Minimax Approximation Synthesis in PSS Design by Embedding Gravitational Search Algorithm

Dr. Akash Saxena
Department of Electrical Engineering
Swami Keshvanand Institute of Technology
Jaipur, India
Introduction

Power System Stability:

- “Power system stability is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.” (IEEE CIGRE Taskforce Committee, 2004)

- “Power system stability is the tendency of a power system to develop restoring forces equal to or greater than the disturbing forces to maintain the state of equilibrium.”
Classifications

Power System Stability

- Rotor Angle Stability
- Frequency Stability
- Voltage Stability

Rotor Angle Stability
- Small-Signal Stability
  - Short Term
  - Short Term

Frequency Stability
- Transient Stability
  - Short Term

Voltage Stability
- Large-Disturbance Voltage Stability
  - Short Term
  - Long Term
- Small-Disturbance Voltage Stability
  - Long Term

Consideration for Classification

Physical Nature/ Main System Parameter

Size of Disturbance

Time Span
Type of Oscillations

a) Inter-unit Oscillations

These oscillations involve typically two or more synchronous machines at a power plant or nearby power plants. The machines swing against each other, with the frequency of the power oscillation ranging from 1.5 to 3 Hz.

b) Local-Mode Oscillations

These oscillations generally involve one or more synchronous machines at a power station swinging together against a comparatively large power system or load centre. The frequency of oscillation is in the range of 0.7–2 Hz. These oscillations become troublesome when the plant is at high load with a high reactance transmission system.

c) Interarea Oscillations

These oscillations usually involve combinations of many machines on one part of a power system swinging against machines on another part of the power system. Interarea oscillations are normally in the frequency range of less than 0.5 Hz.
Rotor Angle Stability

- The rotor angle stability problem involves the study of the electromechanical oscillations inherent in power systems.
- Under steady-state conditions, there is equilibrium between the input mechanical torque and the output electromagnetic torque of each generator, and the speed remains constant.
- If the system is perturbed i.e.,
  - Power outputs of synchronous machines vary,
  - Their rotor angles change,
  - And this equilibrium is upset.
resulting in acceleration or deceleration of the rotors of the machines according to the laws of motion of a rotating body.
Equilibrium

Case I
If \( x = x_1 \)
and \( \dot{x} = \frac{dx}{dt} = 0 \)

Case II
If \( x = x_2 \)
and \( \dot{x} = \frac{dx}{dt} = 0 \)
Small-Disturbance (Or Small-signal) Rotor Angle Stability

- Small-Signal Stability is the ability of a power system to maintain synchronism under small disturbances. (i.e. change in load, generated power and reference voltage)

- Instability that may result can be of two forms:
  - Increase in rotor angle through a non-oscillatory or a periodic mode due to lack of synchronizing torque
  - Rotor oscillations of increasing amplitude due to lack of sufficient damping torque

- In today's practical power systems, SSS problems are usually associated with oscillatory modes 0.8 to 2.0 Hz
Power System Stabilizers

PSS are generator control equipments which are used in feedback to enhance the damping of rotor oscillation caused due to small signal disturbance.

This disturbance may be caused by the even small change in the reference voltage of the automatic voltage regulator/exciter which results in ever increasing rotor oscillations.

This is achieved by modulating the generator excitation so as to develop components of electrical torque in phase with rotor speed deviations. The PSS thus contributes to the enhancement of small-signal stability of power systems.
System Diagram of Power System Stabilizer (PSS)

Functional Block Diagram of PSS

\[ \Delta \omega \rightarrow K_{stabilizer} \rightarrow \frac{sT_w}{1 + sT_w} \rightarrow \frac{1 + sT_1}{1 + sT_2} \rightarrow \frac{1 + sT_3}{1 + sT_4} \rightarrow V_{ST_{max}} \rightarrow V_{ST} \rightarrow V_{ST_{min}} \]
MINIMAX APPROXIMATION

\[ J = \min_{p \in A} \min_{\max \leq K_i \leq \max} \| f - p \|_{\infty} = \min_{p \in A} \max_{\min \leq T_1 i \leq \max} \max_{\min \leq T_3 i \leq \max} \left| f(x) - p(x) \right|_{x \in [a,b]} \]
Multi Objective function based on damping factor and damping ratios

$$Min \ J3 = \sum_{z=1}^{n_z} \left( \max_{1\leq k \leq n_k} \sigma_k - \sigma_o \right)_z + \bar{\omega} \sum_{z=1}^{n_z} \left( \zeta_0 - \min_{1\leq k \leq n_k} \zeta_k \right)_z$$

Where $\bar{\omega}$ is a scalar value
Rotor Speed Deviations

\[ J = \min \sum_{i=1}^{n} \int_{t=0}^{t=tsim} [\Delta \omega_i]^2 \]

\( t_{sim} \) = simulation time and \( \Delta \omega \) is speed deviation
Eigen value Based Objective Functions

Fig.(a) Objective function based on eigen values
Fig.(b) Objective function based on damping ratio
Fig (c) Multi objective function
Fig.(d) Objective function based on damping scale (overshoot minimization)
Table 1 - Proposed Design of PSS

