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Coordination of PSS and PID Controller for Power System Stability Enhancement – Overview

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Abstract

In power systems, Low Frequency Oscillations (LFO) in the range of 0.1 – 2.5 Hz have been solved through Power System Stabilizer (PSS). Proportional Integral Derivative (PID) controller is the simplest and effective solution to the most of control engineering applications today. Based on advantage, the PID controller combined with PSS to enhance the stability in power system. In practice most of the PID controller and parameters of PSS are tuned manually and fixed for certain operating conditions. In general power systems are non linear, conventional methods had lack of robustness. Therefore it is necessary to take advantage in simplifying the problem and implementation by utilizing most efficient optimization methods. From this view, many optimization methods and algorithms have been employed to tune the PID gains and PSS parameters. This paper broadly reviews the optimization methods and algorithms such as Conventional methods, Soft Computing, Genetic Algorithm (GA), Evolutionary Programming (EP), Differential Evolution (DE) and Swarm Intelligence methods were available for tuning the PID gains and PSS parameters successfully. Research showed the design of controllers based on conventional methods; soft computing and population based algorithms suffer from limitations. However, swarm intelligence techniques proved to be able to overcome these limitations. Swarm intelligence based coordinated controller (PID+PSS), will effectively enhance the small signal stability and transient stability in power system. An effort is made in this paper to present a broad analysis of tuning the PID gains and PSS parameters by various researchers.

Keywords: Algorithms, Optimization Methods, PID Controller, Power System Stabilizer

1. Introduction

The demand for electricity is increasing phenomenally in developing countries like Malaysia. This continuous demand leads to the operation of the power system at its limit. Power system engineers should take the responsibility to provide quality and stable power to the consumers. These issues make the engineers to concentrate on power system stability. The ability of the system to retain its steady state when subjected to any disturbances is said to be power system stability. In power system, voltage and frequency should be maintained constantly under any vulnerable conditions. The disturbances could be faults, load changes, voltage collapse etc. In analyzing the power system's stability, two types of system oscillations are identified. The oscillation of power system contains frequency components determined by generator inertia, impedance of transmission line, excitation control etc[1]. Inter area mode oscillations have frequencies in the range of 0.1 to 0.8 Hz. In Inter-area mode the generators are in the same area, because of strong electric link, the oscillation between these generators tend to be higher frequency. Therefore the generators in the same area swinging against the generators in other areas. In local mode, the oscillations have frequency in the range of 1 to 2 Hz. In generating station if one generator swings against the rest of the system is said to be Local mode oscillations. Power Swings must be effectively damped to maintain the system stability[2].

Stability in power systems is commonly referred as the ability of generating units to maintain synchronous operation[3,4]. It is common to divide stability into the following types:

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1.1 Transient stability

It is the ability to maintain synchronism when the system is subjected to a large disturbance. In the resulting system response, the changes in the dynamic variables are large and the nonlinear behavior of the system is important.

1.2 Small Signal Stability

It is the ability of the system to maintain stability under small disturbance. Such disturbances occur continuously in the normal operation of a power system due to small variations in load and generation.

Demello and Concordia[1] analyzed the phenomena of stability of synchronous machines under small perturbations and had provided a set of guidelines for stabilization through supplementary excitation control. They used a single-machine infinite bus system to analyze the nature of the low frequency electro-mechanical oscillations in power systems.

Kundur et al.[3] presented a comprehensive approach for conventional tuning of PSS parameters and its effect on the dynamic performance of the power system. They concluded that by proper tuning, the fixed-parameter PSS can satisfy the requirements for a wide range of system conditions and hence the need of adaptive PSS is of little incentive. But, PSS alone is not robust enough for large disturbances. It is necessary to provide the additional controller to increase the stability of the power system within a short time. The controller should have some degree of robustness to the variation of loading conditions and change in machine parameters for different operating conditions. To overcome this problem, a PID controller is introduced to the system.

Proportional Integral Derivative (PID) controller is one of the earliest control technique widely used in industrial control system, because of its robust performance and easy implementation. In view of the advantage of a PID controller, this paper proposed a method of combining the PID controller and PSS to improve the damping of a synchronous machine. The PID calculation involves three parameters: Proportional (K_P), Integral (K_I) and Derivative (K_D) gains[5]. The parameters of PID controller can be tuned using traditional methods and intelligent methods.

