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Stabilization Of Power System Using Artificial Intelligence Based System

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Abstract— This paper reviews limitations of traditional control system and modern control system controllers, which are overcome to some extent using artificial intelligent techniques, such as ANN, Fuzzy Logic, Expert System, Particle Swarm Optimization, Genetic Algorithm, etc. The review shows that efforts are made towards Power System Stabilizer based on Artificial Intelligent Techniques, which will give positive impact on the system stabilities and improve system performances.

Keywords—ANN; PSO; Fuzzy Logic; Genetic Algorithm.

I. INTRODUCTION

Power system engineering forms a vast and major portion of electrical engineering studies. It is mainly concerned with the production of electrical power and its transmission from the sending end to the receiving end as per consumer requirements, incurring minimum amount of losses. The power at the consumer end is often subjected to changes due to the variation of load or due to disturbances induced within the length of transmission line. For this reason the term power system stability is of utmost importance in this field, and is used to define the ability of the of the system to bring back its operation to steady state condition within minimum possible time after having undergone some sort of transience or disturbance in the line. Ever since the 20th century, till the recent times all major power generating stations over the globe has mainly relied on AC distribution system as the most effective and economical option for the transmission of electrical power.

The Automatic Voltage Regulator (AVR) and exciter are the main components of the generator excitation system. The terminal generator voltage sensed and compared with the reference voltage to control the exciter output. Subsequent to any disturbance the damper and the field winding attempt to damp rotor swing. The damping process repels by the negative damping torques introduced by AVR.

As a result, the power system may expose undesirable oscillations or lose synchronism. For this concern, the Power System Stabilizer (PSS) become technologically advanced and expanded to serve for an effective functioning. The main function of the PSS in the excitation system is introducing an additional signal to provide a damping component that is in the phase with the rotor speed deviation. Therefore, the System Stability will be enhanced by adding PSS device.

Stabilizers that developed according to classical and modern control theories are based on liberalized machine model. Power system is a nonlinear, complex system and is subjected to different kinds of disturbances that yield unresolved issues and uncertain consequences in different power system problems. With such limitations, it is difficult to stabilize power system efficiency by these kinds of PSSs. Therefore, other types of modern control techniques like adaptive controller and H_∞ control system were used to achieve better operating performance as distinguished from conventional stabilizers.

Artificial Intelligence (AI) techniques proved to be effective tools to resolve many power system problems and those they could be more effective when properly joined together with conventional mathematical approaches were proposed based on these AI techniques. In this work, a serious attempt is made to present a comprehensive analysis of artificial intelligent techniques for designing PSS, which are proposed by researchers recently. The performance of a variety of controllers is demonstrated and compared with other types of controllers.

II. POWER SYSTEM STABILIZER

A. Application Support

Excitation systems with high gain and fast response times greatly aid transient stability (synchronizing torque), but can also reduce small signal stability (damping torque). Power system stabilizer (PSS) control provides a positive contribution by damping generator rotor angle swings, which are in a broad range of frequencies in the power system. These range from low frequency intertie modes (typically 0.1 - 1.0 Hz), to local modes (typically 1 - 2Hz), to intra-plant modes (about 2 -3 Hz).

B. Tuning Modes

The PSS provides modulation of field voltage that damps out power and speed oscillations through normal AVR control. The tuning study determines the optimum PSS settings, based on the particular generator, AVR settings, and system characteristics. Special purpose detailed models are used for this analysis. Our studies determine the key adjustment of PSS phase compensation. To complement this offering, we also perform PSS/Torsional Interaction screening for steam turbines with low modal frequencies. These studies are performed to determine if a torsional filter is required.

C. Testing's of the AVR/PSS Control

Testing of the PSS is normally performed during plant commissioning. The test condition for PSS is at or near base load output of the plant. The testing of modern excitation systems is facilitated by the use of internal data recording and test signals.
The basic types of tests usually performed are given in the following list.
1. Step test in AVR reference (base load – without PSS).
2. Gain margin test to determine the PSS gain to be used.
3. Step test in AVR reference (base load – with PSS).

