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Particle Swarm Optimization Based PID Power System Stabilizer for a Synchronous Machine

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***Abstract*—**This paper proposes a swarm intelligence method that yields optimal Proportional-Integral-Derivative (PID) Controller parameters of a power system stabilizer (PSS) in a single machine infinite bus system. The proposed method utilizes the Particle Swarm Optimization (PSO) algorithm approach to generate the optimal tuning parameters. The paper is modeled in the MATLAB Simulink Environment to analyze the performance of a synchronous machine under several load conditions. At the same operating point, the PID-PSS parameters are also tuned by Ziegler-Nichols method. The dynamic performance of proposed controller is compared with the conventional Ziegler-Nichols method of PID tuning controller to demonstrate its advantage. The analysis reveals the effectiveness of the proposed PSO based PID controller.

***Keywords*—**Particle Swarm Optimization, PID Controller, Power System Stabilizer.

I. Introduction

THROUGHOUT these years, the control techniques have made great advances in the industry [1]. The proportional-integral-derivative (PID) controller has been chosen over other controller because it is simple and having a wide range of robust performance. Its universal acceptability can be attributed to the familiarity with which it is perceived amongst researchers and practitioners within the control community [2]. However, this PID controller tuning method is inefficient [3]. Hence, empirical tuning methods have been proposed by researchers. One of the most commonly used proposed methods is the Ziegler-Nichols (ZN) method [4]. In general, this method is hard to determine optimal PID parameters [8]. Hence, swarm intelligence (SI) methods came into function. Swarm Intelligence is the property of a system whereby the collective behaviors of several agents interacting locally with their environment cause coherent functional global patterns to emerge. Swarm intelligence is having two based methods, which are Particle Swarm Optimization (PSO) and Ant Colony Optimization (ACO). PSO is a stochastic population based optimization algorithm [5], [6]. It is a concept for optimizing nonlinear functions using particle swarm methodology. The advantage of PSO technique is that it is simple in concept, easy to implement and found to be computationally efficient compare to other methods.

This technique combines social psychology principle in socio-cognition human agents and evolutionary computations. Thus, this technique is seen to be widely applied in the fields today. PSO does not have genetic operators like crossover and mutation. Particles update themselves with the internal velocity. Therefore, PSO method is an excellent optimization methodology in the process of solving the optimal PID controller parameters problem. In this paper, an optimal PSO-based PID PSS is developed, which uses the speed deviation as the input [11]. Several simulations have been carried out in order to generate the output using a single machine infinite bus power system. Simulation of the responses of the proposed PID-PSS to small disturbances has demonstrated the effectiveness of the PSO method in comparison to other conventional methods.

This paper is organized as follows. Section II explains the power system stabilizer (PSS) design. In Section III, the PSO algorithm and its implementation into the PSO-PID controller are discussed. Further, the simulation results and discussion is established in Section IV and Section V provides important conclusions.

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II. Power System Stabilizer Design

A. Overview

The basic function of power system stabilizer is to add damping to the generator rotor oscillations by controlling its excitation using auxiliary stabilizing signal(s). In order to provide damping, the stabilizer will produce electrical torque which minimized the rotor speed deviations. The theoretical basis for a PSS may be illustrated with the aid of block diagram, shown in Fig 1. The excitation system is controlled by an automatic voltage regulator (AVR) and a power system stabilizer (PSS).

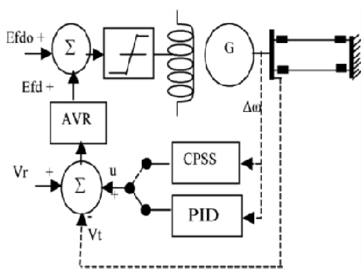

Fig. 1 General control model of SMIB power system

The block diagram of a speed input conventional lead-lag PSS is shown in Fig. 2. The stabilizer contains a washout term, stabilizer gain, phase lead-lag compensation and output limiters.

