

**Multimachine PSS Design Based on Fuzzy Controller with Particle Swarm Optimization Tuning**

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**Abstract**— This paper presents PSS (Power system stabilizer) design based on fuzzy controller (FLPSS). The main motivation for this design was to stabilize and improve the damping of synchronous machine. A speed deviation and active power deviation are selected as fuzzy controller inputs. The controller output is injected into AVR. FLPSS parameters ($K_p$, $K_\omega$, $K_u$) are tuned by PSO (Particle Swarm Optimization) to reach optimal stability. The optimal criteria of the Integral of Time multiplied by Absolute Error (ITAE) is used to search optimal setting. The performance of the proposed PSS under small perturbation and large perturbation is tested. The simulation results show the effectiveness of the proposed PSS to damp out the system oscillations of multimachine power system.

**key words** – Fuzzy Logic Controller, power system stabilizer, Particle Swarm Optimization

1. **Introduction**

Low-frequency oscillations are a common problem in large power systems. PSS (power system stabilizer) is one of alternative solution for this problem. PSS can provide auxiliary control signal to the excitation system and/or the speed governor system of the electric generating unit. This can also damp oscillation and improve its dynamic.

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performance. PSSs have been extensively studied and used in power systems for many years.

Most PSSs employ the classical linear control theory. PSS design approach is based on a linear model in fixed configuration of the power system. This results in fixed-parameter of PSS. It is called a conventional PSS (CPSS) and widely used in power systems to damp out small oscillations [1-3].

In the conventional fixed-parameter spectrum controllers, the gains and other parameters may not ideally suit the entire spectrum of operation. Developments in digital technology have made it feasible to develop and implement improved controllers based on modern, more sophisticated techniques. Power system stabilizers based on adaptive control, artificial neural networks, and fuzzy logic are being developed. Each of these control techniques possesses unique feature and strength. Fuzzy logic-based PSS (FLPSS) shows great potential in increasing the damping of generator oscillations [4] [5].

In this papers, an fuzzy-based PSS is developed, which uses a speed deviation and active power deviation as the inputs.

Results presented in the paper show that the optimal fuzzy logic based PSS (FLPSS) can offer better dynamic performance than the multiband power system stabilizer (MB PSS) and the conventional PSS (Delta w PSS and Delta Pa PSS) when the power system is subject to a mayor disturbance that would result in a significant change in system operating condition. The proposed stabilizer is easy to implement digitally because the structure of a fuzzy logic based PSS is simple and only locally output signal are required.
2. Fuzzy Logic based PSS

The basic principles underlying the design of the proposed fuzzy logic based PSS can be illustrated by the block diagram in Fig.1, in which a synchronous generator with a static exciter is equipped with a fuzzy controller whose gain settings are tuned by PSO. The generator speed deviation $\Delta \omega$ and active power deviation are as the input signal of the proposed stabilizer.

PSS based on Fuzzy logic controller algorithm has been developed. The goal of this application is to stabilize and improve the damping of the synchronous machine. A speed deviation $\Delta \omega$ and active power deviation $\Delta P_e$ are selected as the controller input. The controller output is injected into the exciter system.

A fuzzy logic based PSS has two input parameters, $K_\omega$ and $K_p$, and output parameter, $K_u$, as seen in Figure 2. The selection of these parameters is usually subjective and requires previous knowledge of fuzzy control variables (input and output signal).
Using the automatic rule generation and sampled data set generated by using the conventional power system stabilizer, a proper set of rule was obtained [4]. The rule used in all the following are shown in figure 3.

<table>
<thead>
<tr>
<th>Speed deviation</th>
<th>Active power</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>NB</td>
</tr>
<tr>
<td>NM</td>
<td>NB</td>
</tr>
<tr>
<td>NS</td>
<td>NB</td>
</tr>
<tr>
<td>Z</td>
<td>NM</td>
</tr>
<tr>
<td>PS</td>
<td>NM</td>
</tr>
<tr>
<td>PM</td>
<td>NS</td>
</tr>
<tr>
<td>PB</td>
<td>Z</td>
</tr>
</tbody>
</table>

Figure 3. FLPSS rules

3. Particle Swarm Optimization

Particle swarm optimization (PSO) is a population-based global optimization method based on a simple simulation of bird flocking or fish schooling behavior. PSO was introduced in 1995 by Kennedy and Eberhart [6]. Although several modifications to the
original swarm algorithm have been made to improve performance and adapt it to specific
types of problems, a series version has been previously implemented [6,7].