This paper provides a broad review about the optimization of PSS parameters and PID gains by various researchers. In the literature, the optimization of PSS and tuning of PID controller using various optimization techniques to damp out low frequency oscillations has been extensively investigated. The limitation identified from the conventional and other methods was reported. And, wide spread investigation on the swarm intelligence techniques for designing PSS and PID controller also provided.

2. Background

2.1 Power System Stabilizer

Power System Stabilizer (PSS) is a feedback controller, for a synchronous generator which provides an additional stabilizing signal to Automatic Voltage Regulator (AVR) through voltage reference input in order to damp out Low Frequency Oscillations (LFO). The purpose of PSS is to damp out the generator rotor oscillation in the range of 0.1 to 2.5 Hz. To damp out the electromechanical oscillations, PSS is expected to produce an electrical torque components should be in phase with rotor speed deviation of the generator. A block diagram is provided in Figure 1 to explain the operation of a PSS. The excitation system is controlled by AVR and PSS. The output of the PSS–PID is used as an additional input (u) to the AVR block. The input of the PSS is the deviation of the speed of the machine (Δω).

A block diagram of a conventional lead–lag PSS is shown in Figure 2. A generic PSS may be modeled as a non-linear system with a stabilizer gain, wash-out term, and phase compensation system and output limiter[6].

Gain: The overall gain (K) of the generic PSS determines the extent of damping the stabilizer imposes.

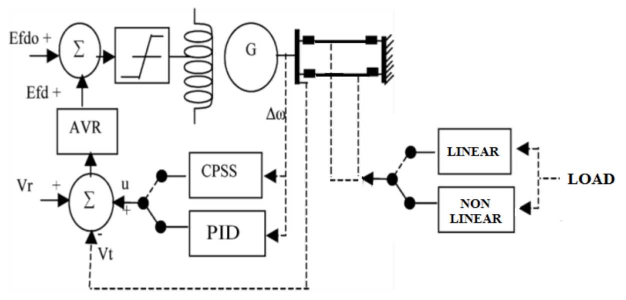

Figure 1. General control model of SMIB power system.

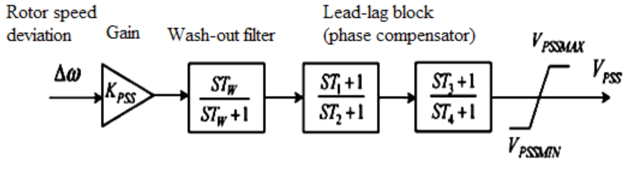

Figure 2. Conventional power system stabilizer (PSS).

Wash-Out Time Constant: The wash-out high-pass filter eliminates low frequencies that are present in the speed deviation signal and allows the PSS to respond only to speed changes.

Lead–Lag Time Constants (Phase Compensation System): The phase-compensation system is represented by a cascade of two first-order lead–lag transfer functions, which are used to compensate for the phase lag between the excitation voltage and the electrical torque of the synchronous machine.

Limiter: The output of the PSS must be limited to prevent it from countering the action of the AVR. The PSS must provide greater feedback when the signal deviation increases above the desired value, compared with the feedback to be provided when the deviation is below the desired value.

2.2 Proportional Integral Derivative (PID) Controller

The PID was an essential element of early governors, and it became the standard tool when process control emerged. Now more than 95% of the control system is still PID controller. The most critical step in application of PID controller is parameter tuning. Today the self tuning PID controller provides much convenience in engineering. The PID calculation involves three parameters: Proportional (K_P), Integral (K_I) and Derivative (K_D) gains[5]. The proportional value calculates the current error, integral value determines the result of the sum of recent errors and the derivative value determines the reaction based on the rate at which the error has been changing[7]. The closed loop performance of the any system can be achieved by tuning the PID parameters. The stabilizing signal of the coordinated controller Upss can be written as:

$$U_{PSS} = \left[K_P + \frac{K_I}{s} + K_D s \right] \Delta\omega(s) + V_{PSS} \tag{1}$$

Where, K_P is proportional gain, K_I is integral gain, K_D is derivative gain, $\Delta\omega$ - Rotor Speed Variation and U_{pss} – PID – PSS output.