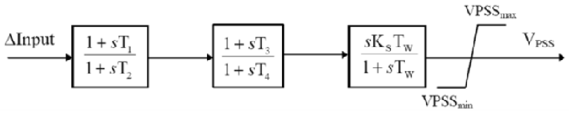

Fig. 2 Lead-Lag Power System Stabilizer

B. PID Power System Model

For simplicity, a PID type PSS is modeled by some identical stages, PID which is represented by a gain KP, KI and KD, washout function, the value of TW is not critical and may be in the range of 1 to 20 seconds and the output limits Vsmax and Vsmin [12]. The structure of the PID type power system stabilizer, to modulate the excitation voltage is shown in Fig. 3.

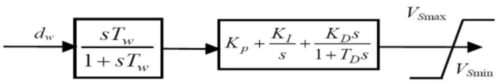

Fig. 3 Structure of PID type Power System Stabilizer

III. Particle Swarm Optimization Algorithm

A. Background

Emerging technologies such as Swarm Intelligence (SI) have been utilized to solve many non-linear engineering problems. Particle Swarm Optimization (PSO) is a sub-field of SI and was inspired by swarming patterns occurring in nature such as flocking birds [6]. It was observed that each individual exchanges previous experience, hence knowledge of the "best position" attained by an individual becomes globally known. PSO is one of the evolutionary computation methods to solve optimization problems. The method can be applied to non-linear optimization problem that includes constraints without the graduate of the objective function.

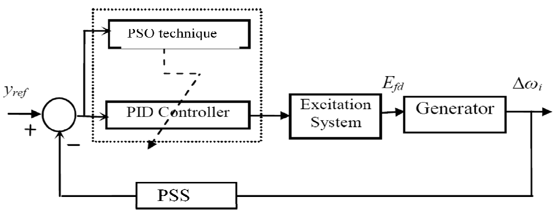

Fig. 4 PSO-PID controller design

In this study, the problem of identifying the PID controller parameters is considered as an optimization problem. An attempt has been made to determine the PID parameters by employing the PSO technique [7], [10]. A good set of controller parameters K_p, K_i, K_d will yield a good system response and results in the minimization of performance index in time domain. Hence, the PID controller using the PSO algorithm was developed to improve the step transient response of a typical power system stabilizer. When applying the PSO method for searching the controller parameter, the use of "particle" is replaced by "individual" and "group" is used to define the "population". The three controller parameters K_p, K_i, K_d composed an individual by K= [K_p, K_i, K_d], hence there are three members in an individual. If there are n individuals in a swarm, then the dimension of the swarm is n×3.

The PSO concept consists of changing velocity of each individual toward its *pbest* and *gbest* locations at each time step [9]. Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward *pbest* and *gbest* locations. For example, the *i*th individual is represented as $x_i = (x_{i,1}, x_{i,2}, x_{i,3})$ in the *3*-dimensional space. The best previous position of the *i*th individual is recorded and represented as $pbest_i = (pbest_{i,1}, pbest_{i,2}, pbest_{i,3})$. The index of best individual among all of the individuals in the group is represented by the $gbest_j$. The rate of the position change (velocity) for individual *i* is represented as $v_i = (v_{i,1}, v_{i,2}, v_{i,3})$. The modified velocity and position of each individual can be calculated using the current velocity and the distance from $pbest_{i,j}$ to $gbest_j$ as shown in the following formulas:

$$v_{ij}^{(k+1)} = w \times v_{ij}^{(k)} + c_1 \times rand() \times (pbest_{ij} - x_{ij}^{(k)}) + c_2 \times rand() \times (gbest_{ij} - x_{ij}^{(k)}) \quad (1)$$

$$x_{ij}^{(k+1)} = x_{ij}^{(k)} + v_{ij}^{(k+1)} \quad (2)$$

where *i* is the number of individuals in a group, *j* is the PID parameter number, *k* is the iteration number, *x* is the PID parameter, *v* is the velocity, *pbest* is a personal best of an individual *i*, *gbest* is a global best of all individuals, *w*, C_1 and C_2 are weight parameters, *rand( )* is a uniform random number from 0 to 1.

