Particle Swarm Optimization for Tuning PSS-PID Controller of Synchronous Generator

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Abstract:
In this paper the design an optimal PSS-PID controller for single machine connected to an infinite bus (SMIB). We presented a novel application of particle swarm optimization (PSO) for the optimal tuning of the new PSS-PID controller. The proposed approach has superior features, including easy implementation, stable convergence characteristic and good computational efficiency. The synchronous generator is modeled and the PSO algorithm is implemented in Simulink of Matlab. The obtained results have proved that (PSO) are a powerful tools for optimizing the PSS parameters, and more robustness of the system IEEE SMIB.

Keywords: *Synchronous Generator, PSS, particle swarm optimization, PID controller*

1. Introduction

Over the past decade, more than 90% of industrial controllers are still implemented based on PID control algorithms as no other controller matches the simplicity, effectiveness, robustness, clear functionality and ease of implementation [3]

The Power System Stabilizer (PSS-PID) is a device that improves the damping of generator electromechanical oscillations. Stabilizers have been employed on large generators for several decades; permitting techniques applied in the automatic excitation regulator of powerful synchronous generators: the robust stabilizer (PSS-PSO) and (PSS-PID) control schemes against system variation in the SMIB power system, with a test of robustness against parametric uncertainties of the synchronous machines (electric and mechanic), and make a comparative study between these two control techniques for PSS systems.

One of the most recent heuristic algorithms, the particle swarm optimization (PSO), is a population based stochastic optimization technology by Eberhart and Kennedy in 1995, inspired by social behavior of bird flocking and fish schooling. It is used for optimization of continuous nonlinear functions [1, 2].

The fundamental essence of the contribution of this work is to overcome the building of robust controller that has high order than that of the system where the controller is not easy to implement for this system in practical engineering application. This difficulty can be solved by the proposed algorithm that built a robust PSS-PID controller through applying the cognitive control methodology based PSO technique, the proposed algorithm works as online auto tuning for the PSS-PID controller parameters on the real time without time consuming as well as no requiring for tedious efforts.

2. Mathematical Modeling of Power System

In this paper a simplified dynamic model of power system, namely, a single machine connected to an infinite bus (SMIB) is considered. It consists of a single synchronous generator connected through a parallel transmission line to a very large network approximated by an infinite bus as shown in Fig. 1.

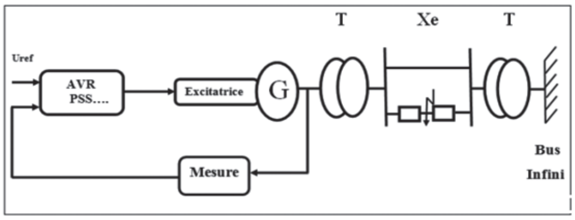

Fig. 1. Block schematic diagram of the proposed SMIB Power system controller

$$x1 = \Delta w \quad (1)$$

Let the state variable of interest be the machine's rotor speed variation and the power system acceleration.

$$x2 = \Delta P = P_m - P_e \quad (2)$$

Where $x1$ is the speed deviation and $x2$ is accelerating power, P_m and P_e represents respectively the mechanical and electrical power. It is possible to represent the power system in the following form:

$$x_1 = \Delta w \quad (3)$$

$$\alpha\, x_2 = f\,(x_1, x_2) + g\,(x_1, x_2)u \quad (4)$$

$$y = x_1 \quad (5)$$

Where α=1/2H and H is the per unit inertia constant of the machine. x=[x1x2] is the state vector of the system and f(x1,x2) and g(x1,x2) are nonlinear functions and u is the PSS (Power System Stabilizer) control signal.

The PSS-PID controller is well known and widely used to improve the dynamic response as well as to reduce or eliminate the steady state error. The derivative controller adds a finite zero to the open loop system transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady state error due to a step function to zero. The transfer function of a PSS-PID controller is given in the s-domain as follows:

$$\Delta E_f = \omega(p).\ [(\omega_{0u}(p) + \omega_{1u}(p))\Delta U(p) + (\omega_{0\omega}(p) + \omega_{1u}(p))\ \omega_{bf}(p).\ \Delta\omega_u(p) + \omega_{if}(p).\ \Delta i_f(p) + \omega_{uf}(p).\ \Delta u_f(p)] \quad (6)$$

E_{fd0} – value of the control signals in the steady state generator.

3. Particle Swarm Optimization (PSO) Algorithm

PSO is one of the optimization techniques first proposed by Eberhart and colleagues [4, 8].

