Power System Stabilizers Based on Different Methods and Techniques

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ABSTRACT : Power system stability has received a great deal of attention over the year. Stability is now a major concern in planning and operating electric power System. A large interconnected power system is exposed to many disturbances, which make the system unstable and thus are a threat to its security. In recent days, the effects of these disturbances are more serious considering the intensive use available electric power and its wide transmission. These disturbances result in electromechanical oscillations being set up in the interconnected system. The capability of the system to achieve an operating equilibrium after disturbances are caused in it depends on its inherent strength and on the nature and intensity of the disturbance .Increasing attention has been focused on the eff.ect of excitation control on the damping of oscillations, which characterize the phenomena of stability. In particular it has been found useful and practical to incorporate transient stabilizing signal derived from speed, terminal frequency or accelerating power superimposed on the normal voltage error signal to provide for additional damping of this oscillation. Such device is known as Power System Stabilizer (PSS). The PSS extend the system stability limits by modulating generator excitation to provide damping to the oscillation of synchronous machine rotors relative to one another. The PSS produces a component of torque, which is in phase with the rotor speed deviations, in order to enhance system damping. Damping due to low frequency oscillation problems are very difficult to solve because power system are very large, complex. Therefore it is very necessary to utilize efficient techniques for implementation. From this perspective many successful methods and algorithms have been developed .This paper presents a survey of literature on the various methods, algorithms and optimization methods applied to solve the PSS problems. The purpose of this paper is to present an overview of the PSS, based on different techniques and optimization methods on published literature from 1994 to the present.

Keywords: PSS, Fuzzy logic, PSO, Low frequency oscillation.

I. INTRODUCTION

As interconnected power system depending upon size has hundreds to thousands modes of oscillation. In the analysis and control of system stability, two distinct type of system oscillations are usually recognized. One type is associated with unit at a generating station swinging with respect to the rest of the power system. Such oscillations are referred as "Local Plant Mode" oscillations. The frequencies of these oscillation and are typically the range 0.8-2.0 Hz. the second type of oscillation is associated with the swinging of many machine in one pare of the system machine at other part. These are referred to as "inter Area Mode". Oscillation and have frequencies in the range 0.1-0.7-Hz [13]. The basic function of the PSS is to add damping to both types of system oscillation. It provides a positive damping torque in phase with the speed signal to cancel the effect of the system negative damping torque.

The effect of power system stabilizers on the oscillatory modes of a generating plant, which consists of a number of equal, identical generators, is discussed. It is shown that the power system stabilizer design and the type of power system stabilizer input may alter the damping produced by the stabilizer on the exciter mode and the intra-plant electromechanical modes. A power system stabilizer which is designed to match the ideal phase lead over a wide frequency range is shown to add damping to plant, inter-area and intra-plant electromechanical modes. The exciter mode damping is shown to be reduced by power system stabilizers having frequency input [5].

The need of power system stabilizations has been increasing day by day. The demand for electric power requirement has motivated the usage of power system in an effective and reliable way. The stability of the power system is the ability to extend restoring forces equal to or greater than the disturbing forces to sustain the state of equilibrium. Power industries are restructured to provide effective utilization to more users at lower prices and better power efficiency. The complexity of the Power systems has been increasing as they become inter-connected. Load demand also increases linearly with the increase in users. Since stability phenomena limits the transfer capability of the system, there is a need to ensure stability and reliability of the power system due to economic reasons. With these conditions, experts and researchers were continually tasked to find simple, effective and economical strategy of attaining stabilization of the power system, which is considered of highest priority. Thus, because of the importance of the stability of the power systems, methods. The optimal sequential design for multi-machine power systems is very essential. As a result, serious consideration is now being given on the concern of power system stabilization control. In recent times, the utilization

of optimization techniques becomes possible to deal with control signals in power system stabilizing control techniques have been used for the multi-machine power system with the help of intelligent [32].