D. Conventional PSS Schematic Diagram

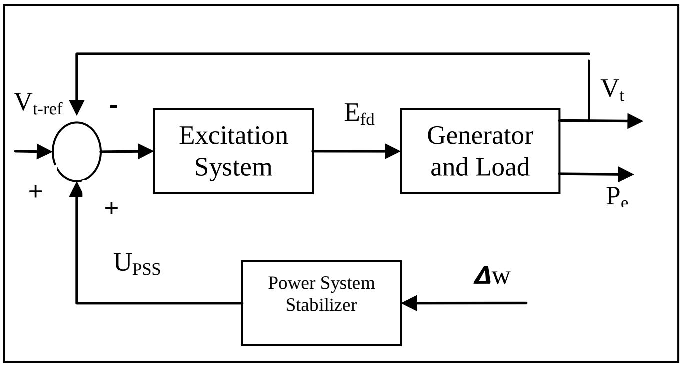

Figure 1: Schematic Diagram of PSS

A schematic block diagram of a generator, excitation system and power system stabilizer (based on a speed error signal) is shown in Figure 1. A phase compensation approach is usually employed for design of the PSS. At the natural mechanical frequency of oscillation, or local mode frequency, the phase lead of the PSS is chosen to compensate for the combined lag of the excitation system and the generator relating A V_{t-ref} t AP_e. The PSS then provides a component of electrical power in phase with speed and therefore directly contributes to the system damping at that frequency. The magnitude of this damping component is determined by the chosen compensator gain.

III. INTELLIGENT TECHNIQUES BASED CONTROLLERS

In the recent year of developments, the classified and reviewed techniques include fuzzy logic system, ANN, optimization based AI, and hybrid AI.

A. Fuzzy Logic Controller

Sir Zadeh has introduced the concept of fuzzy logic in 1963. The fuzzy logic is derived from fuzzy set theory. In fuzzy set, infinite number of membership are allowed. The degree of each membership for each element is indicated by a number between 0 and 1.

To design traditional controllers, it is necessary to liberalize nonlinear systems. Then, control laws are derived based on the new model. These controllers are used to control the system. Fuzzy logic controllers are nonlinear. Moreover, fuzzy logic controllers do not need a controlled plant model, and not sensitive to plant parameter variations. By using fuzzy logic, the human experience can be used in designing the controller.

Fuzzy logic controllers are rule-based. The rules of the system are written in natural language and translated in fuzzy logic. First, the crisp inputs values are converted through fuzzification process to corresponded linguistic fuzzy sets with appropriate membership values using normalized member functions.. There are different ways to define the result of a rule e.g. max-min inference method, etc. Finally, defuzzifire converts the linguistic variables to crisp values using normalized membership functions and output gains.

El-Sherbiny et al. presented a simple controller based on state feedback control system. The excitation control signal comprises both of the fuzzy controller and the conventional PI controller output signals.

A stabilizer which covers both heavy and light conditions can provide better performance than conventional PSS. This is investigated in study. In this study, two linear PSSs were developed based on the conventional frequency domain method to accommodate above conditions. Fuzzy reasoning was formed to find a single stabilize signal in such away that the signal matches the operating condition optimally.

Hossein-Zadeh and Kalam introduced an indirect adaptive fuzzy power system stabilizer. The power system was represented by two unknown nonlinear differential equations. Two fuzzy logic systems built based on these equations and then the stabilizer designed according to that. Lyapunov's synthesis method applied to adapt the fuzzy logic systems.

A direct adaptive fuzzy logic stabilizer proposed by with a small rule base as to compared to a standard fuzzy logic stabilizer. In order to adapt the stabilizer to different operating conditions, the rule-base was tuned on-line for Single Machine Infinite Bus (SMIB) and multi-machine power systems. Here, the controller parameters are estimated using the variable-structure algorithm.

Mitra et al. proposed a fuzzy power system stabilizer with a new input signals. These signals are tie line connecting two areas and the speed deviation. The approach gave better dynamic performance compared to a conventional PSS and fuzzy PSS with a usual speed deviation and acceleration input signals. The cost and scanning time of the approach were reduced because the same signal can fed to each of the fuzzy logic PSSs.

A new global tuning technique proposed by for fuzzy power-system stabilizers in a multi-machine power system in order to damp the power system oscillations. This technique is based on an iterative adaptive efficient partition algorithm. Numerical results show that this algorithm can find the optimal global solution faster than a conventional Genetic Algorithm (GA).