The following is a brief introduction to the operation of the PSO algorithm. Consider a swarm of \( p \) particles, with each particle’s position representing a possible solution point in the design problem space \( D \). For each particle \( i \), Kennedy and Eberhart proposed that its position \( x_i \) be updated in the following manner:

\[
x_{k+1}^i = x_k^i + v_{k+1}^i
\]

(1)

with a pseudo-velocity \( v_{k+1}^i \) calculated as follows:

\[
v_{k+1}^i = \omega_k v_k^i + c_1 r_1 (p_k^i - x_k^i) + c_2 r_2 (p_k^g - x_k^i)
\]

(2)

Here, subscript \( k \) indicates a (unit) pseudo-time increment, \( p_k^i \) represents the best ever position of particle \( i \) at time \( k \) (the cognitive contribution to the pseudo-velocity vector \( v_{k+1}^i \)), and \( p_k^g \) represents the global best position in the swarm at time \( k \) (social contribution). \( r_1 \) and \( r_2 \) represent uniform random numbers between 0 and 1. To allow the product \( c_1 r_1 \) or \( c_1 r_1 \) to have a mean of 1, Kennedy and Eberhart proposed that the cognitive and social scaling parameters \( c_1 \) and \( c_2 \) be selected such that \( c_1 = c_2 = 2 \).

The serial PSO algorithm (Fig. 4) as it would typically be implemented on a single CPU computer is described below, where \( p \) is the total number of particles in the swarm. The best ever fitness value of a particle at design co-ordinates \( p_k^i \) is denoted by \( f_{best}^i \) and the best ever fitness value of the overall swarm at co-ordinates \( p_k^g \) by \( f_{best}^g \). At time step \( k = 0 \), the particle velocities \( v_0^i \), \( v_0^{max} \) are initialized to values within the limits \( 0 \leq v_0 \leq v_0^{max} \). The vector \( v_0^{max} \) is calculated as a fraction of the distance between the upper and lower
bounds $v_{0}^{maks} = \zeta (x_{UB} - x_{LB})$ with $\zeta = 0.5$. With this background, the PSO algorithm flow can be described as follows [7]:

1. Initialize
   (a) Set constants $k_{maks}$, $c_1$, $c_2$, $k$, $v_{0}^{maks}$, $\omega_k$, $d$, and $w_d$
   (b) Initialize dynamic maximum velocity $v_{max}^k$ and inertia $w_k$
   (c) Set counters $k = 0$, $t = 0$, $i = 1$. Set random number seed
   (d) Randomly initialize particle positions $x_{i0} \in \mathbf{D}$ in $\mathbb{R}_a$ for $i = 1, \ldots, p$
   (e) Randomly initialize particle velocities $0 \leq v_{0} \leq v_{0}^{maks}$ for $i = 1, \ldots, p$
   (f) Evaluate fitness values $f^i_0$ using design space co-ordinates $x_{i0}$ for $i = 1, \ldots, p$
   (g) Set $f_{best}^i = f^i_0$, $p^i = x_{i0}$ for $i = 1, \ldots, p$
   (h) Set $f_{best}^g$ to $f_{best}^i$ and go to corresponding $x_{i0}$

2. Optimize
   (a) Update particle velocity vector $v_{k+1}^i$ using Equation (2)
   (b) Update particle position vector $x_{k+1}^i$ using Equation (1)
   (c) Update dynamic maximum velocity $v_{k}^{maks}$ and inertia $w_k$
   (d) Evaluate fitness value $f_k^i$ using design space co-ordinates $x_k^i$
   (e) if $f_k^i \leq f_{best}^i$, then $f_{best}^i = f_k^i$, $p^i = x_k^i$
   (f) if $f_k^i \leq f_{best}^g$ then $f_{best}^g = f_k^i$, $p^g = x_k^i$
   (g) if $f_{best}^g$ best was improved in (e) then reset $t = 0$. Else increment $t$
   (h) if $k > k_{maks}$ go to 3
(i) if \( t = d \) then multiply \( w_{k+1} \) by \((1-w_d)\) and \( v_{k+1}^{max} \) by \((1-v_d)\)

