a static gain Kpss which is adjusted to obtain the desired damping for unstable or poorly damped modes. The time constant Tw represents in washout block with range of (1 to 20 seconds) so it works as a filter for low frequencies (0.8 to 2 Hz). The time constants T1, T2, T3 and T4 defined in two blocks lead-lag of the input signal **[1-2].**

III. HISTORICAL AND EVOLUTION PERSPECTIVE

Despite their relative simplicity, Power System Stabilizers (PSS) may be one of the most misunderstood and misused pieces of generator control equipment. The ability to control synchronous machine angular stability through the excitation system was identified with the advent of high speed exciters and continuously-acting voltage regulators. By the mid-1960’s several authors had reported successful experience with the addition of supplementary feedback to enhance damping of rotor oscillations **[2-6].** Since the early 1960s, power system stabilizers have been considered as integral components of the excitation systems installed on all large generators on the Ontario Hydro system. The use of these PSS units continues to produce millions of dollars of annual benefits **[3-4, 7].**

IV. AN OVERVIEW ISSUES OF PSS

Power system stabilizers (PSS) have now been with us for several decades. Papers in [6, 8-16] have covered the problems associated with the application of stabilizers on hydraulic and thermal units from the late 1960s to the late 1980's. The problems discussed in those papers covering the early years of this technology, had to do with the actual design of the stabilizer hardware, the choice of signal, the implementation problems, the interaction between the stabilizer signal and shaft torsionals, effects of loading and unloading on terminal voltage, and of course, the acceptability of the excitation systems themselves, as perceived at that time.

V. PSS DESIGN CONCEPTS

The developments in the area of PSS in the power systems have been discussed through the various PSS system designs methods. Most of the PSS designs are based on the application of techniques developed in the area of control system designs. Different designing methods from late 1980s to till 2014 have been discussed in this section. The design procedure in [17] has been successfully applied to the design of power system stabilizers and the resulting stabilizers provide good damping at several extreme operating conditions. Their performance in nonlinear environment is validated using line switching's, machine outages, and faults. The new stabilizer performs better than the traditional PSS especially if a machine outage occurs.

There are uncertainties in electric power system and thus always exist unmodelled dynamics in power system which causes in effective performances of PSS. It is overcome by Fuzzy Logic PSS in [18]. The simulation results show that the proposed FLPSS provided better dynamic performance under disturbance conditions than the conventional PSS. The design of the FLPSS does not require mathematical model representation of the synchronous machine and power plant and is quicker and easier to implement than the self tuning PSS which requires real-time model identification.

The application of weighting function in designing PSS is explained in [19]. Some investigations on applying $H\infty$ methods to the PSS design are also presented in [20-21]. A simple and effective way of selecting weighting functions is discussed in [22]. The design method presented in [23] for single-machine power systems are extended to multi machine systems in [24]. The design is based on the use of Pseudo Global System Models (PGSM).

Same $H\infty$ Optimization Method [25-26] is used and to test the robustness of the designed PSS, experiment was conducted over various operating points. A new robust design of PSS applying $H\infty$ mixed sensitivity technique is proposed to mitigate low frequency oscillations [27]. The motivation to apply this control strategy is the simplicity and flexibility of synthesis procedure. The reduction in the controller complexity is averted by reducing system size keeping in view suitability for practical installation. Zames originally formulated the $H\infty$ optimal control theory [28]. Demonstrations of $H\infty$ based design techniques for controllers applicable to power system have been reported in literature [29].

Lyapunov's Approach [30], which shows that the system is exponentially stable with the properly chosen control gains. The proposed PSS is linear and decentralized, and is robust against operating point variations, locations of disturbances, and system topology changes.

Application of an Eigen solution Free Method [31] make use of the [32]. The major contributions of this paper are the presentation of a new method of reduced-order modal analysis, which is completely independent of the eigensolution. Recently, heuristic search algorithms such as genetic algorithm (GA) [33-35] have been applied to the problem of PSS design. Supplementary constant output produced in [36] to improve stability while the operating condition changes and is always suited to operating conditions.

Particle Swarm Optimization (PSO) technique was developed by Eberhart and Kennedy [37] which was inspired by the Social behavior of Bird flocking and fish schooling. The results in [38] show the potential of PSO technique for optimal design of PSS and can work effectively over a wide range of loading conditions and system configurations. The performance of the proposed PSOPSSs [39] is compared to that of GAPSSs given in [40] and gradient-based PSSs given in [41]. It is clear that the system performance with the proposed PSOPSSs is much better than that of GAPSSs and the oscillations are damped out much faster than CPSS.

Many methods have been used in the design of PSS, among the various robustness techniques optimal control [42-44] technique has received considerable attention. LPV theory [45] has been developed in the past ten years. It is a natural extension of the conventional gain scheduling approach [46]. The LPV method can guarantee the stability and performance not only for slowly changing parameters but also for arbitrarily fast changing parameters.

It is difficult to obtain accurate physics model of power system **[47].** Prony analysis describes the mathematical model of equal space sampling data by a linear combination of exponential functions. The results of small disturbance analysis show that the method improves system eigenvalue and enhance system damping after PSS whose parameters are optimized by above method is set into system. Therefore, according to the result based on iterative Prony analysis, to adopt residue method to configure PSS parameter optimally is viable **[48].**

In the last few years, it is found that the drawback of GA is that, the performance depends on the optimal selection of its operators. To cope with the GA limitations, Population-Based Incremental Learning (PBIL) was originally proposed by Baluja [**49-50**]. The issue of tuning the parameters of the PSSs has been converted into an optimization problem which is solved via PBIL and GAs. Eigenvalue analysis show that the PBIL-PSSs perform better than the CPSSs.

Comparison between PBIL-PSSs and GA-PSSs in **[51]** shows that PBIL-PSSs perform better than GA-PSSs and gives adequate and consistent damping.