Soliman et al. proposed a linear matrix inequalities (LMI) design of a model-based fuzzy static output-feedback PSS. Here, a power system design model is represented by a Takagi–Sugeno (T–S) fuzzy model. This model is used to develop a stabilizer working with different operating conditions and disturbances. A static fuzzy PSS that guarantees robust pole-placement in an LMI region has been designed. Simulations results show capability of the proposed approach in damping of inter area oscillations for 4-machine 2-area power system.

Wide-area measurement systems (WAMS) can be used to improve the large scale power system performance. Delay time during sending and receiving signal may be corrupt system performance. To overcome this drawback, Dou et al. proposed the delay-independent robust control problem based on WAMS using H_∞ fuzzy control method. Here, the nonlinear large interconnected power systems represented by a set of equivalent T–S fuzzy model. The model stabilized by using feedback decentralized control scheme.

B. Artificial Neural Network Controller

An artificial neural network is a mathematical model or computational model based on Biological neural networks. It consists of a number of simple nodes (neurons) connected together to form either a single layer or multiple layers. The connections between neurons are weights that should be trained. Connections from one layer back to a previous layer, and connections between neurons in the same layer are called feedback connections.

There are different types of Neural Networks (NNs); a NN is said to be feed-forwarded network if the input and intermediate signals (connections) are always propagated forwards i.e. the information moves from input to output through hidden layers in forward direction without any loops, while a recurrent NN is a network that has more than one cycle.

ANN as an effective tools used for many years for identification and control of complex systems due to the non-linear mapping properties of the neural networks. Neural network when sufficiently trained may be used as controller instead of conventional PSS. To achieve good performance, the NN must be trained for different operating conditions to tune the parameters of the conventional PSS. The process of learning using the conventional back propagation network under different conditions makes interference. To overcome this drawback, Pillutla and Keyhani suggested a modular NN instead of back propagation network. This model consists of three local expert networks and a single gate network with three layers for each one. The ANN was trained directly from the input and output of the conventional PSS. The simulation results demonstrated that the modular PSS is more effective in damping system oscillations and providing good performances.

A feed forward neural network with single hidden layer was used, to develop a neural adaptive power system stabilizer. These approaches used different techniques. Each stabilizer is comprises of two sub networks; Adaptive Neuro-Identifier (ANI) and adaptive neuro-controller (ANC). Both sub-networks were trained by using the back propagation algorithm. While the first one approach based on the direct adaptive control scheme, the second one based on the indirect adaptive control scheme and adapted on-line.

Radial basis function network (RBFN) has three layers which are: input, hidden, and output layers. Here, RBF is usually a gaussian function. The hidden layer is trained at first using an unsupervised learning algorithm to find centers and widths of the radial basis functions for individual pattern units. To find the weights between the pattern units and the output units, the output layer is trained using supervised learning algorithm.

Abido and Abdel-Magid developed an RBFN to re-tuned PSS parameters on-line based on real-time measurement of the machine loading conditions.The proposed stabilizer was trained for different operating conditions and system parameter variations. A set of significant radial basis network parameters were obtained using orthogonal least squares learning algorithm functions and the

A very large number of training is required in the neural network as is used in the approach presented by. To avoid this problem a self-tuning PSS based on ANN proposed by [21]. In this approach the ANN was introduced for tuning the conventional PSS parameters in real-time. A new method applied for selecting the number of neurons in the hidden layer.

To improve the transient stability of power systems under different operating conditions and parametric uncertainties, Senjyu et al. proposed a Recurrent Neural Network (RNN) stabilization controller. The proposed supplementary RNN controller was applied for both AVR and the governor. The weight of the controller adjusted on-line. The signal output of first RNN was added to the PSS signal output for excitation control. The signal output of second RNN was used as a stabilizing signal for the governor system. The proposed approach applied to single-machine infinite bus.

Due to complexity of large-scale power systems, design of intelligent controllers based ANN, requires large training time and large number of neurons. These motivate Chaturevdi and Malik to use Generalized Neurons (GN) to develop a generalized neuron-based adaptive PSS. The stabilizer was trained off-line for a wide range of operating conditions and different disturbances. It was then trained on-line on the power system. The simulation achieved on SMIB system and the results reveals that the proposed stabilizer performs well under severe disturbances.