II. POWER SYSTEM STABILIZER (PSS)

Power System stabilizer (PSS) has board application through out the world. Power system stabilizer (PSS) applied to generate exciter to limit the excitation system phase lag in the frequency range corresponding to the natural frequency of the interconnected system. With interconnection of large electric power system, low frequency oscillations have become the main problem for power system small single stability. They restrict the steady state power transfer limits, which therefore affects operational system economics and security. Considerable efforts has been placed on the application of PSS's to damp low frequency oscillation and thereby improve the small signal stability of power system. [8]. The introduction of the supplementary controller for the power system not only improves the dynamic performance but also increase the stability margin.

Power systems stabilizers have been developed, using liner control theory to damp the oscillation of synchronous machine following any disturbance. Power system stabilizer design and characteristics have been discussed and dynamic model of PSS with excitation control system and generator for small perturbation has been analyzed. The Commonly used structure of the PSS is shown in Fig. 1. Where the PSS signal Vpss can be provided from a number of different input signals measured at the generator terminal. The measured quantity (or quantities) is passed through low and high pass filters. The filtered signal is then passed through a lead and / or lag element in order to obtain the required phase shift and finally, the signal is amplified passed to a limiter. When designing the phase compensation, it is necessary to take into account the phase shift of the input signal it and that introduced by the low and high pass filter.
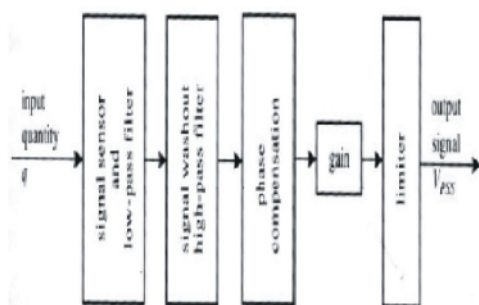
The major elements of a PSS

Fig. 1.

III. DIFFERENT TECHNIQUES IN PSS

A. Fuzzy logic based PSS

Fuzzy logic has emerged as a promising tool for several power system applications. A large body of the literature in this area is concerned with the stability of the electric power system, and considerable effort has been directed to the development of a fuzzy logic based power system stabilizer (FLPSS).Robustness of fuzzy logic stabilizers using the information of speed and acceleration states of a study unit has been investigated. The input signals are the real power output and/or the speed of the study unit. Non-linear simulations show the robustness of the fuzzy logic power system stabilizers. All the non-linear simulation studies show the efficiency of the proposed FPSS. The FPSS does not require heavy computations on the micro-computer; therefore, the real-time control is available by the FPSS. The experiments also show the efficiency and the feasibility of the proposed FPSS [1]. A micro-computer based fuzzy logic power system stabilizer is applied to a micro-machine system to investigate its efficiency in real time control. The stabilizing signal is determined by using measured speed or real power signals at every sampling time to damp the system oscillations. The results show the proposed stabilizer improves the system damping effectively subject to various types of disturbances [2].

The phase-plane is very useful for designing the rule base for FLC. Under this methodology, the rule base can be easily built and updated. The delayed information can be easily incorporated to reduce the dead time effect of the process. A phase plane is used to bridge the gap between the time-response and rule base. The rule base can be easily built using the general dynamics of the process, and then readily updated to contain the delayed information for reducing the dead time effects of the process. An adaptive gain method is also proposed to help the data base design and the controller tuning. Under the new methodology-adaptive gain adjustment, better performances of both the transient and static period can be achieved. This methodology is much more efficient than using multi decision tables. Experimental results show that for a process with long dead times, or varying dead times, FLC can achieve a better performance than a PID controller. FLC can achieve a good result for a complex process with dynamic variation [3].