The Recurrent Neural Network PSS proposed in **[52]** shows the faster convergence than the Fuzzy Logic Neural Network PSS because the proposed neural network consists of only two layers, the time of updating the weights is faster than the conventional three layer neural networks.

Synergetic control theory was first introduced by Russian scholars **[53]**. Recently, this theory has been successfully applied in **[54**] and some practical aspects with reference to both simulations and actual hardware were discussed in **[55-57].** It is also applied in a practical battery charging system **[58]**. This paper presented a new nonlinear approach based on synergetic control theory to design a power system stabilizer for single-machine infinite-bus power systems. The proposed approach overcomes the problems of the linear controls by explicitly using a nonlinear model of the power system for control synthesis.

The idea of Artificial Immune System is derived from biological vertebrate immune system **[59-61].** Based on the immune system network some mathematical immune algorithm is obtained **[62].** It uses Improved Varela Immune Network Controller (IVINC), the new immune controller has the learning and memorizing characteristics and has proved that it works well in power systems stabilizers to optimize the stability of power and enhances the system performance damping low frequency oscillation.

With Tustin's method being very popular **[63].** A digital PSS is designed by discretizing a third-order analog lead-lag type PSS using Tustin's mapping method. The method is simple to implement. Dynamic simulations were carried out using the single- machine system connected to an infinite-bus to validate the effective of the proposed digital PSS.

The proposed stabilizer in **[64]** is made adaptive by the online modification of ILWs and CPs, according to the procedure indicated in this paper. Compared to a conventional neural-network-based stabilizer, the proposed PSS uses a priori knowledge in the form of fuzzy if-then rules, and consequently, the time in the design stage is affected favorably.

Genetic Algorithm design based on Fuzzy Logic Power System Stabilizers is discussed in **[65].** Moreover, Fuzzy logic controller's complexities are discussed in **[66].** GA has been applied successfully to various power system problems and the recent approach is to integrate the use of GA and fuzzy logic systems in order to design power system stabilizer **[67].** The coordination between genetic based fuzzy logic power system stabilizer (GFLPSS) and CPSS provide good damping characteristics during small disturbance and large disturbances for local as well as inter area modes of oscillations

The major difficulties in **[68]** approach are the requirement of all state information, which is hard to realize in practice, and the polytopic vertices used in the design are determined by a trial and error procedure. These limitations are overcome by **[69].** Robust output feedback PSS design using LMI approach is considered in this paper. The design of output feedback controller that achieves robust pole clustering while minimizing an $H\infty$ performance criterion has been derived resulting in new BMI conditions and provides good transient response specifications and good performance for all expected operating conditions.

Taguchi method has been employed to solve economic dispatch problems **[70]** and optimal power flow of power systems **[71].** The proposed PSS provide better damping over a wide range of operating conditions. Finally, it can be concluded that the Taguchi principle can be effectively employed to achieve an intrinsic robustness in the PSS parameters against variations in operating conditions.

The proposed coordinated PSS/AVR design **[72]** procedure is established within a frequency-domain framework and serves as a most useful small-signal complement to established large-signal transient simulation studies.

The PSS designed using conventional method performs well around the nominal operating condition. However, its performance degrades as the system becomes more loaded **[73].** Breeder Genetic Algorithm, BGA-PSS performs slightly better than the GA-PSS. GA however has some limitations such as premature convergence, difficulties in selecting optimal genetic operators as well as the high computational capacity required in solving complex optimization problems. In order to deal with some of the limitations, BGA was proposed by John Greene **[74].** This paper uses a slightly different version of BGA known as adaptive mutation BGA.

The method proposed in **[75]** for the PSS design is based on the conventional design technique as described in **[76]** and **[77].** However, as opposed to a conventional stabilizer design, the system dynamics are linearized by taking the secondary bus voltage of the step-up transformer **[78]** as reference instead of the infinite bus **[79].**

The transient stability of a power system is a nonlinear property and cannot be understood and properly addressed using linear analysis. Nonlinear controller, inspired and designed using the nonlinear Hopf bifurcation theory, can give great insight into the understanding and improving the transient stability margins of the power system. Hopf bifurcation (HB) is a nonlinear theory that is useful in explaining some of those phenomena **[80].** Existence of a HB in a system can be inferred using the linearized model of the system. This has been used, for instance, in **[81],** a new technique based on PSO is proposed to optimize the parameters settings of CPSS is developed and Simulation results show the effectiveness and robustness of the proposed OPSS over CPSS.

The Bacteria Foraging Algorithm, BFA has been reported by Mishra, Tripathy, and Nanda **[82]**. A new procedure for improving BFA called Smart BFA is a modification of the classical BFA and is applied for tuning the PSS coefficients in a multi machine power system. Due to having the bacteria conduction at a smart direction, the cost function decrease is better than the classical BFA and the speed convergence is also increased **[83]**. In all past researches of classic BFA, only the social intelligence of bacteria is considered **[84-86].**

Recent work combining nonconvex, nonsmooth optimization with the use of concepts of pseudospectra for the design of low order controllers including robustness requirements is suited to the design of power system stabilizers **[87].** In this paper the PSS design is based on nonconvex, nonsmooth optimization. The use of concepts of pseudospectra for the design of low order controllers including robustness requirements is explained in **[88-89].**

Using Balance Truncation technique **[90]**, lower order model is obtained from the higher order model and for this reduced model a stabilizing state feedback gain is obtained. With Fast output Sampling approach proposed by Werner and Furuta **[91-92].** Large order models are reduced by PSO technique. In decentralized power system stabilizer, the control input for each machine should be function of the output of that machine only **[93]** and the decentralized stabilizer design problem can be translated into a problem of diagonal gain matrix design for multi machine power system **[94].** Complexity of working with large order complex systems in their original form is presented in **[95].**