The algorithm adopted uses a set of particles flying over a search space to locate a global optimum, where a swarm of *n* particles communicate either directly or indirectly with one another using search directions, in each iteration of PSO, each particle updates its position.

Based on three components, by determines its velocity using, previous velocity, best previous position, and the best previous position of its neighborhood [5, 7] Figure 2 illustrates the flow chart of PSO algorithm. The basic concept of PSO lies in accelerating each particle toward the best position found by it so far (pbest) and the global best position (gbest) obtained so far by any particle, with a random weighted acceleration at each time step, this is done by the equations (7) and (8):

$$V_i(t+1) = \omega \cdot V_i(t) + \varphi_1 \cdot r_1 \cdot (P_{bi}(t) - X_i(t)) + \varphi_2 \cdot r_2 \cdot (P_g(t) - X_i(t)) \quad (7)$$

$$X_i(t+1) = X_i(t) + V_i(t) \quad (8)$$

Where: Pg = Global Best Position. Pb = Self Best Position. Φ_1 and φ_2 =Acceleration Coefficients. w = Inertial Weight. V_i = Velocity. X_i = Particle.

Once the particle computes the new Xt it then evaluates its new location. If fitness (X t) is better than fitness (pb), then pb = Xt and fitness (pb) = fitness(X t), in the end of iteration the fitness (Pg) = the better fitness (pb) and Pg = pb

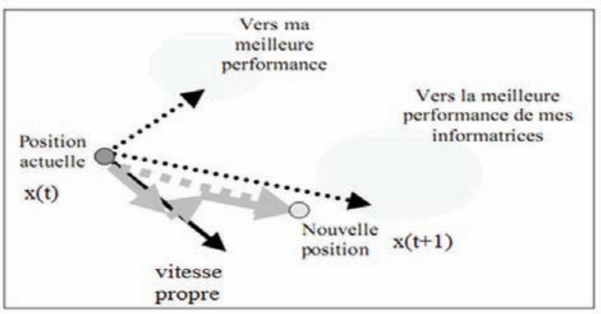

Fig. 2. Schematic diagram of the displacement of a particle

4. Implementation of PSO Based PSS-PID Controller

The optima value of PSS-PID controller parameters K1w, K2w, T1, T2 are to be found using GA. All possible sets of controller parameters values are particles whose values are adjusted to minimize and maximize the objective function, which in this case is the error criterion, and it is discussed in detail. For the PSS-PID controller design, the controller settings estimated results in a stable closed loop system are ensured.

This function must maximize the stability margin by increasing damping factors while minimizing the system real eigenvalues. Therefore, all eigenvalues are in the stability area, the multi-objective function calculating steps are:

1) Formulate the linear system in an open-loop (without PSS);
2) Locate the PSS and its parameters initialized by the PSO through an initial position and acceleration;
3) Calculate the closed loop system eigenvalues and take only the dominant modes: $\lambda = \sigma \pm jw$;
4) Find the system eigenvalues real parts (σ) and damping factor ζ;
5) Determine the (ζ) minimum value and the (- σ) maximum value, which can be formulated, respectively, as: (minimum (ζ)) and (maximum -(σ));
6) Gather both objective functions in a multi-objective function F as follows: $Fobj = -\max(\sigma)+\min(\xi)$;
7) Return this Multi-objective function value the to the AG program to restart a new generation.

5. SIMULATION RESULT

To evaluate the effectiveness of the proposed PSS-PSO to improve the stability of power system, the dynamic performance of the proposed PSS was examined under different loading conditions. The performance of the PSO based PSS is compared with the PSS.

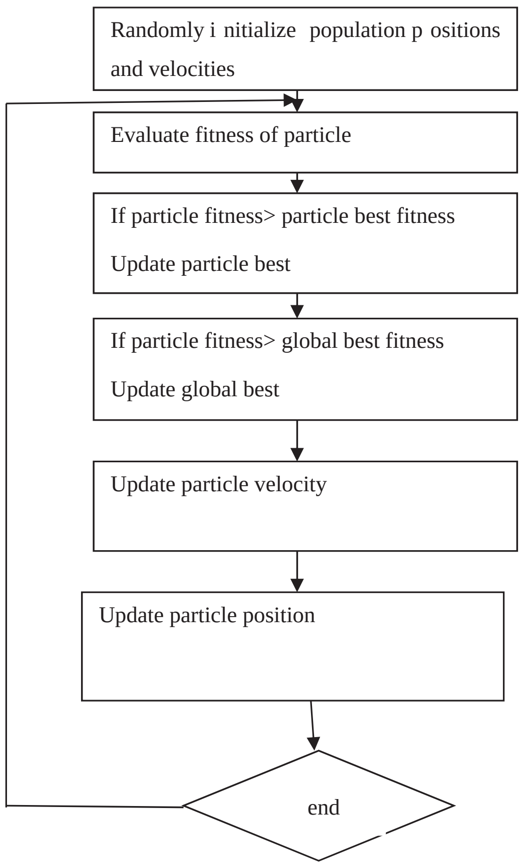

Fig. 3. Flowcharts of PSO

TBB = 500, Q = 0.1896(pu), XL = 0,5(pu)
Initialization
Sized swarm = 20.