(j) If stopping condition is satisfied then go to 3

(k) Increment \( i \), if \( i > p \) then increment \( k \), and set \( i = 1 \)

(l) Go to 2(a)

3. Report results

4. Terminate

Clerc indicates that the use of a constriction factor \( K \) may also be necessary to ensure convergence of the particle swarm algorithm, defined as when all particles have stopped moving. Their update rule for velocity is:

\[
v_{k+1}^i = \chi [v_k^i + c_1 r_1 (p_k^i - x_k^i) + c_2 r_2 (p_k^i - x_k^i)]
\]

\[
\chi = \frac{2}{2 - \sqrt{\varphi^2 - 4\varphi}}
\]

where \( \varphi = c_1 + c_2 \) and \( \varphi > 4 \).

In recent research, Xu and Xin [8] point out that the combined use of gbest and lbest may be helpful for the search process, and the velocity should still be constricted by the constriction factor:

\[
v_{k+1}^i = \chi [v_k^i + c_1 r_1 (p_k^i - x_k^i) + c_2 r_2 (p_k^i - x_k^i) + c_3 r_3 (p_k^i - x_k^i)]
\]

4. Formulation Problem

In this section, a simple performance index that reflects small steady state error, small overshoots and oscillations is selected as objective function. PSO search employs \textit{Integral of Time multiplied by Absolute Error} (ITAE) optimization technique. The performance index (objective function) is defined as
\[ J = \sum_{i=1}^{N} \int_{0}^{t_i} |\Delta \omega_i - \Delta \omega_1| dt \]

where \( \Delta \omega_i = \text{speed deviation of machine } i \)

\( \Delta \omega_1 = \text{speed deviation of machine } 1^{\text{st}} \)
Figure 4. Serial PSO flowchart [7]
5. Simulation Results

To evaluate the effectiveness of the proposed stabilizer to improve the stability of power system, a simple two-area power system is studied [1]. Fig. 6 shows a simple two-area system. The nominal operating conditions and system parameters are given in Appendix [1]. A multimachine power system with synchronous generator provided with excitation system and governor system is considered. The power system dynamic performance of the proposed stabilizer was examined under small signal perturbation and large signal perturbation. The performance of the fuzzy logic based PSS is compared with three PSS that are the same setting for all machines. Three PSS are multiband PSS and the two conventional PSS whose parameters were optimized using phase compensation technique, ie, \( w \) delta PSS and \( Pa \) delta PSS. [1]

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**Fig. 6 A simple two-area system**
Without power system stabilizer, the system damping is poor and the system exhibits highly oscillatory response [1,2]. It is therefore necessary to install PSS to improve the dynamic performance.

A small perturbation 12-cycle pulse of 5% magnitude at the voltage reference of machine 1 and a large perturbation 8-cycles, three-phase fault with line outage are applied at nominal operating condition. The dynamic responses of machine all PSS are compared.

In this work, the PSO options used in this study are shown in Table 1.

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SwarmSize</td>
<td>30</td>
</tr>
<tr>
<td>$k_{max}$</td>
<td>50</td>
</tr>
<tr>
<td>$c_1$</td>
<td>2</td>
</tr>
<tr>
<td>$c_2$</td>
<td>2</td>
</tr>
<tr>
<td>$c_3$</td>
<td>1</td>
</tr>
<tr>
<td>$\omega_{k \text{ start}}$</td>
<td>0.97</td>
</tr>
<tr>
<td>$\omega_{k \text{ end}}$</td>
<td>0.4</td>
</tr>
<tr>
<td>$\omega_d$</td>
<td>0.5</td>
</tr>
<tr>
<td>$V_{max}$</td>
<td>2</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>0.5</td>
</tr>
<tr>
<td>$\chi$</td>
<td>1</td>
</tr>
<tr>
<td>$x_{UL}$</td>
<td>[0 0 0]</td>
</tr>
<tr>
<td>$x_{UB}$</td>
<td>[80 5 10]</td>
</tr>
</tbody>
</table>