The performance of the proposed GAPSS is compared with random parameters PSS. The design problem is converted to an optimization problem which is solved by NSGAII **[96].**

A new method based on the big bang-big crunch theory is introduced **[97]**. BB-BC algorithm has already been applied to different areas such as airport gate assignment problem [98], fuzzy model inversion **[99],** non-linear controller design **[100]** and target motion analysis **[101].**

Artificial Bee Colony proposed by Karaboga **[102-104]** is a new technique proposed to optimize the parameters settings of CPSS. PSS parameters settings are computed using linear control theory [**105**]. Simulation results show the effectiveness and robustness of the proposed ABCPSSs over CPSSs. Another version of ABC is Interactive ABC, Investigations reveal the performance of IABC based multiband power system stabilizers in a multi machine infinite bus system is better in terms of settling time and peak overshoot under fault conditions and provide good damping characteristics during small disturbance and large disturbances for local as well as inter area modes of oscillations **[106].**

The slip signal is taken as output in **[107]** and the fast output sampling feedback **[108]** is applied at appropriate sampling rate. This method is also compared with Conventional PSS and without PSS.

Fuzzy set was singlehandedly introduced by Lotif A Zadeh **[109].** Different types of membership functions are considered for fuzzy control system**.** The results of the study indicate that Gaussian MF gives the best system performance, and the triangular MF response is very close to that of Gaussian MF [**110**].

The application of ANFIS-PSS has been produced the better response with compare to the GA-PSS. The time response parameters like overshoot and settling time are significantly improved by using of ANFIS-PSS. Combined GA-PSS and ANFIS-PSS are extensively reduced the oscillations in power angle and rotor speed, and provided good damping to low frequency oscillation by stabilizing the system rapidly **[111].**

The closed-loop performance of the system model was evaluated for an input disturbance in the mechanical torque. The results show that the optimal output controller exhibits better performance than the conventional controller. Results also show the robustness and the validity of the output optimal controller **[112]**. The usage of optimal control is discussed in **[113-115].**

A comparison of a PSS controller based on hybrid intelligent technique by combining the advantages of
Differential evolution and tabu search is compared with a controller based on differential evolution only **[116].** It is concluded that the performance of the hybrid PSS controller is similar to DE PSS controller. Both the controllers are able to damp the transients that are present in the system when it is subjected to pulse disturbance. A novel method of designing PID controller in **[117]** for the power system considered using modified Philip-Heffron's Model **[118].**

It is found that the total power output necessary to compensate the disturbance of the steady state is at an extreme amount and relative to the non-linear gain value, albeit the fact that the optimal methods created the greatest state responses **[119].** In this work, the method that has been created by [**120-121**] will be used so that a system's small signal stability with a machine that is synchronous could be analyzed.

S Paul and K RO proposed Oppositional gravitation search algorithm **[122].** The computed results obtained are compared with other population based optimization techniques like GSA, DE and the proposed algorithm show more potential than other population based optimization algorithms.

UPFC Based on Fuzzy Logic Power System Stabilizer proposed in **[123]** is simulated using MATLAB-SIMULINK and compared with the conventional system with PSS. Results indicated that by incorporating FLPSS with UPFC, the damping of low frequency oscillation shown a better performance than conventional PSS thus improving the dynamic power system stability.

The approach model in **[124]** was tested on the 16-machine in 68- bus New England-New York interconnected system, and its effectiveness was established during the Eigenvalue analysis and nonlinear simulation results. In addition, the results demonstrated that the minimum damping ratio can be increased, and the number of PSSs can be reduced by adding UPFC-based stabilizer to the system. The coordinated design of the UPFC-PSS **[125-126]** and PSS-TCSC [**127-128**] and PSS-SVC [**129**] stabilizers are significantly more efficient in damping oscillations and improving stability compared to an individual design of these stabilizers.

VI. CONCLUSSION

This paper discusses about the Power System Stabilizer (PSS) which gives an overview of issues in PSS and control system design concepts were followed by discussion about different design methods for PSS Intelligent control techniques which may give better results for Power System Stabilizer. Various designing techniques that tackled the problem are overviewed. This review is undertaken to explore and report that fast and accurate acting controllers design developed based on designing techniques are required to maintain system stability and damping of oscillation. Therefore, it is efficient for solving many problems for which it is difficult to find accurate mathematical models.

REFERENCES

[1]. P.Kundur “Power System Stability”, Tata McGraw-Hill.

[2]. Using Power System Stabilizers (Pss) And Shunt Static Var Compensator (Svc) For Damping Oscillations In Electrical Power System Dr. Hussein Thani Rishag Department of Electromechanical Engineering, University of Technology/Baghdad.

[3]. Effect of High-speed Rectifier Excitation Systems on Generator Stability Limits, P.L. Dandeno, A.N. K m , K.R. McClymont and W. Watson, IEEE Trans. Vol.PAS-87 January 1968, pp.190-201.

[4]. Excitation Control to Improve Power Line Stability, F.R. Schleif, H.D. Hunkins, G.E. Martin, and E.E. Hattan, IEEE Trans. Vol. PAS-87, June 1968, pp. 1426-1434.

[5]. F.R. Schleif, H.D. Hunkins, G.E. Martin, E.E. Hattan, "Excitation Control to Improve Power line Stability", IEEE Trans. Vol. PAS-87, June, 1968, pp. 1426-1434.

[6]. C. Concordia, F. P. De Mello, 'Concepts of Synchronous Machine Stability As Affected by Excitation Control', IEEE Trans PAS Vol. 88, Apr. 1969.

[7]. Practical Utility Experience with Application of Power System Stabilizers, G.R. BCrub C, L.M. Hajagos and Roger Beaulieu, 0-7803-5569-5/99/$10.00 0 1999 IEEE.