<table>
<thead>
<tr>
<th>Proposed Design</th>
<th>Parameters of PSSs</th>
<th>Maximum Deviation(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$T_w$</td>
<td>$T_1$</td>
</tr>
<tr>
<td>Design 1</td>
<td>10</td>
<td>0.897</td>
</tr>
<tr>
<td>Design 2</td>
<td>10</td>
<td>0.256</td>
</tr>
<tr>
<td>Design 3</td>
<td>10</td>
<td>0.003</td>
</tr>
<tr>
<td>Design 4</td>
<td>10</td>
<td>0.7656</td>
</tr>
<tr>
<td>Design 5</td>
<td>10</td>
<td>0.7656</td>
</tr>
</tbody>
</table>
GRAVITATIONAL SEARCH ALGORITHM

• Rashedi et.al, anticipated a new meta-heuristic algorithm called GSA in year 2009[17-19]. A beautiful analogy between Newton’s gravitational laws with the optimization prototype of the era is presented in the algorithm.

• The postulates of the algorithm say that every particle attracts towards each other and force exerted between two objects (agents) is proportional to the mass of the objects and inversely proportional to square of the distance between them.

• Force causes a global movement of all objects towards the objects with heavier mass. Heavier mass is analogous to the agent which has higher fitness values.

• GSA propose four prepositions of a gravitational mass: its position, inertial mass, gravitational mass (active and passive). The position of mass is representation of a solution and masses are specified by fitness of a function.
### Different Contingency

<table>
<thead>
<tr>
<th>Fault Location &amp; Type (Base-Case)</th>
<th>Line Outage (Case-A)</th>
<th>Line Outage (Case-B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line 3-4 (3 Phase)</td>
<td>22-23</td>
<td>10-13</td>
</tr>
<tr>
<td>Line 14-15 (3 Phase)</td>
<td>16-24</td>
<td>22-23</td>
</tr>
<tr>
<td>Line 10-13 (Single phase)</td>
<td>4-14</td>
<td>16-17</td>
</tr>
</tbody>
</table>

![Diagram]

---

[Diagram showing network connections and grid points labeled from 1 to 39, with points 26, 27, 28, and 29 connected to nodes G1, G8, G6, and G9 respectively.]
Fault on line 3-4 (Base Case)

![Graph 1: Machine Speed Deviations of generator 3 and 4](image1)

![Graph 2: Machine Speed Deviations of generator 4 and 5](image2)
Fault on line 3-4 (Case A)
Fault on line 3-4 (Case B)

Machine Speed Deviations of generator 6 and 7

Machine Speed Deviations of generator 7 and 8
Fault on line 10-13 (Base Case)

![Graph of Machine Speed Deviations of generator 2 and 3](image1.png)

![Graph of Machine Speed Deviations of generator 9 and 10](image2.png)
Fault on line 10-13 (Case-A)

Machine Speed Deviations of generator 2 and 3

Machine Speed Deviations of generator 3 and 4
Fault on line 10-13 (Case B)

- $10^{-3}$ Machine Speed Deviations of generator 4 and 5

- $10^{-3}$ Machine Speed Deviations of generator 5 and 6
Fault on line 14-15 (Base Case)
GSA Parameters

- Parameter for GSA:
  - $\alpha = 20$;
  - $G_0 = 100$;
  - $N = 50$;
  - Maximum Iteration = 1000;

Convergence Characteristics for 1st order Polynomial
## Optimal parameters of proposed PSSs

<table>
<thead>
<tr>
<th>Gen</th>
<th>Linear</th>
<th>Poly-2</th>
<th>Poly-3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$K_{STAB}$</td>
<td>$T_1$</td>
<td>$T_3$</td>
</tr>
<tr>
<td>1</td>
<td>20.40</td>
<td>0.06</td>
<td>0.28</td>
</tr>
<tr>
<td>2</td>
<td>20.86</td>
<td>0.54</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>28.47</td>
<td>0.98</td>
<td>0.18</td>
</tr>
<tr>
<td>4</td>
<td>17.39</td>
<td>0.69</td>
<td>0.01</td>
</tr>
<tr>
<td>5</td>
<td>22.18</td>
<td>0.89</td>
<td>0.95</td>
</tr>
<tr>
<td>6</td>
<td>26.12</td>
<td>0.98</td>
<td>0.49</td>
</tr>
<tr>
<td>7</td>
<td>18.84</td>
<td>0.84</td>
<td>0.77</td>
</tr>
<tr>
<td>8</td>
<td>20.07</td>
<td>0.63</td>
<td>0.64</td>
</tr>
<tr>
<td>9</td>
<td>17.11</td>
<td>0.86</td>
<td>0.23</td>
</tr>
</tbody>
</table>
CONCLUSION

• A minimax approximation approach for forming a new objective function based on frequency responses is presented here. The objective function is transformed into three multi-order polynomials. The main objective is to find the suitable fit for ideal phase curve and the curve obtained from random parameters.
• Optimization process is initiated with the help of GSA. Total 27 parameters are obtained by optimization processes which are gain and time constants of PSSs.
• Analysis of the obtained results is based upon the responses under different contingencies, fault types and network configurations. Speed deviations between different generators are plotted. It is observed from the responses that the proposed design methodology is able to mitigate all the frequency deviations lying in the range (0.2-2.5 Hz).
• It is observed that the overshoot of the swing curves is best bounded by the linear fit. Apart from some extreme hard cases like fault on line 14-15. The overall response is well bounded and settling time is reduced for linear fit.
Thank You