# Design of Optimal Robust PID-Power System Stabilizer using Particle Swarm Optimization

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Abstract- Power system stabilizers (PSS) are used to generate supplementary damping control signals for the excitation system in order to damp the low frequency oscillations of the electric power system. The PSS is usually designed based on classical control approaches but this conventional PSS (CPSS) has some problems. To overcome the drawbacks of CPSS, various techniques have been proposed. This paper proposes design methodology for a robust optimal PID-PSS for stability robustness, posing the controller design problem as optimization problem and, then, solving it using particle swarm optimization algorithm (PSO). The performance index to be minimized is the $H_2$ - norm of the tracking error and constraint is the frequency domain performance of stability robustness. The PSO is used to solve the constrained optimization problem. The PID-PSS is evaluated against the conventional power system stabilizer (CPSS) at a single machine infinite bus power system considering system parametric uncertainties. The simulation results clearly indicate the effectiveness and validity of the proposed method.
KEYWORDS-Power System Stabilizer, Robust Control, Particle Swarm Optimization

## 1. INTRODUCTION

Power system stabilizers (PSS) are used on synchronous generator to improve the damping of oscillations of rotor/turbine shaft[1]. Oscillations of low frequency arises due to changes in load, changes in shaft speed and faults. These low frequency oscillations limit the power transfer capability of the system. In order to damp power system oscillations we can use classical PSS (CPSS) which is not robust due to uncertainties.

In the present paper procedure for designing a robust optimal PID-PSS is explained . PSO has been used to solve optimization problem to get the parameters of the PID-PSS[2-3]. The system under study is a synchronous generator connected to large power system through an external transmission line. The time domain simulations are performed to compare the performance of the SMIB without controller (PSS), with CPSS and with PID-PSS using simulink. Plots of rotor angle and relative speed are plotted as function of time without PSS, with CPSS and with PID-PSS.

## 2. PROBLEM FORMULATION

The system under study is a synchronous generator connected to large power system through an external transmission line as shown in Fig. 1. For simplicity; we will assume a synchronous machine neglecting damper windings both in the d- axes and q- axes. (It is possible to approximate the effects of damper windings by a non linear damping term, if necessary.) Also, the armature resistance of the machine is neglected and the excitation system is represented in Fig.1.

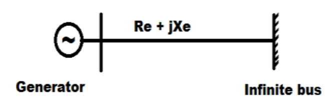


Fig. 1 A single machine infinite bus system

The block diagram representing the single machine infinite bus system shown in Fig. 1 is in terms of a few basic small signal transfer function[1], the relationship between the applied torques on the turbine-generator shaft and the resulting generator rotor speed $w_o$ and the rotor angle displacement (delta). The electrical torque is considered to have two components, viz (a) that which is produced by the power system stabilizer solely by the modulation of generator flux, (b) that which results from all other sources, including shaft motion. Consider the control system shown in Fig.2, where $G_o(s)$ is the nominal plant and C(s,k) is the PID controller with the following form:

$$C(s,k) = k_1 + \frac{k_2}{s} + k_3 s \qquad (1)$$

Here, $k$ is the vector of controller parameters:

$$k = [k_1, k_2, k_3]^T \qquad (2)$$

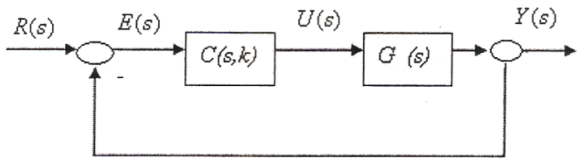


Fig. 2 PID control system with plant perturbation

The Plant model, using multiplicative uncertainty is given by

$$G(s)=G_o(s)[1+\Delta G(s)] \tag{3}$$

Where, $G_o(s)$ is the nominal transfer function of the plant, the plant perturbation $\Delta G(s)$ is assumed to be stable but uncertain[4-5]. Suppose the $\Delta G(s)$ is bounded according to

$$\left|\Delta G(j\omega)\right| \langle \left|W_m(j\omega)\right|, \forall \omega \in [0,\infty), \tag{4}$$

Where the weighting function $W_m$ is stable and known.