3. Optimization Techniques

Optimization of PSS parameters and tuning of PID controller appears easy, but finding the set of gains that guarantee the best performance of your system is a complex task. Traditionally, PSS and PID controllers are tuned either manually or using rule based methods for certain operating conditions. Lack of robustness exists for wide range of operating conditions such as non linear load and different kinds of faults. To overcome these limitations Artificial Intelligence, Adaptive control and population based algorithms was developed.

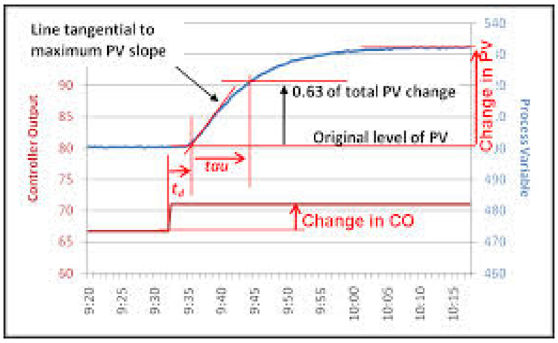

Figure 3. Process reaction Curve Method.

3.1 Manual Tuning

3.1.1 Ziegler–Nichols Open and Closed Loop Tuning Method

In 1942, Ziegler and Nichols[8], developed two methods for tuning the parameters of P, PI and PID controllers are Z-N open loop method and Z-N closed loop method, and explained simple mathematical procedures for tuning PID controllers. The process reaction curve method, often called as the Zeigler-Nichols open loop tuning method. Process reaction curve method is a way of relating the process parameters such as delay time, process gain and time constant to the controller parameters. The PID parameters are calculated from the response in the process measurement y_m after a step with the height U in the control variable u. These procedures are now accepted as standard in control systems practice.

3.1.2 Cohen-Coon Method

The Cohen-Coon auto tuning method is an offline method used for tuning PID controllers. This method is also known as Process reaction Curve method shown in Figure 3. This method uses PID parameters from an open loop transfer function experiment. This method is similar to the Zeigler – Nichols method, but provides better results when the controller has a large dead time (T_d) relative to time constant (T). This method is only used for first order models with time delay The Cohen-Coon method is classified as an offline method for tuning, i.e. the step change can be introduced to the input once it reaches the steady state[9]. Then the output can be measured based on the time constant and the time delay and this response can be used to evaluate the initial control parameters.

Traditional methods such as Ziegler Nichols and Cohen – Coon methods were used for PID based PSS and analyzed to damp out low frequency oscillations[6]. The coordinated controller improves and enhances the stability of power system. However, these methods have drawbacks such as the parameters of PSS are fixed[3] and PID gains are optimized using Z&N method for certain operating conditions. In power system, these conventional methods are not applicable for wide range of operating conditions and not feasible to complex systems[10].

3.2 Soft Computing

In power system operation and planning, refined computer programs are required and designed in such a way that they could be robust to any type of operating conditions. Soft computing is knowledge based approach and has the ability to deal with non linear system[11]. In this paper, four main soft computing techniques are considered namely Artificial Neural Network (ANN), Fuzzy Logic (FL), Evolutionary Computation (EC) and Hybrid Artificial Intelligence techniques to damp out low frequency oscillation in power systems. The main objective of soft computing techniques is to minimize the mathematical complexity.

3.2.1 Artificial Neural Network (ANN)

An ANN is a mathematical model based on the function of biological neural networks and is an information processing model that is inspired by the way biological nervous systems such as the brain processes the information. It is composed of number of highly interconnected processing components neurons working in unity to overcome the problems. Like human beings, ANN learns by example. Many researchers applied ANN technique to enhance the small signal stability and transient stability in power systems. Zhang et al.[12] proposed ANN based power system stabilizer for good damping in power system over a wide range of operating conditions. In this approach, ANN was trained by the data generated by adaptive power systems stabilizer. ANN based adaptive power system stabilizer was proposed by He[13]. The structure based on two recurrent neural networks, one is used as tracker for dynamic characteristics and other as a controller to damp low frequency oscillations. Segal[14] proposed a self tuning power system stabilizer based on ANN. The parameters of PSS were tuned automatically using NN when disturbances occur. To improve the optimization further, population based algorithms and fuzzy logic were used to train the ANN for designing power system stabilizer[15,16]. Rani Fathima and Raghavebdiran[17] extend their idea further by presenting novel control scheme using back propagation feed forward artificial neural network control algorithm for improving power system stabilization. Most of researches carried out in late nineties, this may be due to problems with single objective. Training the ANN model for multi-objective functions is quite difficult. Even though ANN had the robustness, some drawbacks of ANN are selection of training method, large dimensionality and generate output for unreasonable input. Apart from this, training the neural network consumes more time and require computation burden.