A fuzzy logic power system stabilizer (FPSS) has been developed using speed and active power deviations as the controller input variables. The inference mechanism of the fuzzy logic controller is represented by a (7×7) decision table, *i.e.* There is no need of a plant model to design the FPSS. Two scaling parameters have been introduced to tune the FPSS. These scaling parameters are the outputs of a neural network which gets the operating conditions of the power system as inputs. This mechanism of tuning the FPSS by the neural network makes the FPSS adaptive to changes

in the operating conditions. Therefore, the degradation of the system response, under a wide range of operating conditions, is less compared to the system response with a fixed-parameter FPSS. The tuned stabilizer has been tested by performing nonlinear simulations using a synchronous machine-infinite bus model. The responses are compared with tie fixed-parameter FPSS and a conventional (linear) power system stabilizer. It is shown that the neuro-fuzzy stabilizer is superior to both of them [4].

A multiobjective problem is formulated to optimize a composite set of objective functions comprising the damping factor, and the damping ratio of the lightly damped electromechanical modes. The problem of robustly selecting the parameters of the power system stabilizers is converted to an optimization problem which is solved by a genetic algorithm with the eigen value based multiobjective function. The effectiveness of the suggested technique in damping local and inter area modes of oscillations in multimachine power systems, over a wide range of loading conditions and system configurations, is confirmed through eigenvalue analysis and nonlinear simulation results. Optimal multi objective design of robust multi machine power system stabilizers (PSSs) using GAs is presented. The nonlinear time-domain simulation results show that the presented PSSs work effectively over a wide range of loading conditions and system configurations [7]. deviation of active power through the tie line connecting two are as is used as one of the inputs to the fuzzy PSS in conjunction with the speed deviation presented a new input signal based fuzzy power system stabilizer in multi-machine environment. The advantage of this input is that, the same signal can be fed to each of the fuzzy logic PSS attached with each machine, which reduces cost, scanning time and thus simplifies the structure. Apart from the simplicity and cost effectiveness, it is found that the proposed PSS is performing satisfactorily within the whole range of disturbances [9].

The fuzzy logic power system stabilizer use estimated load angle of synchronous generator as the input. The load angle estimation is based on the real parameters of asynchronous generator, which are given by the corresponding Voltage-current vector diagram. [10] The enhancement of damping the power system oscillation via coordinated design of the Fuzzy Power System Stabilizer (FPSS) and Fuzzy FACTS Device Stabilizer (FFDS) by using an opportune local and remote signal for FPSS and FFDS has been used [12]. A new method was presented for design of power system stabilizer (PSS) based on relay-free sliding mode control technique. The slip signal is taken as output and relay-free sliding mode control is applied at an appropriate sampling rate. It is found that designed controller provides good damping enhancement. The simulations clearly show the elimination of chattering in control by the proposed technique [13]. The performance of fuzzy-logic power system stabilizer (FPSS), which is tuned automatically as the

operating conditions of power system change, was investigated by applying it to a multi-machine power system. FPSS is developed using speed deviation and the derivative of speed deviation as the controller inputs variables [14]. An adaptive fuzzy logic power system stabilizer (AFPSS) consisting of a generalized neuron (GN)-based predictor and a fuzzy logic controller (FLC) was proposed. The inference mechanism of the FLC is represented by a rule-base and a database. Two parameters, decided on the basis of the GN-predictor output and the current system conditions, are used to tune the AFPSS. This mechanism of tuning makes the fuzzy logic-based power system stabilizer adaptive to changes in the operating conditions. Therefore, variation in the system response, under a wide range of operating conditions, is less compared to the system response with a fixed-parameter conventional PSS [15]. The focus of this paper was to use fuzzy logic principles to develop supervisory power system stabilizers (SPSS) to enhance damping of inter-area oscillations to improve stability and reliability of power systems subjected to disturbances [16].