2.1 Condition for stability robustness

The condition for robust stability is given as follows [6] : If the nominal control system($\Delta(s)=0$) is stable with the controller C(s,k),then the controller C(s,k) guarantees robust stability of the control system, if and only if the following condition is satisfied:

$$\left\| \frac{C(s,k)G_o(s)W_m(s)}{1+C(s,k)G_o(s)} \right\|_\infty \langle 1 \tag{5}$$

Here, it is assumed that no unstable poles of $G_o(s)$ are cancelled in forming G(s).The $H_\infty$ norm is defined as

$$\left\| A(s) \right\|_\infty = \sup_{\omega\in[0,\infty)} \left| A(j\omega) \right| \tag{6}$$

Applying the defination of $H_\infty$ norm, the robust stability condition results in the following:

$$\left\| \frac{C(s,k)G_o(s)W_m(s)}{1+C(s,k)G_o(s)} \right\|_\infty =$$

$$= \max_{\omega\in[0,\infty)} \left[ \frac{C(j\omega,k)G_o(j\omega)W_m(j\omega)C(-j\omega,k)G_o(-j\omega)W_m(-j\omega)}{(1+C(j\omega,k)G_o(j\omega)(1+C(-j\omega,k)G_o(-j\omega)} \right]^{0.5}$$

$$= \max_{\omega\in[0,\infty)} (\alpha(\omega,k))^{0.5} \tag{7}$$

Then, the condition of robust stability in the frequency domain is expressed as

$$\max_{\omega\in[0,\infty)} (\alpha(\omega,k))^{0.5} \langle 1 \tag{8}$$

Then function $\alpha(\omega,k)$ in equation (7) can also be expressed in the following form:

$$\alpha(\omega,k) = \frac{\alpha_z(\omega,k)}{\alpha_n(\omega,k)} = \frac{\sum_{j=0}^{p} \alpha_{zj}(k)\omega^{2j}}{\sum_{i=0}^{q} \alpha_{ni}(k)\omega^{2i}} \tag{9}$$

3. OPTIMAL ROBUST CONTROLLER DESIGN

In Fig.1, for the nominal case, the tracking error signal is given by

$$e(s) = \frac{r(s)}{1+G_o(s)C(s,k)} \tag{10}$$

The performance index ,J, is given by

$$J = \min_c \int_0^\infty e^2(t)dt \tag{11}$$

It can be described in the frequency domain of the Parseval theorem]:

$$J = -\frac{1}{2\pi j} \int_{-j\infty}^{+j\infty} E(s)E(-s)ds \tag{12}$$

The reference signal (set point) is an unit step function given by:

$$R(s) = \frac{1}{s} \tag{13}$$

The error E(s) can be expressed then as a rational function:

$$E(s) = \frac{D(s)}{A(s)} = \frac{\sum_{j=0}^{m} d_j s^{m-j}}{\sum_{i=0}^{n} a_i s^{n-i}} \tag{14}$$

In this case, the degree m of the polynomial D(s) must be smaller than the degree n of the polynominal A(s), so that the squared error J in equation (12) has a finite value. Introducing the error E(s) from equation (14) into equation (12) results in the following

$$J = -\frac{1}{2\pi j} \int_{-j\infty}^{+j\infty} \frac{[\sum_{j=0}^{m} d_j s^{m-j}][\sum_{j=0}^{m} d_j (-s)^{m-j}]}{[\sum_{i=0}^{n} a_i s^{n-i}][\sum_{i=0}^{n} a_i (-s)^{n-i}]} ds$$

In design of optimal robust controller, both the tracking performance and robust stability are considered. The controller design is formulated as constrained optimization problem as follows:

$$\min_{k} J_n(k) \text{ subject to } \max_{\omega}(\alpha(\omega,k))^{0.5}\langle 1$$

The objective of the minimization is to find out the vector of controller parameters k so that the value of the performance index $J_n(K)$ is minimum and the condition of robust stability is satisfied.

$$\max_{\omega\in[0,\infty)}(\alpha(\omega,k))^{0.5}\langle 1$$

## 4. PARTICLE SWARM OPTIMIZATION

It is a population based stochastic optimization technique developed in 1995 [7],from the simulation of social behavior of bird flocking or fish schooling. PSO has been found to be simple, effective and robust in solving problems with nonlinearity, non-differentiability and multidimensional optimization [8].

In PSO, each particle represents a candidate solution to the optimization problem. At the beginning, each particle spans randomly through the problem space and updates its velocity and position with the two best values. The first best value, called pbest is the best solution achieved so for. Another value, called gbest is the Global best solution obtained so far by any particle in the swarm. At each interaction, each particle moves to pbest and gbest locations. The cost function evaluates the performance of particles to determine whether the best solution is achieved. In this paper, the PSO is used to solve the constrained optimization problem.

In PSO algorithms each particle moves with an adaptable velocity within the regions of decision space and retains a memory of the best position it ever encountered. The best position ever attained by each particle of the swarm is communicated to all other particles.