[8]. Roger E. Beaulieu and Murray E. Coultes, “Suitability of Excitation Systems for Power System Stabilizer Application”, 0-7803-7989-6/03/$17.00@ 2003 IEEE.

[9]. S. V. Larsen, D. A. Swann, “Applying Power System Stabilizer., Part I , II, III ”,IEEE Trans. on PAS Vol. 100, No. 6, June 1981, pp. 3017-3024.

[10]. De Mello, Hannett and Undrill, "Criteria and Definitions for Excitation Systems for Synchronous Machines'. IEEE Standards 421- 72, December, 1972.

[11]. Bayne, Watson & Lee, 'IEEE Guide for Identification, Testing, and Evaluation of the Dynamic Performance of Excitation Control System,' IEEE Standards 42.1.2 – 1990.

[12]. J.P. Bayne, D.C. Lee and W. Watson. A Power System Stabilizer for Thermal Units Based on Derivation of Accelerating Power. IEEE Transactions Vol. 96 (PAS) No 61777-1783, November December 1977.

[13]. W. Watson and G. Manchur. Experience with Supplementary Damping Signals for Generator Static Excitation Systems. IEEE Transactions Vol. 93 (PAS) No 1:199-203, January February 1973.

[14]. J.P. Bayne, P. Kundur and W. Watson. Static Exciter Control to Improve Transient Stability. IEEE Transactiom Vol. 94 (PAS) No 4:1141-1146, July/August 1975 .

[15]. D.C. Lee,R.E. Beaulieu, J.R.R. Service. APower System Stabilizer Using Speed and Electrical Power Inputs-Design and Field Experience. IEEE Tramactions Vol. 100 (PAS), No 9, September 1981.

[16]. W. Watson and M.E. Coultes. Static Exciter Stabilizing Signals on Large Generators - Mechanical Problem. IEEE Transactions Vol. 92 (PAS):204-211, January February 1972.

[17]. J.H. Chow, "A Pole-Placement Design Approach for Systems with Multiple Operating Conditions," Proc. 1988 CDC, pp. 1272-1277.

[18]. Juan Shi ,L.H.Herron and A.Kalam, “DESIGN AND IMPLEMENTATION OF A PC-BASED AUTOMATIC VOLTAGE REGULATOR AND FUZZY LOGIC POWER SYSTEM STABILIZER”, IEE 2nd International Conference on Advances in Power System Control, Operation and Management, December 1993, Hang Kong.

[19]. Tai C. Yang, “WEIGHTING FUNCTION SELECTION BASED POWER SYSTEM STABILIZER FOR $H\infty$ DESIGN”, 0-7803-2550-8/95$4.00O1995 IEEE.

[20]. R. Asgharian, “A robust $H\infty$ power system stability with no adverse effect on shaft torsional modes”, IEEE Trans., Vol.EC-9,No.3, pp.475-481, 1994.

[21]. J.H.Chow, L.P. Harris, M.A. Kale, H.A.Othman, J.J.Sanchez-Gasca, “Robust control design of power system stabilizers using multivariable frequency domain techniques”, Proc. 29th CDC Conf. pp.2067-2073, Dec. 1990.

[22]. F.P deMello and C.Concordia, “Concepts of synchronous machine stability as affected by excitation control ”, IEEE Trans., Vol. PAS-88, pp.316-325 1969.

[23]. Yang T C and Munro N, 1991, “Power system stabiliser design based on the pole assignment technique for SIMO systems”, Int. J. Electrical Power and Energy Systems, -13, 298-302.

[24]. T C Yang and N Munro, “APPLICATION OF A POLE ASSIGNMENT ALGORITHM TO MULTI-MACHINE POWER SYSTEM STABILISER DESIGN”, UKACC International Conference on CONTROL '96,2-5 September 1996, Conference Publication No. 427 @ IEE 1996.

[25]. Yeonghain Chun , Takuhiko Ohashi , Yoichi Hori ,Kook Hun Kim, Jong Bo Ahn, Seok Joo Kim, “Robust Power System Stabilizer Design with $H\infty$ Optimization Method and Its Experiment on a Hardware Simulator”, 0-7803-3823-5/97/$10.000 1997 IEEE.

[26]. J.H.Chow, L.P. Harris, M.A. Kale, H.A.Othman, J.J.Sanchez-Gasca, “Robust control design of power system stabilizers using multivariable frequency domain techniques”, Proc. 29th CDC Conf. pp.2067-2073, Dec. 1990.

[27]. Amitava Sil, T. K. Gangopadhyay, S. Paul, A. K. Maitra, “Design of Robust Power System Stabilizer Using $H\infty$ Mixed Sensitivity Technique”, 2009 Third International Conference on Power Systems, Kharagpur, INDIA December 27-29, 978-1-4244-4331-4/09/$25.00 Â©2009 IEEE.

[28]. Skogestad Sigurd & Postlethwaite Ian – “Multivariable Feedback Control Analysis and Design” (John Wiley & Sons, Ltd).

[29]. B. Chaudhuri, B. C. Pal, A C. Zolotas, I. M. Jaimoukha and T. C. Green – Mixed-Sensitivity Approach to $H\infty$ Control of Power System Oscillations Employing Multiple FACTS Devices – IEEE Trans. Power Systems, vol. 18, No. 3, August 2003 pp. 1149–1156.

[30]. H.Cai, Z.Qu, D.Gan and J.F.Dorsey, “A Robust Power System Stabilizer Design Based on Lyapunov's Approach”, Proceedings of the American Control Conference Albuquerque, New Mexico June 1997 0-7803-3832-4/97/$10.00 0 1997 AACC.

[31]. H.F. Wang, “Application of an Eigensolution Free Method to Design Power System FACTS-based Stabilizers”, 0-7803-5546-6/99/$10.00 @ 1999 IEEE

[32]. WANG, H.F., SWIFT, F.J., and LI, M.‘Selection of installing locations and feedback signals of FACTS based stabilizers in multi-machine power systems by reduced-order modal analysis’, ZEE Proc. , Gener. Transm. Distrib., 1997, 144, (3), pp263-269.