The convergence rate of the objective function $J$ is shown in Fig. 6. The following solution with optimal fuzzy logic based PSS (FL-PSO) with minimum index performance is selected for the control purpose:

<table>
<thead>
<tr>
<th>$K_w$</th>
<th>$K_p$</th>
<th>$K_u$</th>
</tr>
</thead>
<tbody>
<tr>
<td>69.70082</td>
<td>1.58145</td>
<td>8.69267</td>
</tr>
</tbody>
</table>
5.1 Small Signal Perturbation Test

A small perturbation 12-cycle pulse of 5% magnitude at the voltage reference of machine 1 was applied at nominal loading condition. The dynamic responses of FL-PSO stabilizer are compared with the three PSS. Fig. 8 – Fig. 10 shows that the FL-PSO stabilizer has lower peak over-shoots and damps out low frequency oscillations very quickly as compare to other PSS.
Fig 8. Dynamic response for $\Delta \omega_{21}$ for small perturbation with nominal load
Fig 9. Dynamic response for $\Delta \omega_{31}$ for small perturbation with nominal load
Fig 10. Dynamic response for $\Delta \omega_{41}$ for small perturbation with nominal load
Fig 11. Dynamic response for $\Delta \omega_{32}$ for small perturbation with nominal load

5.2 Large Signal Perturbation Test

A large perturbation 8-cycles, three-phase fault with line outage are applied at nominal operating condition. Response to a three-phase fault for nominal loading condition are shown Fig. 12 - Fig. 15. All figures show that the FLPSS has lower peak over-shoots and damps out low frequency oscillations very quickly as compare to other PSS.
Fig. 12 Dynamic response for $\Delta \omega_{21}$ for large perturbation with nominal load
Fig. 13 Dynamic response for $\Delta \omega_{31}$ for large perturbation with nominal load
Fig. 14 Dynamic response for $\Delta \omega_{41}$ for large perturbation with nominal load
Fig. 15 Dynamic response for $\Delta \omega_{32}$ for large perturbation with nominal load

6. Conclusions

In this paper, a new technique for the stabilization of power system and a different approach for designing a power system stabilizer are presented by using a fuzzy logic stabilizer. PSO has been employed to perform the function of a fuzzy based PSS to improve the stability and dynamic performance of the power system. Computer simulation studies described in the paper show that the performance of the fuzzy logic stabilizer can provide very good performance.
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APPENDIX

Nominal System Parameters

The nominal parameters and operating conditions of the system are given below. All data are in per unit, except that H and the time constants are in seconds.

The system consists of two similar areas connected by a weak tie. Each area consists of two coupled units, each having a rating of 900 MVA and 20 kV. The generator parameters in per unit pu the rated MVA and kV base are as follows:

\[
\begin{align*}
X_d &= 1.8 \quad X_q = 1.7 \quad X_1 = 0.2 \quad X_d' = 0.3 \quad X_q' = 0.55 \\
X_d'' &= 0.25 \quad X_q'' = 0.25 \quad R_a = 0.0025 \quad T_{d0}' = 8.0 \text{ s} \quad T_{q0}' = 0.4 \text{ s} \\
T_{d0}'' &= 0.03 \text{ s} \quad T_{q0}'' = 0.05 \text{ s} \quad A_{sat} = 0.015 \quad B_{sat} = 9.6 \quad \psi_{TI} = 0.9
\end{align*}
\]

H = 6.5 (for G_1 and G_2) \quad H = 6.175 (for G_3 and G_4) \quad D = 0

Each step-up transformer has an impedance of 0 + j0.15 per unit on 900 MVA and 20/230 kV base, and has an off-nominal ratio of 1.0.

REFERENCES


I. BIOGRAPHIES

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