The updating equations of the velocity and position are given as follows:-

A particle position is given by $x_i(k)$
A particle velocity is given by $v_i(k)$
A best "remembered" individual particle position is given by $p_i(k)$
A best "remembered" swarm position is given by $p_g(k)$.
Cognitive and social parameters referred to as acceleration constants are given by $c_1$ and $c_2$.
Random numbers between 0 and 1 are $r_1$ and $r_2$.
A inertia weight is given by w.
$P_i$ refers who best position found by particles.
Velocity of Individual particle is updated as follows:
$v_i(k+1) = wv_i(k) + r_1c_1[\, p_i(k) - x_i(k)\,] + r_2c_2\,[\, p_g(k) - x_i(k)\,]$
Position of individual particle is updated as follows:
$x_i(k+1) = x_i(k) + v_i(k+1)$
The details of the PSO algorithm are given in flowchart.

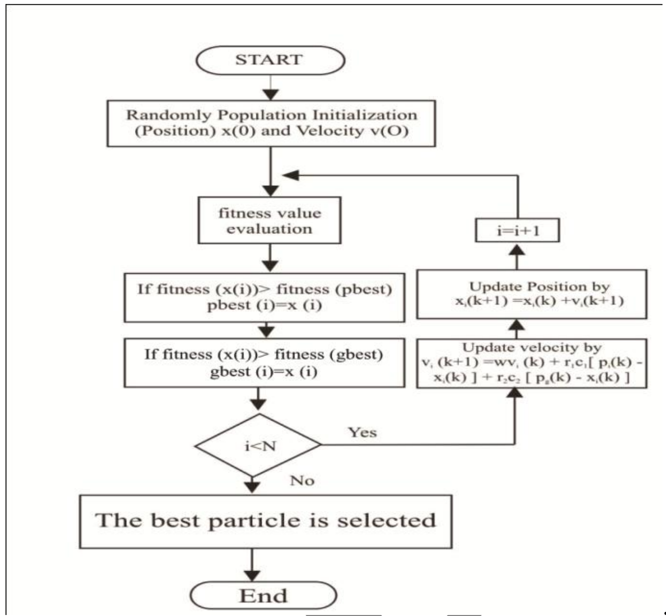


Fig.3 Flowchart of the PSO algorithm

## 5. SYSTEM RESPONSE AND ANALYSIS

The system data taken for the designed controller has the following parameters[1].

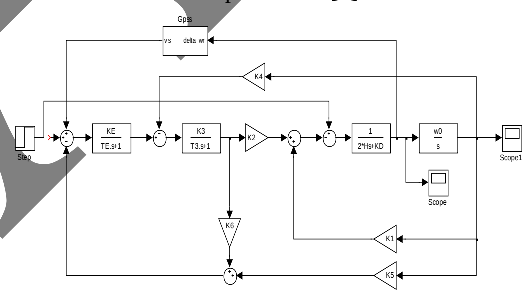


Fig. 4 SMIB Model with CPSS

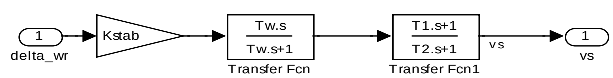


Fig. 5 CPSS Model

TABLE 1
LINE PARAMETERS

| Parameter | Values |
|---|---|
| Re | $0.1133\Omega km^{-1}$ |
| L | $1.618 \times 10^{3} Hkm^{-1}$ |
| C | $8.488 \times 10^{-9} Fkm^{-1}$ |
| Line length | 300km |

TABLE 2

SYSTEM DATA

| parameter | Values in p.u. |
|---|---|
| M | 7 |
| $T_3$ | 8 |
| $X_d$ | 1.81 |
| $X'_d$ | 0.30 |
| $X_q$ | 1.76 |
| $K_D$ | 4 |
| F | 60 |
| $W_o$ | 377 |
| H | 3.5 |
| $K_E$ | 50 |
| $T_E$ | 0.01 |

TABLE 3
HEFFRON-PHILLIPS CONSTANTS

| Parameter | Values in p.u. |
|---|---|
| $K_1$ | 0.7094 |
| $K_2$ | 1.2019 |
| $K_3$ | 2.4005 |
| $K_4$ | 1.1071 |
| $K_5$ | -0.0495 |
| $K_6$ | 0.6735 |

TABLE 4
CPSS CONSTANTS

| Parameter | Values in p.u. |
|---|---|
| $T_1$ | 0.8 |
| $T_2$ | 0.1 |
| $T_w$ | 10 |
| $K_{stab}$ | 9.5 |

The vector k of controller parameter is given *by* $k = [k_1, k_2, k_3]^T$ which is to be obtained solving the optimization problem.

The error signal *E(s)*, assuming the input signal to be unit step, is evaluated as follows:

The squared error $J_5(k) = E' E$ is obtained by calculating error *E* due to step input at a each instant. This squared error is to be minimized under the robust stability constraint.