In order to enhance the system performance, Gain-Scheduling technique was applied to design a PSS. This type of stabilizer functions better than the conventional PSS. Barreiros et al. proposed a neural power system stabilizer which is trained using a set of gain scheduling PSS parameters. These parameters were obtained by applying pole-placement technique for different operating conditions. They conclude that the stabilizers would be more beneficial at the case when the reactive power absorbed by the generators.

The single neuron model was employed by to the probabilistic eigen value analysis for improving the optimization of robust PSS parameters. The PSS performance was self-adjusted to follow the system operating condition by forming an aiding PSS gain from the single neuron model. The approach applied successfully to an eight-machine system equipped with six PSSs.

Adaptive critics and neural networks were used by to design and real time implementation of an Optimal Wide Area Control Systems (WACS). The WACS was implemented on digital signal processor (DSP) which is interfaced to the real time digital simulator (RTDS). In this approach, neural network system developed to estimate the power system dynamics and to build nonlinear optimal control. Simulation results show that the damping of inter-area oscillation was enhanced by adding PSS to the WACS under different operating conditions and contingencies.

C. Optimization Based Intelligent Techniques

Different types of intelligent optimization techniques are used to search for optimal or near optimal solution for many power system problems. These techniques are GA, Particle Swarm Optimization (PSO), Tabu Search (TS) algorithm etc.

i) Genetic Algorithm (GA) technique

A GA is a type of evolutionary algorithms used as a search technique to find an optimal or near optimal solution for many problems. It is categorized as global search heuristics. A GA is implemented as an iterative procedure in which a population of function inputs (strings) is randomly selected. Then the population is used to create a new population in the string and the process is repeated in the next iterations. The process of creating a new population passes through selection, mating, and mutation operations.

GA has been applied by many authors for tuning PSS parameters. Simulation results show activity of GA in tuning PSS parameters with fixed location. However, these PSSs cannot guarantee good damping performance when the location of the stabilizer is changed. Therefore, Sebaa, and Boudour applied a simple method to find the optimal locations and the best PSSs parameters simultaneously in multi-machine power systems using GA. Nonlinear simulation and eigen values analysis demonstrate the effectiveness of the technique in damping of oscillations under different scenarios.

It is difficult to use binary for representation when dealing with continuous search space with large dimensions. Therefore, the real-coded genetic algorithm was employed by to search for optimal PSS and SVC-based stabilizer parameters. The eigen value analysis and non-linear simulation were carried out for a weak connected power system. The results demonstrate the ability of the proposed stabilizers to improve stability of the system.
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ii) Particle Swarm Optimization (PSO) technique

PSO is one of the modern heuristic algorithms. It is also a population based evolutionary algorithm. PSO is motivated by the simulation of the social behavior of birds. Individual particles in the swarm with a position and velocity fly in a multidimensional search space. The velocity is continually adapted according to the corresponding particle's own experience and other accompanying particles' experiences. It is expected that the particles will be flying in the course of finding better areas. El-Zonkoly et al. proposed PSO technique for tuning parameters of brushless exciter and lead-lag power system stabilizer. Simulation results demonstrate the activities of the stabilizer in damping of oscillations of multi-machine power system.

D. Hybrid Artificial Intelligent Controller

Two or more artificial intelligent techniques are used to produce a hybrid intelligent system. Through cooperative interactions such techniques are applied in series or in integration to gain successful results. In last two decades, hybrid systems applied in engineering applications.

Gain-scheduling PID stabilizer is proposed by and to enhance the stability of the power systems. A hybrid conventional PSS, a fuzzy logic based PSS and simple switching criteria was used in Lie and Sharaf 1996. This approach applied to a SMIB under various transient disturbances including faults. In, the parameters of the proposed stabilizer were tuned on-line based on the speed error signal and its derivative. This controller applied to SMIB and multi-machine power systems.

Djukanovic et al. presented adaptive fuzzy control based on unsupervised learning neural nets for improving the generating unit transient of a hydro power system. By using appropriate means, a linguistic control strategy of optimal state-feedback regulator design was converted to a variable control strategy. The proposed controller contains a set of fuzzy logic based controller modules and a neural net classifier. The relationship between controller inputs and controller output generated by using unsupervised learning of NN and stored in a matrix called fuzzy associative matrix.