3.2.2 Fuzzy Logic Systems (FL)

In 1965, Lotfi A. Zadeh[18] developed Fuzzy logic system to address inaccuracy and uncertainty which usually exist in engineering problems. It is a superset of conventional logic that has been extended to handle the concepts of 'completely true' and 'completely false' values. Generally, fuzzy logic theory has many advantages over other techniques such as the concept is easy to understand, has ability to handle ambiguity of expressed in diagnostic processes and tolerance to a data that are precise. A quite number of papers published in the area of damping low frequency oscillations in power system. Momoh *et al.*[19] presented the basic principles of fuzzy theory and set of detailed references on various areas of study in power system using fuzzy applications. Kamalesh *et al*[20] presented the application of fuzzy logic power system stabilizer for dynamic stability enhancement. Here, rotor speed deviation and power used as input and the parameters of PSS were optimized using fuzzy logic. The parameters of the PID stabilizer are tuned online using a fuzzy rule and a fuzzy interference mechanism for manipulating the speed error and its derivative[21]. Hsu and Cheng[22] designed fuzzy logic power system stabilizer for multi-machine power systems. In this approach, the input signals to PSS are characterized by linguistic variables using fuzzy set notations. El-Metwally[23] introduced hybrid fuzzy PID power system stabilizer and it provides online automatic adjustment of the PID parameters. In some research, other optimization methods were used to tune the parameters used in FLPSS[24,25]. Fuzzy logic also has serious disadvantages such as hard to develop a model, require finer tuning, fuzzy logic uses approximation, computational cost and defining the rules.

3.3 Evolutionary Computing (EC) Methods

Evolutionary computation is a subfield of artificial intelligence that involves continuous optimization and combinatorial optimization problems. Most of the researchers focused the EC toward the biological form of evolution. These include survival of the fittest, natural selection and reproduction. Evolutionary Algorithm (EA) is a term used to describe computer based problem solving systems which uses computational models of evolutionary process in their design and implementation. The variety of EA methods have been proposed by researchers for power system problems. EA involves meta-heuristic optimization algorithm includes: Genetic Algorithm (GA), Evolutionary Programming (EP), Differential Evolution (DE), and Swarm Intelligence Methods.

3.3.1 Genetic Algorithm (GA)

Genetic Algorithm is a stochastic global search method that mimics the process of natural evolution. In 1970, Holland introduced this method for optimization. Mitchell[26] used this heuristic to generate useful solutions to optimization and search problems using some techniques inspired by natural evolution, such as inheritance, mutation, selection and crossover. GA starts with an initial population containing a number of chromosomes where each one represents a solution of the problem in which its performance is evaluated based on a fitness function. Based on the fitness of each individual, a group of chromosomes are selected to undergo selection, crossover and mutation. Recently, GA has been extensively studied by many researchers in searching for power system stabilization. Abido[27] applied GA to search for optimal settings of rule based power system stabilizer and shown that the performance of PSS improved significantly by incorporating GA based learning mechanism. Farahani et al[28] applied GA to solve the optimization problem of tuning lead-lag power system stabilizer parameters of a multi-machine system. The proposed GA-PSS is evaluated on IEEE 14 bus test system. A quite number of research papers have also been published in the area of power system stabilization[29–31]. Some researchers proposed GA for tuning PID based power system stabilizer. Here, the optimization problem is to tune the PID gains[32–34]. Even though, GA has proved its capability, it has some drawbacks on applying to real time systems: poor premature convergence, optimization response time and no absolute assurance that GA will find global optimum solution.