The $H_\infty$ norm is calculated using MATLAB function normhinf.

PID-PSS Parameters come out as shown in the Table 5.

TABLE 5
PSS-PID PARAMETERS

| Parameter | Values |
|---|---|
| $K_1$ | 54.3236 |
| $K_2$ | 42.96 |
| $K_3$ | 10 |

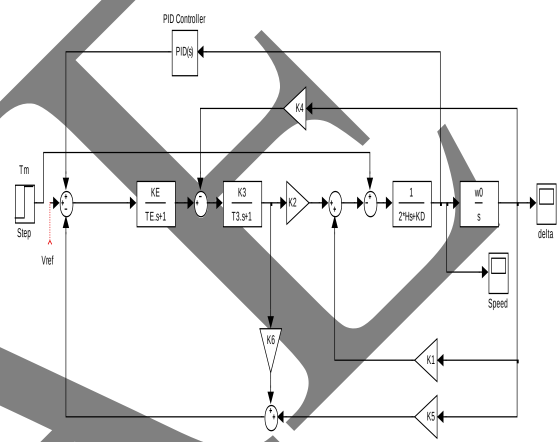


Fig. 6 SMIB Model with PID-PSS

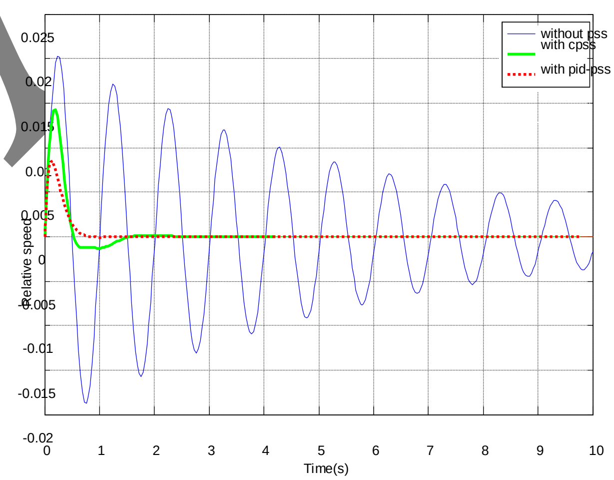


Fig. 7 Rotor speed deviation of SMIB without PSS, with CPSS and with PID-PSS

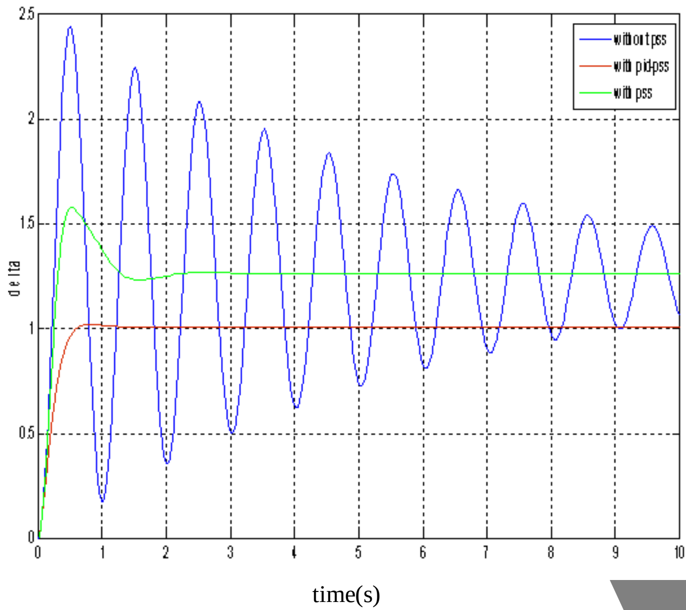


Fig.8 Rotar angle deviation of SMIB without PSS, with CPSS and with PID-PSS

In Fig. 5 for rotor speed deviation the settling time with CPSS is 1.8 sec and with PID-PSS is .8 sec. The over shoot without PSS is .02, with CPSS is .0149 and with PID-PSS is .008.In Fig. 6 for rotor angle deviation the settling time with CPSS is 1.8 sec and with PID-PSS is .8 sec. The over shoot without PSS is 2.49, with CPSS is 1.52 and with PID-PSS is 1.001.

## 6. CONCLUSIONS

In this paper a method is presented to design an optimal robust PID-PSS. The design problem is formulated as an optimization problem with constraint of type $H_\infty$ norm. The tracking performance of the PID-PSS with proposed method has been found better than with CPSS. The response of speed deviation and rotor angle deviation settles down smoothly. The simulation results reveal that PID-PSS gives superior performance than CPSS. Therefore the proposed control algorithms are shown to be effective. In the future, this control method can be further extended and applied to multivariable system.

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