N	K1w	K2w	T1	T2	segma
1	8.1472	6.5574	0.0437	0.0751	-4.2137
2	9.0579	0.3571	0.0380	0.0255	-1.9318
3	1.2699	8.4913	0.0762	0.0505	-0.2249
4	9.1338	9.3399	0.0791	0.0698	-2.6095
5	6.3236	6.7874	0.0186	0.0890	-2.4152
6	0.9754	7.5774	0.0487	0.0958	-0.1659
7	2.7850	7.4313	0.0443	0.0547	-0.8864
8	5.4688	3.9223	0.0643	0.0138	-1.6597
9	9.5751	6.5548	0.0706	0.0149	-2.8314
10	9.6489	1.7119	0.0751	0.0257	-2.9341
11	1.5761	7.0605	0.0275	0.0840	-0.4399
12	9.7059	0.3183	0.0676	0.0254	-2.5975
13	9.5717	2.7692	0.0652	0.0813	-3.0369
14	4.8538	0.4617	0.0162	0.0243	-1.0794
15	8.0028	0.9713	0.0118	0.0928	-2.8566
16	1.4189	8.2346	0.0496	0.0350	-0.3977
17	4.2176	6.9483	0.0955	0.0196	-1.1644
18	9.1574	3.1710	0.0339	0.0251	-1.9807
19	7.9221	9.5022	0.0582	0.0615	-3.8044
20	9.5949	0.3445	0.0223	0.0473	-2.0597

Number of iterations = 6.

N	K1w	K2w	T1	T2	segma
1	8.1472	6.5574	0.0437	0.0751	-4.2137
2	8.1472	6.5574	0.0437	0.0751	-4.2137
3	7.8169	5.3741	0.0392	0.0705	-4.4529
4	7.8169	5.3741	0.0392	0.0705	-4.4529
5	7.9242	5.7720	0.0404	0.0720	-4.5472
6	7.9242	5.7720	0.0404	0.0720	-4.5472

The optimized parameters: K1W = 7.9242, K2W = 5.7720, T1 = 0.0404,T2 = 0.0720. With segma = –4.5472.

Figures show examples of simulation results, respectively, "Ug" the stator terminal voltage; 'Pe' the electromagnetic power system, 'g' skid, 'delta' the internal angle.

ξ	PSS-PSO	PSS-PID
NO variation	-0,03594	-0,3568
Electrique variation	-0,1886	-0,3243
Mecanique variation	-0,005899	-0,3736
Electrique and mecanique variation	-0,1329	-1 ,544