Imam Robandi, *et al.* presented the performance of an application of latest development of type1 fuzzy logic which is interval type 2 fuzzy logic as a Power System Stabilizer (PSS). Interval Type 2 Fuzzy Logic PSS (IT2FLPSS) is a proportional-derivative type fuzzy logic PSS consists of interval type2 fuzzy logic controller and adjustable proportional and derivative gain. IT2FLPSS uses rotor speed deviation as a main input and armature power as auxiliary input. Simulations were done with several fault tests at transmission line on Kundur Test System. As reference Type1 Fuzzy Logic PSS (T1FLPSS), IEEE PSS4B (Multi Band PSS) and IEEE PSS2B (wPSS) from IEEE std 421.5 have been used to be compared to IT2FLPSS [19].

Vani *et al.* presented a step-by-step design methodology of an Adaptive Neuro-Fuzzy Inference System (ANFIS) and *H* optimization methods based Automatic Voltage Regulator (AVR) and Power System Stabilizer (PSS). The ANFIS design employed a zero and a first order Sugeno fuzzy model, whose parameters were tuned off-line through hybrid learning algorithm. This algorithm was a combination of Least Square Estimator and Error Back propagation method [19]. During a major disturbance such as a fault, the operating point of a power system drifts; a nonlinear controller will be more effective under such conditions. The Fuzzy PID controller is such a controller. To cover a wider range of operating conditions, fuzzy logic power system stabilizers was proposed. Particle Swarm Optimization was used to tune the parameters of FLPSS was presented [21].

Now the recent work has been done by Hasan. Hasan et al presented the effect of the reactive power deviation (ΔQ) auxiliary signal on the classic power system stabilizers (PSS) with ?P+ ?? inputs. and then the multi-input power system stabilizer (MPSS) with $\Delta\omega + \Delta Q + \Delta P$ inputs was investigated. Then, the effect of communication lines active

power variance signal between two ΔP Tie-line regions, as one of the inputs of fuzzy multi-input power system stabilizer (FMPSS), on the increase of low frequency oscillation damping is examined. The efficiency of the proposed model is examined by simulating a four-machine power system. Results show the model reduces the cost of system [27].

B. Optimization methods Based PSO

A new technique based on particle swarm optimization PSO was proposed to optimize the parameters settings of CPSS. The problem is formulated as an optimization problem, the objective is to compute the optimal parameters settings such that damping ratio maximized as much as possible. The performance and robustness of optimized CPSS (OPSS) is then, tested on 9-bus multi-machine system under normal operating conditions, heavy loadings and response to three phase short circuit. Eigen values results and nonlinear time domain simulation show the effectiveness and robustness of the proposed OPSS over CPSS under different proposed cases [19].

A novel evolutionary algorithm-based approach to optimal design of multimachine power-system stabilizers (PSSs) was proposed. The proposed approach employed a particle-swarm-optimization (PSO) technique to search for optimal settings of PSS parameters. Two eigen value-based objective functions to enhance system damping of electromechanical modes are considered. The robustness of the proposed approach to the initial guess is demonstrated. The performance of the proposed PSO-based PSS (PSOPSS) under different disturbances, loading conditions, and system configurations is tested and examined for different multimachine power systems [6]. Hu Guoqiang, et al presented a GA based optimization scheme for simultaneous coordination of multiple machines power system damping controllers. The proposed algorithm will be applied to tuning of single and multiple power system stabilizers. Controller design will be tested on the small and mid-sized power systems to prove its effectiveness [8].

H. Shayeghi, *et al.* multiobjective design of multi-machine Power System Stabilizers (PSSs) using Particle Swarm Optimization (PSO) was presented. The stabilizers are tuned to simultaneously shift the lightly damped and undamped electro-mechanical modes of all machines to a prescribed zone in the s-plane. A multi objective problem is formulated to optimize a composite set of objective functions comprising the damping factor, and the damping ratio of the lightly damped electromechanical modes. The PSSs parameters tuning problem is converted to an optimization problem which is solved by PSO with the eigenvalue-based multi objective function. The proposed PSO based PSSs is tested on a multimachine power system under different operating conditions and disturbances through eigenvalue analysis and some performance indices to illustrate its robust performance. Time-domain simulations show that the oscillations of

synchronous machines can be quickly and effectively damped for power systems with the proposed PSSs over a wide range of loading conditions. The system performance characteristics in terms of 'ITAE' and 'FD' indices reveal that the proposed multi-objective function based tuned PSSs demonstrates its superiority in computational complexity, success rate and solution quality [17].