The test inputs used to generate the input–output pairs in training neural network may not be rich enough to excite all modes of the system and the design of the traditional fuzzy logic controller requires a lot of trial and error. To avoid these drawbacks, Abido and Abdel-Magid proposed a fuzzy basis function network (FBFN) to develop PSS.

GA is applied by to select and tune the optimal parameters of a neurofuzzy PSS. Suitable fitness function was employed to determine the optimal parameters of the *If* and *Then* parts membership functions during the learning procedure. The proposed stabilize tested on SMIB system and the results show improving dynamic performances under different operating conditions.

In many cases the initial fuzzy rules which are estimated according to the human experiences tuned using feedback, but with insufficient information about the control system the trial and error may be necessary. Recently different techniques employed to avoid this drawback such as TS algorithm, PSO, and Evolutionary Algorithms (EA). These techniques used by many researchers to design fuzzy PSS. To find the optimal parameters of member functions and desired PSS gains, Cheng and Elangovan applied TS algorithm. The approach applied to SMIB and multi-machine power systems and the results reveal that the proposed fuzzy PSSs has robust and adaptive performance under different operating conditions including three phase fault.

Malik presented a comprehensive study to illustrate the possibility of implementing an adapting controller using different approaches. Adaptive PSS designed based on purely analytic techniques, purely AI techniques, and combination of the analytical and AI techniques. These stabilizers used to enhance the stability and damping oscillation of an electrical generating unit. These systems were implemented and tested in real-time on physical models in the Laboratory.

To find the optimal parameters of member functions and desired PSS gains, Hwang et al. applied Adaptive Evolutionary Algorithm (AEA) comprising GA and Evolution Strategy (ES) for designing fuzzy PSS. ES technique is based on the ideas of adaptation and evolution. The approach provides good results when applied to SMIB and multi-machine power systems.

Tuning of the PID controller parameters is very important to get best results. Craziness based Particle Swarm Optimization (CRPSO) and binary coded GA methods were used by to determine the optimal PID gains. These techniques applied to determine off line, nominal, optimal gains of the PID controller for an AVR. For on line off-nominal system parameters Sugeno fuzzy logic has been used. The authors concluded that CRPSO is more robust than GA in performing optimal transient under different operating conditions. Moreover, CRPSO requires less computational time than GA.

Number of variables is based on the complexity of the power system. In a standard fuzzy system, the number of the rules and the complexity of the problem increase exponentially with the number of variables involved. To introduce linear relation between the number of variables and number of rules, the hierarchical fuzzy system can be used. This property motivated Caner et al. to propose the hierarchical fuzzy PSS. The stability enhanced by using this controller for SMIB system with more number of variables and with appropriate number of rules.

The Bacteria Foraging Optimization (BFO) technique was used by to tune the parameters of both single-input and dual-input PSSs. The conventional stabilizer and the three dual-input IEEE PSSs were optimally tuned to obtain the optimal transient performances. Sugeno fuzzy logic was used for on-line, off-nominal operating conditions. Simulation results revealed that the transient performance of dual-input PSS is better than single-input PSS. In addition, the proposed BFO technique provides better transient performance compared to GA.

A robust adaptive fuzzy controller proposed by to design a PSS. Fuzzy logic was used to implement system with both nominal values and adaptive system. A feedback linearization-based control law is implemented using the identified model. The gains of the feedback linearization controller were tuned using a particle swarm optimization technique. The proposed controller tested on a 4-machine 2-area power system. The results show the ability of the proposed stabilizer in damping inter-area oscillation compared to conventional PSS.

El-Zonkoly et al. proposed particle swarm optimization technique for tuning of a fuzzy logic power system stabilizer. The approach applied to multi-machine power system and simulation carried out. The results show that the stabilizer is successfully working under different loading and fault conditions.

CONCLUSION

This paper attempts to present new major studies of AI techniques, such as ANN, fuzzy logic, hybrid artificial intelligent, expert systems, and optimization techniques, applied to develop power system stabilizer (PSS). The controllers that designed based on conventional control theory, modern control theory, and adaptive control theory are found to have certain restrictions. By contrast, the advantages of AI techniques convinced and encouraged many researchers to apply these techniques to solve the problems of Power system control. This review is undertaken to explore and report that fast and accurate acting controllers developed based on AI techniques are required to maintain system stability and damping of oscillation and provide high-quality performance. Different types of AI stabilizers are assessed and compared with other types of stabilizers.

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