The use of linearly decreasing inertia weight factor w has provided improved performance in all the applications. Its value is decreased linearly from about 0.9 to 0.4 during a run. Suitable selection of the inertia weight provides a balance between global and local exploration and exploitation, and results in less iteration on average to find a sufficiently optimal solution. Its value is set according to the following equation:

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (3)$$

where w_{max} and w_{min} are both random numbers called initial weight and final weight respectively. $iter_{max}$ is the maximum iteration number. *iter* is the current iteration number. The termination criterion is to define the maximum amount of iterations that the PSO can perform. Once the PSO reaches the preset maximum iterations, the algorithm is automatically terminated. The individual that generates the latest *gbest* is an optimal controller parameter.

B. PSO Algorithm

Step 1. Initialize an array of individuals with random positions and their associated velocities to satisfy the inequality constraints.

Step 2. Check for the satisfaction of the quality constraints and modify the solution if required.

Step 3. Evaluate the fitness function of each individual.

Step 4. Compare the current value of the fitness function with the individual's previous best value (*pbest*). If the current fitness value is less, then assign the current coordinates (positions) to *pbestx.*

Step 5. Determine the current global minimum fitness value among the current positions.

Step 6. Compare the current global minimum with the previous global minimum (gbest). If the current global minimum is better than gbest, then assign the current global minimum to *gbest* and assign the current coordinates (positions) to *gbestx.*

Step 7. Update the velocities and individual's position according to (1) and (2).

Step 8. Repeat Step 2-7 until optimization is satisfied or the maximum number of iterations is reached.

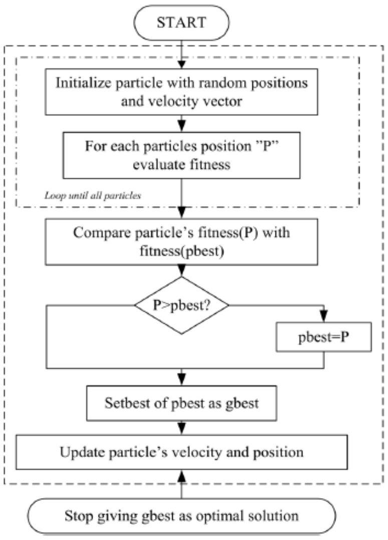

Fig. 5 Flow chart of Particle Swarm Optimization Algorithm

IV. Simulation Results and Discussion

Generally, traditional method of tuning doesn't guarantee optimal parameters and in most cases the tuned parameters needs improvement through trial and error. In this section, the optimal tuning for determining the PID Controller parameters was carried out. To evaluate the effectiveness of the proposed PSO method on PID PSS to improve the stability of the power system, the dynamic performance of the proposed PSO was examined under different loading conditions. For comparison, however, the PID controller parameters were also obtained using the conventional Ziegler- Nichols tuning technique. The Ziegler-Nichols rules were used to form the intervals for the design parameters in tuning the controller by minimizing an objective function. Through the simulation results, it is clearly shown that the proposed PSO-PID controller can perform an efficient search to obtain optimal PID controller parameter that can achieve better performance criterion.

TABLE I
Controller Parameters Defined from the Three Methods

	K_p	K_i	K_d
Trial & Error	50	5	2
Ziegler-Nichols	30	3.226	2.8
PSO	0.4021	-0.0615	6.7505

The dynamic performance of the system is obtained with PSS and PID for the following loading conditions:

1. Nominal loading condition (200MW)
2. Nominal loading condition with three phase fault
3. Heavy loading condition (600MW) with three phase fault

It is recognized that the highest magnitude of power system disturbance is caused by the three phase fault. The PID PSS is able to track the system operating conditions, and thus, as seen from the results in figures below, is able to adjust and provide a uniformly good performance over a wide range of operating conditions and disturbances. A perturbation (i.e., 3-phase fault) is applied and the dynamic performance is observed. The above cases have been illustrated clearly, how the controller reduces the overshoot and settling time to the nominal level when subjected to PID with PSS and the inference of the simulation results are shown below.