3.3.3 Evolutionary Programming (EP)

Evolutionary programming is a stochastic optimization strategy similar to genetic algorithms. It is used to optimize real – valued continuous functions. EP uses selection and mutation operators, does not use the crossover operator. The selection operator is used to determine chromosomes for making in order to generate new chromosomes. EP played role in power system to damp out low frequency oscillations. Abido[35] designed power system stabilizer using Evolutionary programming. In this approach EP employs to search optimal setting of PSS parameters. Dill & Silva[36] used EP to solve multi-objective optimization problem. The approach based on pseudo spectra analysis. Chatterjee et al.[37] proposed hybrid EP to get the optimal parameters of single input conventional PSS and dual input PSS.

The major drawbacks of EP are:

- No guarantee for finding optimal solutions in a finite amount of time (computational complexity)
- Parameter tuning mostly by trial and error.
- Population approach may be expensive.

3.3.3 Differential Evolution (DE)

Storn and Price proposed a Differential Evolution (DE) algorithm for numeric optimization problems. DE has been developed to fulfill the requirement of fast and consistent convergence to the global minimum in consecutive independent trials. Unlike GA, DE uses real coding of floating point numbers for representing problem parameters. Therefore, algorithm has gained great attention in power system problems since it's proposed. Tripathi and Panda[38] applied DE algorithm to design and optimize power system stabilizer. DE is employed to search for optimal controller parameters. Zhang et al.[39] applied hybrid DE algorithm to tune the gain parameters of PSS and tested in single machine infinite bus system. Zhe Sun et al[40] proposed DE algorithm for tuning type – 2 fuzzy logic power system stabilizer. The results show the effectiveness of proposed approach for damping electro mechanical oscillations in power system. Tabatabaee and Joorabian[41] used differential evolution algorithm for tuning the parameters of PSS with small number of iterations. Wang et al.[42] developed mixed integer ant direction hybrid differential evolution algorithm to solve the objective function of tuning of the PSS parameters and tested under various system configuration and loading conditions. In terms of reliability, DE offers consistency in achieving its globally minimum fitness value.

4. Problems Identified

4.1 Parameters are Fixed for Certain Operating Condition

The main drawback of the conventional PSS is with their structures either lead controller (single stage CPSS) or lead lag controller (double Stage CPSS). And the parameters of conventional PSS are tuned and fixed for three operating conditions such as light load, nominal load and heavy load operating conditions. Power systems frequently undergo changes in the load and generation patterns in the transmission network. This results in additional change in small signal dynamics of the system. The CPSS are tuned and fixed for a particular operating condition; usually provide good performance at that operating condition. The performance, at other operating conditions, may be satisfactory and become poor when extreme situations arise. However such PID controller has been very useful in system that could be represented by single machine infinite bus models.

4.2 Time Consumption is More for Iteration Process

A number of conventional techniques are used to design the parameters of PID and PSS. Generally, the computational time and burden is increased when the size of the controller is large. Unfortunately, the population based algorithms and AI techniques consume more time for iteration and require computation burden and also slow convergence.

4.3 Robust Stabilization and Disturbance Attenuation Problem

Most of the researchers proposed PSS alone for stability enhancement. But it's not robust enough for large disturbances. It is necessary to provide the additional controller to increase the stability of the power system within a short time. The controller should have some degree of robustness to the variation of loading conditions and change in machine parameters for different operating conditions.

To overcome these drawbacks from the existing techniques, swarm intelligence based optimization method suggested to optimize the PID gains and PSS parameters of the proposed system.

5. Swarm Intelligence (SI) Techniques

Research interests are more concentrated on SI techniques due to their ability to produce accurate results within a reasonable time and adaptation to wide range of operating conditions. Swarm Intelligence (SI) is the study of computational systems inspired by collective intelligence. Collective intelligence emerges through the interaction of animals and social insects by exchanging locally environment to achieve a global goal. SI consists of a population of simple agents interacting locally with one another and with their environment. The agents follow very simple rules, and although there is no centralized control structure. Many research papers published using SI techniques in the field of power system stabilization. Swarm Intelligence techniques involved in power system problems are: Artificial Bee Colony Algorithm, Ant colony optimization, Particle swarm optimization, Cuckoo Search, Fire Fly Algorithm, and Fruit Fly Optimization Algorithm. Many researcher applied SI optimization algorithm for tuning PID controller.