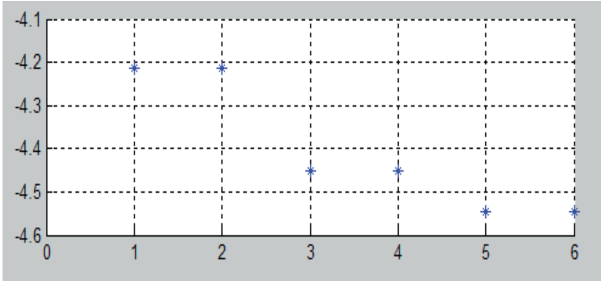

Fig. 4 The iteration

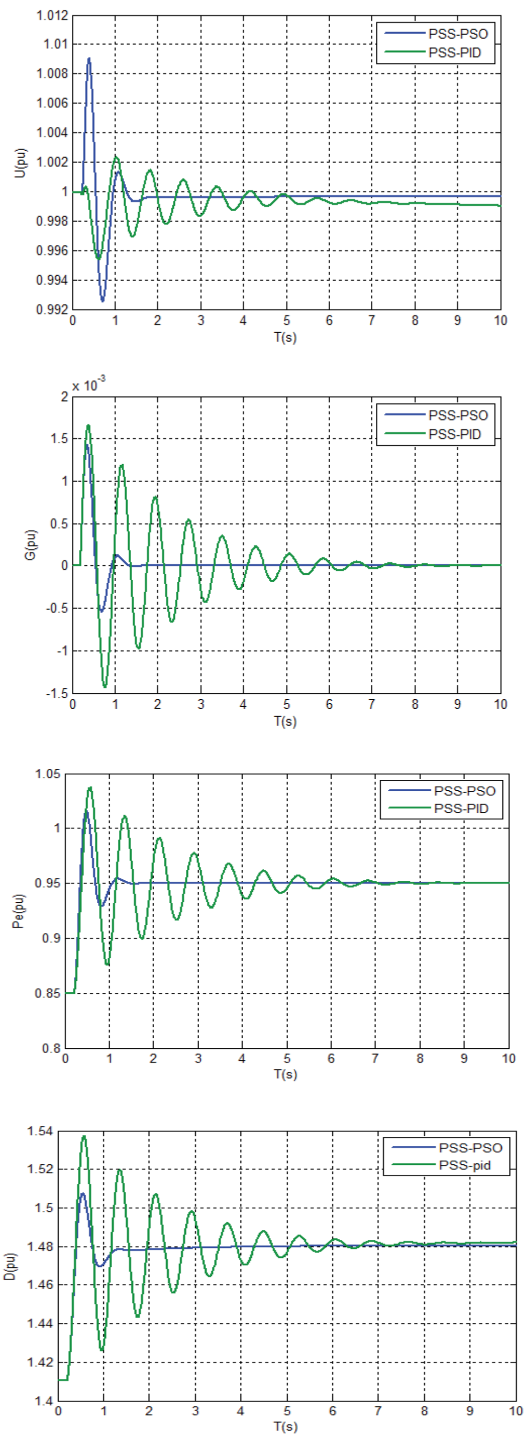

Fig. 5. Functioning system in the nominal regime used of TBB-500 connected to a long line with, PSS-PSO, PSS-PID (Ug, Pe, skid, delta)

5.1. Robustness Tests

1. Electric variation T = 3 s

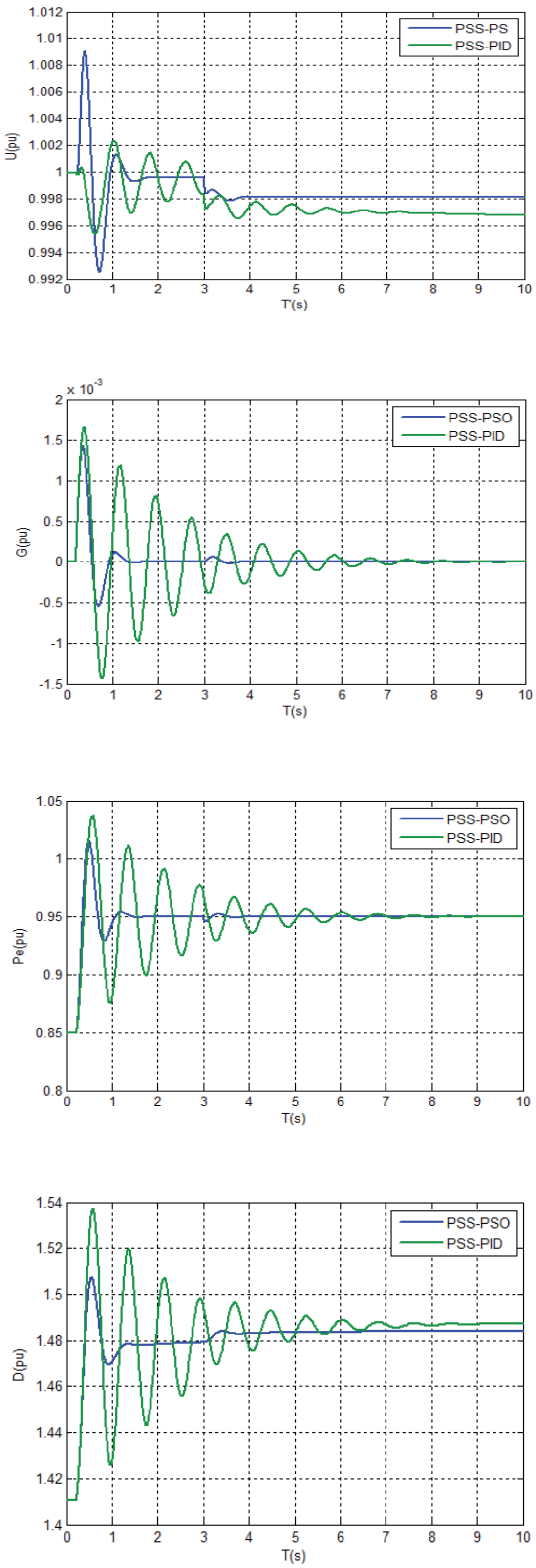

Fig. 6. Functioning system in the nominal regime used of TBB-500 connected to a long line with, PSS-PSO, PSS-PID (robustness tests) (Ug, Pe, skid, delta)