[33]. Y. L. Abdel-Magid, M. A. Abide, S. Af-Baiyat, and A. H. Mantawy, “Simultaneous Stabilization of Multi machine Power Systems Via Genetic Algorithms,” IEEE Trans. PWRS, Vol. 14, No, 4, 1999, pp. 1428-1439.

[34]. M. A. Abide, “A novel approach to conventional power system stabilizer design using tabu search:’ Int. Journal of Electrical Power & Energy Systems, Vol.21, No. 6, 1999, pp. 443-454.

[35]. M. A. Abido, “Robust Design of Multimachine Power System Stabilizers Using Simulated Annealing,” IEEE Tram. on Energy Conversion, Vol. 15,No. 3,2000, pp. 297-304.

[36]. Shigen Cui, Ymhiaki Taka, Hiroyuki Ubi, Hisashi Kando, Koichi Nakamura, and Hideki Fujita, “Design of Power System Stabilizer Based on Robust Gain Scheduling Control Theory”, 0-7803-6338-8/00/$10.00(~) 2000 IEEE.

[37]. J. Kennedy and R.C. Eberhart, “Particle Swarm Optimization”, in Proc. IEEE Conf. Neural Networks IV, Piscataway, NJ , 1995.

[38]. M. A. Abido, “Swarm Optimization for Multimachine Power System Stabilizer Design”, 0-7803-7173-9/01/$10.00 © 2001 IEEE

[39]. M. A. Abido, “Optimal Design of Power–System Stabilizers Using Particle Swarm Optimization”, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 17, NO. 3, SEPTEMBER 2002.

[40]. Y. L. Abdel-Magid, M. A. Abido, S. Al-Baiyat, and A. H. Mantawy, “Simultaneous stabilization of multimachine power systems via genetic algorithms,” IEEE Trans. Power Syst., vol. 14, pp. 1428–1439, Nov. 1999.

[41]. V. A. Maslennikov and S. M. Ustinov, “The optimization method for coordinated tuning of power system regulators,” in Proc. 12th Power Syst. Comput. Conf. PSCC, Dresden, Germany, 1996, pp. 70–75.

[42]. Q. Zhao and J. Jiang, "Robust control design for generator excitation system," IEEE Trans. Energy Conversion, vol. 10, pp. 201–209, June 1995.

[43]. M. Klien, L. X. Le, G. J. Rogers, and S. Farrokhpay, "$H\infty$ damping controller design in large power systems," IEEE Trans. Power Syst., vol. 10, pp. 158–166, Feb. 1995.

[44]. K. A. Folly, N. Yorino, and H. Sasaki, "Robust stabilization of power system using an improved H - PSS," in Proc. Int. Conf. Elect. Eng., Beijing, China, Aug. 1996, pp. 188–192.

[45]. G. Beck and A. K. Packard, "Robust performance of linear parametrically varying system using parameterially dependent linear feedback," Syst. Control Lett., vol. 23, no. 3, pp. 205–215, 1994.

[46]. N. C. Pahalawaththa and U. C. Annakkage, "An optimum gain scheduling power system stabilizer," in Proc. Inst. Elect. Eng. Int. Conf. Advances in Power System Operation, Control, and Management, Hong Kong, Nov. 1991, pp. 211–215.

[47]. Prabha Kundur, Power System Stability and Control, Beijing: China Electric Power Press, 2002.

[48]. Hu Guoqiang, He Renmu, Yang Huachun, Wang Peng, Ma Rui, "Iterative Prony Method Based Power System Low Frequency Oscillation Mode Analysis and PSS Design", 2005 IEEE/PES Transmission and Distribution Conference & Exhibition: Asia and Pacific Dalian, China.

[49]. S. Baluja, "Population-Based Incremental Learning: A method for Integrating Genetic Search Based Function Optimization and Competitive Learning," Technical Report CMU-CS-94-163, Carnegie Mellon University, 1994.

[50]. S. Baluja and R. Caruana, "Removing the Genetics from the Standard Genetic Algorithm", Technical Report CMU-CS-95-141, Carnegie Mellon University, 1995.

[51]. K. A. Folly, "Design of Power System Stabilizer: A Comparison Between Genetic Algorithms (GAs) and Population-Based Incremental Learning (PBIL)", 1-4244-0493-2/06/$20.00 ©2006 IEEE.

[52]. Chun-Jung Chen and Tien-Chi Chen, "Design of a Power System Stabilizer Using a new Recurrent Neural Network", Proceedings of the First International Conference on Innovative Computing, Information and Control (ICICIC'06) 0-7695-2616-0/06 $20.00 © 2006.

[53]. A. Kolesnikov, G. Veselov, et al. "Modern Applied Control Theory: Synergetic Approach in Control Theory", Vol. 2, (in Russian), Moscow – Taganrog, TSURE Press, 2000.

[54]. A. Kolesnikov, G. Veselov, A. Monti, F. Ponci, E. Santi, and R. Dougal, "Synergetic Synthesis of DC-DC Boost Converter Controllers: Theory And Experimental Analysis", Proceedings of 17th Annual IEEE Applied Power Electronics Conference, Vol. 1, pp. 409-415, Dallas, TX, April 2002.

[55]. E. Santi, A. Monti, D. Li; K. Proddutur, R. A. Dougal, "Synergetic control for DC-DC boost converter: implementation options", IEEE Transactions on Industry Applications, Vol. 39, No. 6, pp. 1803 – 1813, Nov. 2003.

[56]. Y. Son, T. Heo, E. Santi, A. Monti, "Synergetic control approach for induction motor speed control", Proceeding of 30th Annual Conference of IEEE Industrial Electronics Society, Vol. 1, pp. 883 – 887, Nov. 2004.