5.1 Artificial Bee Colony (ABC) Algorithm

Artificial bee colony optimization is one of the most recently introduced swarm based algorithms.ABC is an optimization algorithm based on the intelligent foraging behavior of honey bee swarm. This algorithm is used for optimizing a large set of numerical test functions. ABC as an optimization tool provides a population-based search procedure in which individuals called foods positions are modified by the artificial bees with time and the bee's aim is to discover the places of food sources with high nectar amount and finally the one with the highest nectar. Many researchers concentrated on tuning of PID controller gains using ABC algorithm. Eslami and Shareef[43] implemented ABC algorithm for tuning the PSS parameters and the performance of ABC compared with GA. Ravi et al.[44] applied ABC for power system stabilization problems and compared the results with the conventional methods such as GA. Theja et al.[45] applied ABC approach to design PID based PSS for modified Philip-Heffron's model. Abdollahi et al.[46] proposed ABC algorithm for tuning the PSS in order to solve uncertainties in two areas power system.

5.2 Ant Colony Optimization (ACO) Algorithm

Ant Colony Optimization (ACO) initially proposed by Marco Dorigo in 1992. The aim of this algorithm is to search an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food. Initially ants travel randomly and upon finding food return to their colony while laying down pheromone trails. Other ants follow the pheromone pathway. Thus, when one ant finds a good (i.e., short) path from the colony to a food source, other ants are more likely to follow that path, and positive feedback eventually leads to all the ants' following a single path. The idea of the ant colony algorithm is to mimic this behavior with "simulated ants" walking around the graph representing the problem to solve[47]. The fine tuning of PSS parameters considered as an optimization problem that is resolved by an ACO based technique[48]. The outcomes of ACO compared with conventional PSS and Particle Swarm optimization algorithm. Sheeba et al.[49] formulated the controller design as an optimization problem. ACO algorithm was used to drive the controller structure and applied to multi-machine test system. Chatterjee et al.[50] proposed chaotic ant swarm optimization to tune the parameters of single input and dual input power system stabilizers. Results compared with GA and PSO algorithms. Not only for tuning PSS parameters, ACO algorithm successfully applied by many researchers for reactive power compensation.

5.3 Particle Swarm Optimization (PSO) Algorithm

Particle Swarm Optimization was proposed by Eberhart and Kennedy in 1995[51], which is a stochastic optimization technique, based on social behavior of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation[52]. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. Many researchers approached PSO algorithm for stability enhancement in power systems. Habri et al.[53] connected PID controller to SMIB system. The parameters of PID were tuned by PSO algorithm. And proposed approach successfully minimized the objective function. Shayeghi et al.[54] designed and implemented a PID controller for multi-machine power system using a modified iteration particle swarm optimization algorithm. Here, the algorithm used to tune optimal gains of PID controller. Boroujeni et al[55] proposed PSO algorithm to design PID power system stabilizer to enhance stability in power systems. Mehdi Nikzad et al.[56] tuned the parameters of PSS using PSO algorithm for multi-machine infinite bus system. The result shows that the PSO algorithm is more effective on linear systems as well as non linear systems. Many research papers have been published in the field of power system stabilization using PSO algorithm[57–60].

Limited number of researchers applied other swarm intelligence techniques for power system applications, which includes: Cuckoo Search[61–63], Firefly Algorithm[64–65].

6. Conclusion

From the literature review many developments have seen in optimization of PSS using various techniques. Many researchers developed advanced control design approaches such as intelligent control, adaptive control and robust control for power system stabilization and oscillation damping. But the existing controllers need more iteration and had computational burden to optimize the parameters for wide range of operating conditions. And more over the researchers concentrated on optimization of the PSS parameters alone.

Swarm Intelligence appears to have more potential in power system analysis and also the most recent in the field of the computational intelligence techniques. From the survey conclude that SI techniques applied mostly for tuning the PSS parameters. Even-though the PSS suppresses the electro mechanical oscillations, still the synchronous machine needs additional controller to increase the stabilization in power system. Therefore, a SI based PID controller and PSS on a wide range of operating conditions has to be designed, since the power system are non linear. The proposed PID based PSS controller significantly suppress the oscillations of the rotor speed and power angle. Swarm Intelligence algorithm may use to solve the optimization problem and explore for an optimal set of PID gains and PSS parameters. The damping characteristics of the proposed method have been good with low-frequency oscillations, and the system will stabilize quickly. The proposed idea successfully improves the system stability, efficiency, dynamism and reliability.

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