Hisham *et al.* Presented a technique based on particle swarm optimization is developed for tuning the parameters of a fixed structure PSS. Besides ensuring system stability, the proposed controller provides a minimal-overshoot response over a wide range of power system operation while satisfying control constraints imposed on the system. The algorithm overs designers the fexibility to achieve a compromise between conflicting design objectives, the overshoot and control constraint. The design of such a controller is done off-line, so the computational time is not of prime importance. Application of the developed method to a typical problem show edits electiveness in achieving the stated design objectives [18].

A novel algorithm to determine the PSS parameters, using the multi-objective optimization approach called particle swarm optimization with the passive congregation (PSOPC) was introduced. The tuning of the PSS parameters is usually formulated as the objective function with constraints, including the damping ratio and damping factor. Maximization of the damping factor and the damping ratio of power system modes are taken as the goals or two objective functions, when designing the PSS parameters. The optimization procedure handles the problem-specific constraints using a penalty function. This could enhance the diversity of the swarm and lead to a better outcome. The two-area multi-machine power system, under a wide range of system configurations and operation conditions is investigated, to illustrate the performance of the proposed approach. In this paper, the performance of the proposed PSOPC is compared to the Standard Particle Swarm Optimization (SPSO) and Genetic Algorithm (GA) in terms of parameter accuracy and computational time. The results verify that, the PSOPC is a much better optimization technique, in terms of accuracy and convergence, compared to PSO and GA. Furthermore, nonlinear simulation and eigenvalue analysis based results also confirm the efficiency of the proposed technique [24].

Eslami *et al.* presented a bibliographical survey of the work published on the application of different optimization techniques applied to solve the problems of power system stabilizer. PSO accesses deep knowledge of system problems by well-established models. PSO is a kind of random search algorithm that simulates the natural evolutionary process by mimicking the social behavior of swarms of birds and insects (particles). Compared with other optimization algorithms, like GA, HS, TS, SA, and ACO, it has some advantages, including simple implementation, small

computational load, and fast convergence. Therefore, it is efficient for solving many problems for which it is difficult to find accurate mathematical models. Despite these advantages, the PSO algorithm is prone to relapse into local minima and premature convergence when solving complex optimization problems. Also, PSO has much more potential in power system stability and is the latest entry into the artificial intelligence fields and is getting most of the current attention. PSO needs to be understood in relation to the computation requirements and convergence properties [26].

Now a new cost function is presented for the tuning of PSS parameters. Optimization of PSS parameters has been done by Particle Swarm Optimization and Imperialist Competitive Algorithm. Using a new objective function and algorithm of the optimization ICA and PSO, The optimal design of power system stabilizer can be done. The results of simulations show that new objective function, SMVS-DFT is a suitable objective function to study stability. This function decreases when the deviation speed of generator is damped. It is shown that ICA and PSO algorithms have fast convergence to decrease SMVS-DFT and consequently to find PSS parameters and to damp disturbances. The evaluation of the comparison of the conventional PSS and the tuned PSS based on PSO and ICA using SMVS-DFT depicts that the disturbances damping with PSO and ICA using SMVS-DFT is better than CPSS. Also ICA using SMVS-DFT is better than PSO [28].

To overcome the drawbacks of CPSS, a new optimal PID type PSS based on PSO (PSO-PSS) method has been successfully proposed. The design strategy includes enough flexibility to set the desired level of stability and performance, and to consider the practical constraints by introducing appropriate uncertainties. Also the final designed PSO-PSS is low order and its implementation is easy and cheap. The proposed method was applied to a typical single machine infinite bus power system containing system parametric uncertainties and various loads conditions. The simulation results demonstrated that the designed PSO-PSS is capable of guaranteeing the robust stability and robust performance of the power system under a wide range of system uncertainties [29].