[57]. I. Kondratiev, E. Santi, R. A. Dougal, G. Veselov, "Synergetic control for m-parallel connected DC-DC buck converters", Proceedings of IEEE Power Electronics Specialists Conference, Vol. 1, pp. 182 – 188, June 2004.

[58]. Z. Jiang and R. Dougal, "Synergetic Control of Power Converters for Pulse Current Charging of Advanced Batteries from a Fuel Cell Power Source", IEEE Transactions on Power Electronics, Vol. 19, No. 4, pp. 1140-1150, July 2004.

[59]. Freddy Prasetia Ridhuan and Mohd Fauzi Othman, "Application Of Artificial Immune System To Design Power Systems Stabilizer", The 5th Student Conference on Research and Development - SCOReD 2007 11-12 December 2007, Malaysia 1-4244-1470-9/07/$25.OO ©) 2007 IEEE.

[60]. Dipanker Dasgupta, An Overview of Artificial Immune Systems and Their Applications, Artificial Immune Systems and their applications, Springer, 1998.

[61]. D. Dasgupta, Z.Ji F. Gonzalez. "Artificial Immune System (AIS) Research in the Last Five Years.", Published in the proceedings of the Congress on Evolutionary Computation Conference (CEC) Canberra, Australia December 8-12-2003.

[62]. L. Tong. Computer Immunology. Publish House of Electronics Industry. Beijing, 2004.

[63]. N. Hori, T. Mori, P. N. Nikiforuk, "A new perspective for discrete-time models of a continuous -time systems", IEEE Trans. On AC, VOl. 37-7, pp 1013 1017, 1992.

[64]. Miguel Ramirez-Gonzalez, Student Member, IEEE, and O. P. Malik, Fellow, IEEE, "Power System Stabilizer Design Using an Online Adaptive Neurofuzzy Controller With Adaptive Input Link Weights", IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 23, NO. 3, SEPTEMBER 2008.

[65]. Manisha Dubey, "Design of Genetic Algorithm Based Fuzzy Logic Power System Stabilizers in Multimachine Power System", 978-1-4244-1762-9/08/$25.00 ©2008 IEEE.

[66]. Hoang P, Tomsovic K, "Design and analysis of an adaptive fuzzy power system stabilizer", IEEE Transactions on Energy Conversion, 11(2), 1996,pp. 97-103.

[67]. Manisha Dubey and P. Gupta, " Design of Genetic-Algorithm based robust power system stabilizer", International Journal of Computational Intelligence", Vol. 2, No. 1, 2005,pp.48-52.

[68]. S. Chen and 0. P. Malik, "Power System Stabilizer Design Using μ Synthesis," IEEE Trans. Energy Convers., vol. 10, no. 1, pp. 175-181, Mar. 1995.

[69]. M. Soliman, H. Emara, A.Elshafei, A. Bahgat and O. P. Malik, "Robust Output Feedback Power System Stabilizer Design: an LMI approach", ©2008 IEEE.

[70]. D. Liu and Y. Cai, "Taguchi method for solving the economic dispatch problem with non-smooth cost functions", IEEE Trans. Power Syst., Vol. 20, No. 4, 2005, pp. 2006-2014.

[71]. M. Bounou, S. Lefebvre and X. Dai Do, "Improving the quality of an optimal power flow solution by Taguchi method", Int. J. Elect. Power Energy Syst., Vol. 17, No. 2, 1995, pp. 113-118.

[72]. Adam Dys´ko, Member, IEEE, William E. Leithead, and John O'Reilly, Senior Member, IEEE, "Enhanced Power System Stability by Coordinated PSS Design", IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 25, NO. 1, FEBRUARY 2010.

[73]. Severus Sheetekela, Student Member, IEEE, Komla Agbenyo Folly*, Member, IEEE, "Breeder Genetic Algorithm for Power System Stabilizer Design", 978-1-4244-8126-2/10/$26.00 ©2010 IEEE

[74]. John Greene,"The basic idea behind the Breeder Genetic Algorithm" Department of electrical engineering, Technical Report, UCT, 23 August 2005

[75]. Gurunath Gurrala, Graduate Student Member, IEEE, and Indraneel Sen, "Power System Stabilizers Design for Interconnected Power Systems", IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 25, NO. 2, MAY 2010.

[76]. E. Larsen and D. Swann, "Applying power system stabilizers, parts I, II and III," IEEE Trans. Power App. Syst., vol. PAS-100, pp. 3017–3046, Jun. 1981.

[77]. P. Kundur,M. Klein, G. Rogers, and M. Zywno, "Application of power system stabilizers for enhancement of overall system stability," IEEE Trans. Power Syst., vol. 4, no. 2, pp. 614–626, May 1989.

[78]. M. Nambu and Y. Ohsawa, "Development of an advanced power system stabilizer using a strict linearization approach," IEEE Trans. Power Syst., vol. 11, no. 2, pp. 813–818, May 1996.

[79]. G. Gurrala and I. Sen, "A modified Heffron-Phillip's model for the design of power system stabilizers," in Proc. POWERCON 2008, New Delhi, India, Oct. 12–15, 2008.

[80]. A. H. Nayfeh , A. Harb, C. Chin, A. M. A. Hamdan, L. Mili, "A bifurcation analysis of subsynchronous oscillations in power systems," Electric Power Systems Research, vol. 47 pp. 21-28, 1998.

[81]. N. Mithulananthan, C. Mohammed osman Hassan and S. J. Cheng, "Design and Parameters Optimization of Power System Stabilizer to Improve Power System Oscillations," 978-1-4244-5586-7/10/$26.00 C 2010 IEEE.