A. Normal Load without Fault Condition

In this case, the synchronous machine is subjected to a normal load of 200MW in the transmission line and no fault condition is applied to the system. The following observations are made with respect to the stability of the system. Figs. 6 to 8 shows the variation of speed deviation, rotor angle deviation and load angle respectively with respect to time for the above mentioned contingency (Case-1). The PSO-PID controller is compared with Ziegler-Nichols PID method to verify its superiority. It is clearly shown in the figures that optimal tuning of PSO method is less oscillatory than the Ziegler-Nichols as well as the Trial and Error methods. As seen from Fig. 6, although a comparatively smaller rise time (T_r) were obtained from trial and error method and Ziegler-Nichols method, PSO method give shorter settling time (T_s). It only takes about 2 seconds to settle down. It is also clearly shown in Fig. 7 that the settling time (T_s) is less for the output with PSO method. It took 2 seconds to settle down while the system using Ziegler-Nichols method needs 2.5 seconds to finally settle. As for Fig. 8, tuning with PSO method shortened the load angle settling time from 2.4 seconds to about 1.7 seconds. It is seen that with the proposed tuning method, the system had a much smaller oscillation and the oscillation was damped much faster. To conclude this, superior results were obtained in terms of system performance and controller output by using PSO method for tuning PID controllers when these values are compared in figures.