2. Mechanical variation t = 5 s
Electrical and mechanical variation t = 7 s

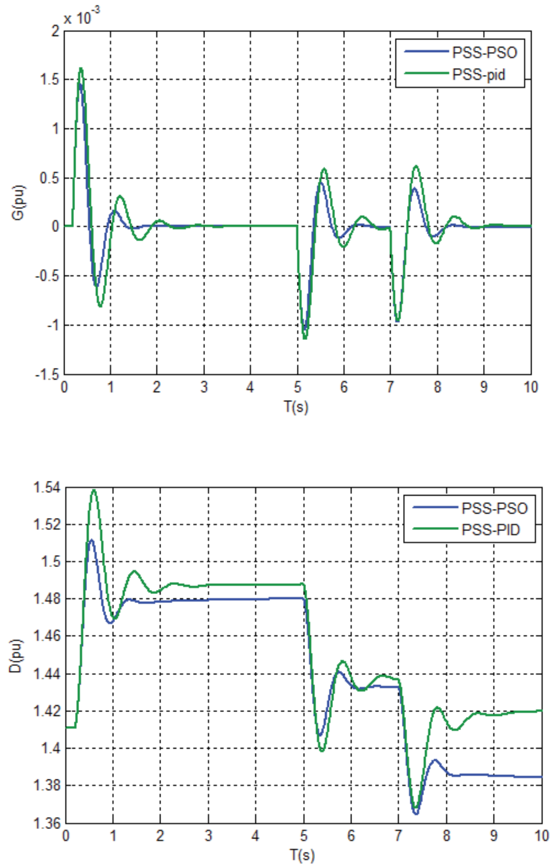

Fig. 7. Functioning system in the nominal regime used of TBB-500 connected to a long line with, PSS-PSO, PSS-PID (robustness tests) (Ug, Pe, skid, delta)

The main advantages of the PSS-PSO controller are the robustness of the system whenever a disturbance occurred and in case of the uncertainty in the parameters.

From the simulation results, the effect of the controller can be realized from decrease of dynamic performances (static errors negligible so better precision, and very short setting time so very fast system, and we found that after few oscillations, the system returns to its equilibrium state even in critical situations (specially the under-excited regime) and granted the stability and the robustness of the studied system.

6. Conclusion

In this work the PSO algorithm has been utilized to find the optimal parameters of conventional PSS.

The result of PSO technique is compared with classical PID. The system becomes more robust and the dynamic performance of the PSS-PSO is superior than the conventionally tuned PSS under small as well large perturbation. Simulation of the response of the proposed PSS to various disturbances changes in network configuration and system loading have demonstrated the effectiveness of the PSS-PSO.

AUTHORS

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Appendix

Parameters of the used Turbo-Alternators

Parameters	TBB-500	Units of measure
Nominal power	500	MW
Power Factor	0.85	p.u.
Xd	1.869	p.u.
Xq	1.5	p.u.
Xs	0.194	p.u.
Xf	1.79	p.u.
Xsf	0.115	p.u.
Xsfd	0.063	p.u.
Xsf1q	0.0487	p.u.
Xsf2q	0.0487	p.u.
Ra	0.0055	p.u.
Rf	0.000844	p.u.
R1d	0.0481	p.u.
R1q	0.061	p.u.
R2q	0.115	p.u.

Parameters of the Regulator AVR

Parameter	SG: TBB-500
T1u	0.039
Te	0.04
K1ua	-7
K0ua	-50

Parameters of the used conventional PID-PSS

Parameter	SG: TBB-500
T1u	0.039
Te	0.04
K1ua	-8
K0ua	-15
Tfc	0.07
T1	0.026
$T0^{\omega}$	1
$K1^{\omega}$	1
$K0^{\omega}$	2
Tif^{ω}	0.03
Kif	-1
Tuf	0.05
Kuf	1

Parameters of the used PSO

PSO Property	Value/Method
*Size of the swarm	100
*C1	0.4
*C2	0.4
* w	0.1
* The range of adjustment parameters	5<K1W<10, 5<K2w<10 0.0005<T1<0.1, 0.0001<T2<0.1
*Objective function	σ)+min(ξ)