[82]. S. P. Ghoshal, A. Chatterjee, V. Mukherjee,"Bio-inspired fuzzy logic based tuning of power system stabilizer", Expert Systems with Applications 36 (2009) 9281–9292.

[83]. E. Daryabeigi, M. Moazzami, A. Khodabakhshian , M. H. Mazidi, "A NEW POWER SYSTEM STABILIZER DESIGN BY USING SMART BACTERIA FORAGING ALGORITHM", IEEE CCECE 2011 – 000713.

[84]. S. P. Ghoshal, A. Chatterjee, V. Mukherjee,"Bio-inspired fuzzy logic based tuning of power system stabilizer", Expert Systems with Applications 36 (2009) 9281–9292.

[85]. B. Sumanbabu, S. Mishra, B.K. Panigrahi, and G.K. Venayagamoorthy, "Robust Tuning of Modern Power System Stabilizers Using Bacterial Foraging Algorithm", IEEE Congress on Evolutionary Computation, pp. 2317-2324, 2007.

[86]. D. H. Kim,"Hybrid GA–BF based intelligent PID controller tuning for AVR system", Applied Soft Computing, Vol. 11, No. 1, pp.11-22, January 2011.

[87]. Gustavo K. Dill and Aguinaldo S. e Silva, "Power System Stabilizer Design Using Optimization and Pseudospectra" , Paper accepted for presentation at the 2011 IEEE Trondheim PowerTech 978-1-4244-8417-1/11/$26.00 ©2011.

[88]. J. V. Burke, A. S. Lewis, and M. L. Overton. Optimization and pseudospectra with applications to robust stability.

[89]. J. V. Burke, D. Henrion, A. S. Lewis, and Overton M. L. Stabilization via nonsmooth, nonconvex optimization. IEEE Transactions on Automatic Control, 51(11):1760–1769, November 2006.

[90]. Alka Sharma and Rajeev Gupta, "Design of Robust Power System Stabilizer Using Balance Truncation Method", 2012 Fourth International Conference on Computational Intelligence and Communication Networks 978-0-7695-4850-0/12 $26.00 © 2012 IEEE.

[91]. H.Werner and K.Furuta, Simultaneous stabilization based on output measurement, Kybernetika Vol.31pp.395-411, 1995.

[92]. Mahendra Kumar and Dr. Rajeev Gupta, "Design of Decentralized PSSs for Multimachine Power System via Reduced Order Model", 2012 Fourth International Conference on Computational Intelligence and Communication Networks 978-0-7695-4850-0/12 $26.00 © 2012 IEEE.

[93]. Rajeev Gupta, "Robust Non-dynamic Multi-rate Output Feedback Technique based Power System Stabilizer," Ph. D. Thesis, IIT, Bombay (India), 2004.

[94]. Rajeev Gupta, B. Bandyopadhyay and A.M.Kulkarni, Design of Decentralized Power System Stabilizer for Multi-Machine Power System using Fast Output Sampling Feedback Technique ,National Power System conference, NPSC2002, IIT Kharagpur (India), pp. 362-367.December 2002.

[95]. Rajeev Gupta, "Robust Non-dynamic Multi-rate Output Feedback Technique based Power System Stabilizer," Ph. D. Thesis, IIT, Bombay (India), 2004

[96]. FARAH A., GUESMI T., HADJ ABDALLAH H. & OUALI A., "Optimal Design of Multimachine Power System Stabilizers Using Evolutionary Algorithms" 2012 First International Conference on Renewable Energies and Vehicular Technology

[97]. O. K. Erol, I. Eksin, "A new optimization method: Big Bang- Big crunch", Adv. Eng. Software, vol. 37, 2006, pp. 106-111.

[98]. H. M. Genc, O. K. Erol, I. Eksin, "An Application and Solution to Gate Assignment Problem for Atatürk Airport", DECOMM 2009, 2009, pp. 125-130.

[99]. T. Kumbasar, E. Yesil, I. Eksin, M. Guzelkaya, "Inverse fuzzy model control with online adaptation via big bang-big crunch optimization", 3rd Int. Symp. on Communications, Control, and Signal Processing, 2008, pp. 697-702.

[100]. M. Dogan, Y. Istefanopulos, "Optimal nonlinear controller design for flexible robot manipulators with adaptive internal model", lET Control Theory and Applications, vol. 1(3), 2007, pp. 770-778.

[101]. H. M. Genc, A. K. Hocaoglu, "Bearing-only target tracking based on Big Bang - Big Crunch algorithm", The 3rd Int. Multi-Conference on Computing in the Global Information Technology, 2008, pp. 229-233.

[102]. D. Karaboga, B. Basturk, On The Performance of Artificial Bee Colony (ABC) Algorithm, Applied Soft Computing, Volume 8, Issue 1, January 2008, pp. 687-697.

[103]. D. Karaboga, B. Basturk, A powerful and Efficient Algorithm for Numerical Function Optimization: Artificial Bee Colony (ABC) Algorithm, Journal of Global Optimization, Vol.39, Issue 3, November 2007, pp. 459-171.

[104]. G. Naresh, M. Ramalinga Raju and M. Sai Krishna, "Design and Parameters Optimization of Multi-machine Power System Stabilizers Using Artificial Bee Colony Algorithm", 978-1-4673-2043-6/12/$31.00 ©2012 IEEE.