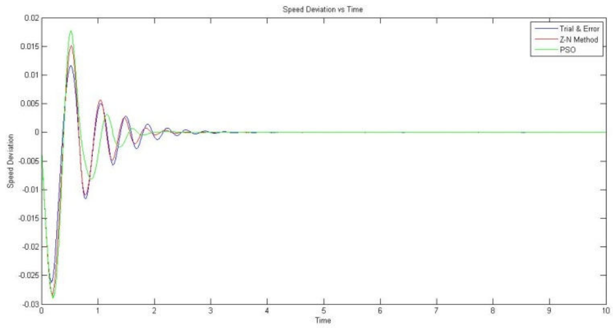

Fig. 6 Response of Speed Deviation

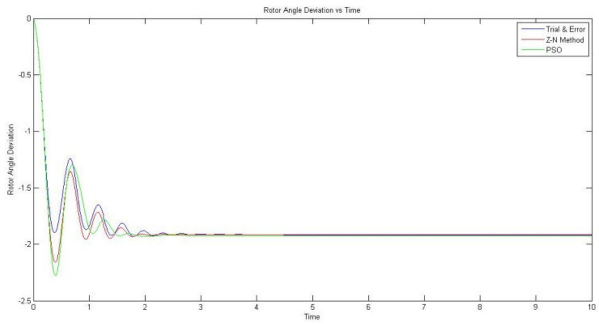

Fig. 7 Response of Rotor Angle Deviation

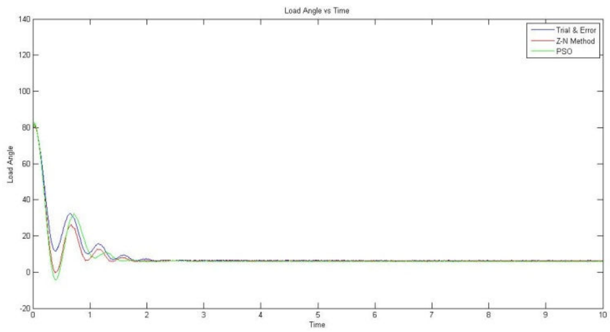

Fig. 8 Response of Load Angle

B. Normal Load with Three Phase Fault Condition

For this case, vulnerable condition occurred where a three phase fault is assumed to happen at the transmission line. The system response for the above contingency is shown in Figs. 9 to 11. By looking at Figs. 9 and 10, the PSO-PID controller greatly improved the speed deviation and rotor angle deviation within 2.2 seconds compared with the other methods which took longer time to achieve the same steady state performance. As for Fig. 11, it is also observed that the load angle performance is much better for a PSO-PID controller. PSO tuned method shortened the load angle settling time to almost 2 seconds. The comparison above shows that the PSO tuning method of PID controller has better performance in every aspect when the power system is subjected to normal load with three-phase fault conditions. Hence, the PID controller with PSO tuning significantly suppresses the oscillations in the system and provides good damping characteristics to low frequency oscillations by stabilizing the system much faster.

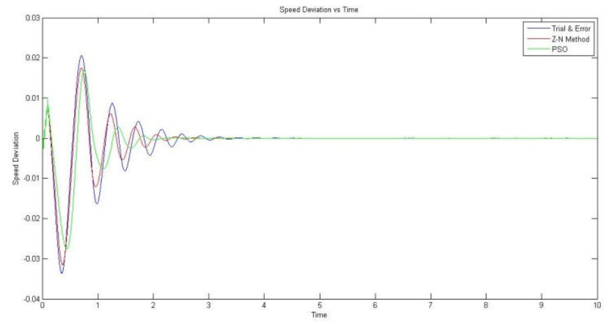

Fig. 9 Response of Speed Deviation

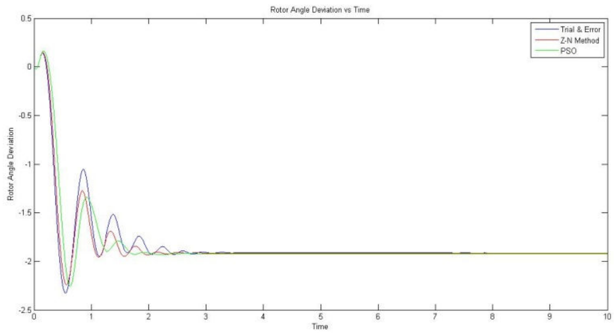

Fig. 10 Response of Rotor Angle Deviation

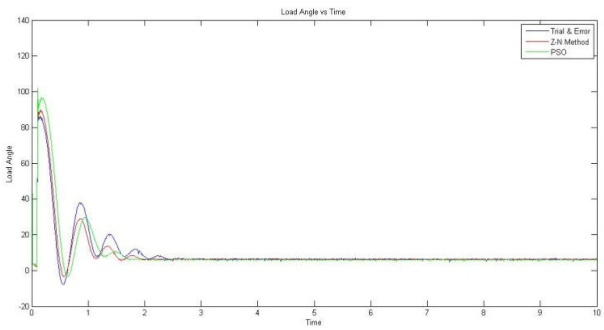

Fig. 11 Response of Load Angle

C. Heavy Load with Three Phase Fault condition

In the following case, another severe disturbance is considered. The synchronous machine is subjected to a three phase 600MW RLC load in the transmission line and a vulnerable condition is applied. The performance parameters of the system during this heavy load and fault condition are illustrated in Figs. 12 to 14. The simulation results obtained with the PSO tuning method is compared with the response of the trial and error method as well as the Ziegler-Nichols method. Based on Fig. 12, the peak time reduced from 0.02136 seconds to 0.017 seconds for the PSO-PID Controller. Therefore, the system reached the steady state quickly in around 2.5 seconds. It is necessary to maintain the speed in the synchronous generator. The system should reach steady state as early as possible. For that, PSO-PID gives better optimal solution compared to the others. Referring to Fig. 13, PSO method improves the rotor angle to the maximum extent by reaching the settling time within 3 seconds, at approximately 2.5 seconds. The overshoot was heavy due to the fault condition which affects the stability of the system. As for the load angle shown in Fig. 14, the system settling time is 1.8 seconds compared to the other two methods which are both at 2.5 seconds. Therefore, the PSO method of tuning is more effective in damping the oscillations of the system.