C. Other methods for PSS

A nonlinear analysis framework based on normal form (NF) theory and center manifold reduction is proposed to determine the most effective selection of generating units to be equipped with power system stabilizers. The proposed method takes into account the nonlinear system structure and provides information on the effect of control action on nonlinear behavior rand modal interaction. Based on a second-order NF representation of the system, the effect of control action on nonlinear behavior is approximated via suitable modi?cation of the initial conditions in the nonlinear coordinate transformations which relate the physical system to the NF coordinates. On the basis of this model, nonlinear

power system stabilizer (PSS) sensitivity indices are then proposed to determine the optimum sites to allocate PSS, and criteria to assess the effect of control action on linear modal interaction are developed [11].

Inspired by observing the similarity between adaptive control systems and recurrent neural networks (RNNs), a new control scheme, the recurrent adaptive control (RAC), was presented. Back propagation through time (BPTT), a learning algorithm for RNNs, can be exploited in RAC. Application of truncated BPTT to RAC is also discussed. Further, a new control algorithm for RAC, termed recursive gradient (RG), is developed to improve the performance of the original and truncated BPTT algorithms [22]. Support Vector Machine based Power System Stabilizer (SVMPSS) using sigmoidal kernel is presented to adapt the PSS parameters to improve power system dynamic stability. Time domain simulations of the system with SVMPSS given a good speed deviation and change in rotor angle response at different type of loading condition. The results show that the performance of the SVMPSS parameters yields the less settling time and less overshoots as compared with conventional PSS parameters [25].

The proposed SFLA was introduced to identify the parameters of a fixed structure lead compensator through the solution of a min-max problem while satisfying the systems constraints. To robustly design the PSS performance under wide loading conditions, a set of operating points is considered. The designed PSS is applied to a single machine infinite bus system operating at different loading conditions and the results demonstrated the effectiveness of the developed technique. The SFLA algorithm offers designers the flexibility to achieve a compromise between conflicting design objectives, the overshoot and setting time. The design was done off-line, which also can be performed on-line for time varying or time dependent systems so that the computational time and global optimization on a single-run process was of prime importance. Application of the developed method to a typical problem, especially in comparison with such traditional implementations illustrated the performance and effectiveness in achieving the stated design objectives [30].

In this paper, a robust and comprehensive technique for the optimization of power system controller parameters is developed. The optimization process, based on Eigen value sensitivity and linear programming approach, aims to shift the critical Eigen value to the left of the *s*-plane as far as possible. The proposed algorithm involves new constraints, a controlling parameter β and a stopping criterion which all aim to maintain the stability of the numerical technique, ensure its convergence and regulate the speed and number of iterations. This technique is applied to a single synchronous generator, connected to an infinite bus, through a transmission line with a shunt load, equipped with PSS [31]. Now the Artificial Bee Colony algorithm for better

stability of the power system has been used by some researcher. Simulation results suggest that the proposed technique has better for power system stabilization when compared to the conventional techniques [32]. A Method presented a location identification of power system stabilizer based on a participation factor . The analysis of the load effect on eigen values confirms that the calculation of best location of PSS by participation factor method is more effective in enhancing the small-signal stability of the system. The Recursive Least Square (RLS) algorithm based PID controller is used to tune the parameters of the PSS to achieve quicker settling time for the system parameters such as load angle and speed deviation.

IV. CONCLUSION

Power system stabilizer design can have a considerable effect on the damping of the electrochemical modes associated with a generating plant consisting or identical generator unit. A power system stabilizer designed to match the ideal phase lead over a wide frequency range generally has a beneficial effect on the damping of both inter-area, local (or plant), and intra-plant modes. This paper has presented an overview of power system stabilizers, based on published literature from 1994 to the present.

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