[105]. Aboul-Ela M.E, Sallam A.A, McCalley J.D and Fouad A.A, “Damping controller design for power system oscillations using global signals” Power Systems, IEEE Transactions on, vol. 11, Issue 2, May 1996 , pp.767 – 773.
[106]. Manisha Dubey and Yogendra Kumar, “Design of Interactive Artificial Bee Colony Based Multiband Power System Stabilizers in MultiMachine Power System”, 978-1-4673-6153-8/13/$31.00@2013 IEEE.
[107]. D.K. Sambariya and Rajendra Prasad, “Design of PSS for SMIB System Using Robust Fast Output Sampling Feedback Technique”, 978-1-4673-4603-0/12/$31.00 ©2012 IEEE.
[108]. H. Werner, "Multi model Robust Control by Fast Output Sampling-An LMI Approach," Automatica, vol. 34, pp. 1625-1630, 1998
[109]. L. A. Zadeh, "Fuzzy Sets," information Control, vol. 8, pp. 338-353, 1965.
[110]. D.K. Sambariya and Rajendra Prasad, “Robust Power System Stabilizer Design for Single Machine Infinite Bus System with Different Membership Functions for Fuzzy Logic Controller”, 978-1-4673-4603-0/12/$31.00 ©2012 IEEE.
[111]. P.R.Gandhi and S.K.Joshi, “GA and ANFIS based Power System Stabilizer”, 978-1-4799-1303-9/13/$31.00 ©2013 IEEE.
[112]. J.A.N. Pombo, S.J.P.S. Mariano, M.R.A. Calado, “Power System Stabilizer Design Based on Output Optimal Control Techniques”, 978-1-4799-2803-3/13/$31.00 ©2013 IEEE.
[113]. Mariano SJPS, Pombo JAN, Calado MRA, Ferreira LAFM (2010) Pole shifting procedure to specify the weighting matrices for a load-frequency controller. In: MELECON 2010 - 2010 15th IEEE Mediterranean Electrotechnical Conference, La Valleta, Malta, 26-28 April 2010.
[114]. Mariano, S.J.P.S.; Pombo, J.A.N.; Calado, M.R.A.; Ferreira, L.A.F.M., "Damping of power system oscillations with optimal regulator," Electrical Machines and Power Electronics and 2011 Electromotion Joint Conference (ACEMP), 2011 International Aegean Conference on , vol., no., pp.496,501, 8-10 Sept. 2011.
[115]. Mariano, S.J.P.S., Pombo, J.A.N., Calado M.R.A., Ferreira, L.A.F.M., "Pole-shifting Procedure to specify the Weighting Matrices for an Optimal Voltage Regulator" International Review of Automatic Control (Theory and Applications), Vol. 2. n. 6, pp. 685-692.
[116]. Syed Ahmed Raza and Syed Akbar Raza Naqvi, “Design of a Power System Stabilizer for a Synchronous Generator Using Hybrid Intelligent Controller”, 2013 IEEE GCC Conference and exhibition, November 17-20, Doha, Qatar.
[117]. Bagepalli Sreenivas Theja, Anguluri Rajasekhar, D.P. Kothari, “Design of PID Controller Based Power System Stabilizer Using Modified Philip-Heffron’s Model: An Artificial Bee Colony Approach”, 978-1-4673-6004-3/13/$31.00_c 2013 IEEE.
[118]. G. Gurrala and I. Sen, "A modified Heffron-Phillip's model for the design of power system stabilizers," Joint International Conference on Power System Technology and IEEE Power India Conference, 2008. POWERCON 2008, pp.1-6, Oct. 2008.
[119]. Muawia A. Magzoub, Nordin B. Saad, Rosdiazli B. Ibrahim, “Power System Stabiliser for Single Machine in Infinite Bus Based on Optimal Control Methods”, 2014 IEEE 8th International Power Engineering and Optimization Conference (PEOCO2014), Langkawi, The Jewel of Kedah, Malaysia. 24-25 March 2014.
[120]. F. Demello and C. Concordia, “Concepts of Synchronous Machine Stability as Affected by Excitation Control,” IEEE Trans. Power Appar. Syst., vol. PAS-88, no. 4, pp. 316–329, Apr. 1969.
[121]. S. I. Safie, S. Majid, A. R. Hasimah, A. Wahab, and M. H. Yusri, “Sliding mode control power system stabiliser (PSS) for single machine connected to infinite bus(SMIB),” no. PECon 08, pp. 122–126, 2008.
[122]. S Paul and K RO, “Optimal Design of Power System Stabilizer Using Oppositional Gravitational Search Algorithm”, Proceedings of 2014 1st International Conference on Non Conventional Energy (ICONCE 2014.
[123]. Z. Arizadayana, M. Irwanto, F. Fazliana, A.N. Syafawati, “Improvement of Dynamic Power System Stability by Installing UPFC Based on Fuzzy Logic Power System Stabilizer (FLPSS)”, 2014 IEEE 8th

International Power Engineering and Optimization Conference (PEOCO2014), Langkawi, The Jewel of Kedah, Malaysia. 24-25 March 2014.

[124]. Lokman H. Hassan, M. Moghavvemi, Haider A.F. Almurib, K. M. Muttaqi, “A Coordinated Design of PSSs and UPFC-based Stabilizer Using Genetic Algorithm”, 10.1109/TIA.2014.2305797, IEEE Transactions on Industry Applications.

[125]. H. F. Wang, "Applications of modelling UPFC into multi-machine power systems," IEE Proc. Gener. Transm. Distrib., vol. 146, pp. 306- 312, 1999.

[126]. S. Mishra, "Neural-network-based adaptive UPFC for improving transient stability performance of power system," IEEE Trans. Neural Networks, vol. 17, pp. 461-470, 2006.

[127]. Y. L. Abdel-Magid and M. A. Abido, "Robust coordinated design of excitation and TCSC-based stabilizers using genetic algorithms," Electr. Power Syst. Res., vol. 69, pp. 129-141, 2004.

[128]. M. A. Abido, "Pole placement technique for PSS and TCSC based stabilizer design using simulated annealing," Int. J. Electr. Power Energy Syst., vol. 22, pp. 543-554, 2000.

[129]. M. A. Abido and Y. L. Abdel-Magid, "Coordinated design of a PSS and an SVC-based controller to enhance power system stability," Int. J. Electr. Power Energy Syst., vol. 25, pp. 695-704, 2003.