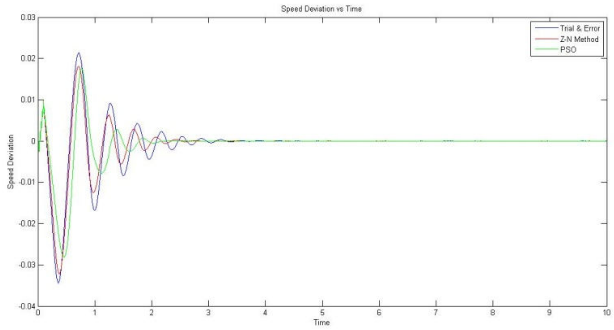

Fig. 12 Response of Speed Deviation

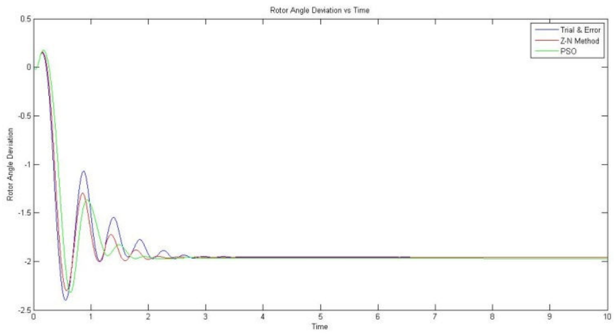

Fig. 13 Response of Rotor Angle Deviation

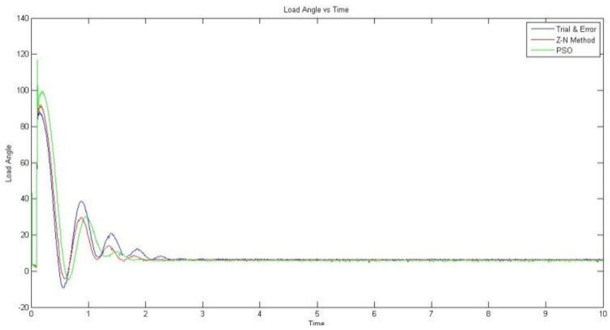

Fig. 14 Response of Load Angle

The numerical values of PID parameters are shown in Table II to demonstrate the robustness performance of the proposed method. T_s is the settling time, T_r is the rise time and T_p is the peak time measured in seconds. It is clearly shown that the system with PSO-PID is having more system stability margin than other methods. Analysis reveals that the proposed method of optimal tuning PID controller gives better dynamic performance as compared to that of conventional Ziegler-Nichols method as well as trial and error method.

TABLE II
RESPONSE CHARACTERISTIC OF THE SPEED DEVIATION

	Normal Load without fault			Normal Load with three phase fault			Heavy Load with three phase fault		
Method	Ts (s)	Tr (s)	Tp (s)	Ts (s)	Tr (s)	Tp (s)	Ts (s)	Tr (s)	Tp(s)
T&E	3	0.26	0.012	3.5	0.46	0.021	3.8	0.47	0.021
Z-N	2.5	0.29	0.015	2.8	0.48	0.018	3	0.48	0.018
PSO	2	0.31	0.018	2.2	0.53	0.017	2.5	0.55	0.018

[a]s = second, Ts = settling time, Tr = rise time, Tp = peak time.

V. CONCLUSION

The particle swarm optimization based approach to optimal design of PID PSS to present the enhancement of the dynamic stability of single machine infinite bus has been studied. The PID parameters searched by this method results a better computation efficiency and accuracy than the previous methods tested. The simulation results show that the proposed controller can perform an efficient search that achieves better performance criterion through multiple iterations in computational steps. Also, the PSO-PID controller design is more superior in terms of consistency and robust stability. With better stability and faster recovery after a fault has occurred, the system can perform smoother and better. Therefore, the effectiveness of proposed PSO-PID tuning for PSS and its dynamic performance is better.

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