Implementation of the Enhanced Binary-SIME method for Finding Transient Stability Limits with PSS/E™

Presenter: Miss Hui-Min Tan
Supervisors: Dr. Rastko Zivanovic
            David Vowles
Transient Stability in Australia

- Susceptible to transient instability
- The critical interfaces - often inter-regional boundaries (transmission corridors have low capacity compared with the regional generation capacity)
- Need to search for transient stability limits on the power system operation.
Alternative Transient Stability Limit Search methods

- Standard Binary search
- SIME (SIngle Machine Equivalent) method
- **Binary-SIME algorithm – faster and more robust**
- Illustrate these approaches by means of an example – search for CCT
- Methods can be extended to other types of limit (e.g. power-transfer limit)

- Search performance is measured in simulation seconds instead of actual computation time
  - Results are independent of computer processor
Example: Kundur’s 2-Area 4 machine Power system

- 3 phase fault applied at bus 7 end of line 7-8, #1 circuit
- Fault clearance: tripping the #1 circuit
- No Governors
- Detailed machine models
• Centre of Inertia Stop criteria: Scenario is unstable if any machine angle deviates more than 180 from COI angle

• CCT = 290ms

• TDS does not provide stability margin information
SIngle Machine Equivalent method (SIME)

- Method developed originally in Liege, Belgium by Ernst & Pavella et. al.
- Provides an approach to:
  - Estimating transient stability margins
  - Predicting transient stability first swing limits
- Defines early stop criterion (ESC) for determining first swing (in)stability
- Derives a Single Machine Infinite Bus (SMIB) system response from the responses of a multi-machine power system model.
- Does not require model simplification.
- Permits application of Equal Area Criterion concepts to the analysis of Multi-Machine systems.

![System Response](image1)

![SMIB](image2)
Derivation of SMIB responses for a stable scenario

Full Response

COI

SMIB
The Power Angle Curve

SMIB responses

- Concepts of the Equal Area Criterion can be used to assess TS of the fully detailed multi-machine system from the equivalent SMIB response.

Life Impact  The University of Adelaide
SIME Margins

Unstable (CT = 375ms)
\[ \eta_u = -(A_{acc} - A_{dec}) \]
\[ = \int_{\delta_0}^{\delta_{limit}} P_d d\delta \]
\[ < 0 \] for instability

Stable (CT = 286ms)
\[ \eta_s = \text{Unused Deceleration Area} \]
\[ = \int_{\delta_r}^{\delta_u} P_d d\delta \]
\[ > 0 \] for stability

\[ P_{accel} = P_m - P_e \]
\[ \eta = -0.0334 \]
SIME: Estimate Forward Swing limit by linear approximation

- From AUPEC 2007 paper
- SMIB system

- From AUPEC 2008 paper
- 2 Area 4 machine system
The Enhanced Binary-SIME algorithm
Faster and more robust approach to limit searching

Search begins with a Binary search

Limit Prediction for the first swing limit

Convergence to the First Swing Limit

\[ 0 < \eta(k) < \eta_{tol} \]

Failure to converge is handled by using a binary step to determine the next scenario
SIME Early Stopping Criteria (ESC)

- Early determination of 1st swing (in)stability
- Insufficient deceleration capacity
- ESC: Following fault clearance: if the Rotor velocity remains superr synchronous when the acceleration power goes from negative (deceleration) to positive (acceleration).

**First-Swing Unstable**

**First Swing Stable**
Limitations of the ESC: Multi-Swing Stability

- A scenario may be first swing stable, but Multi-swing unstable.
- First swing limit needs to be assessed for multi-swing (in)stability

If multi-swing unstable – binary search is used continue the search for the multi-swing limit.
• The reviewed TSL Search techniques can work on simple test systems, but can they work on real systems?

• **PSS/E™** is the Primary transmission systems planning & analysis software used in Australia

• If the Binary-SIME algorithm can be implemented in PSS/E, we can investigate its practicality on real power systems
Implementation of the Binary-SIME Algorithm with PSS/E

Outer loop: Python
Inner loop: PSS/E User-defined model in Fortran 95 (speed advantages)

Input:
Flexible text based configuration of a TSL search
- Toggle use of the ESC
- Specify machine groups
- Search redirection options

Output:
- Comprehensive search summaries
- Full System, SMIB, and Centre of Inertia responses (assessable with MATLAB®)
- Adjustable level of error reporting
- Record search execution times

---

**START SEARCH** ($k=0$)

1. **Input Scenario**
2. Run PSS/E Load Flow

**Binary Step**

- PTL
- **PTL or CCT?**

**Linear Step**

**OTHER**

$k = k + 1$

**Is End Of Search?**

**END SEARCH**

**END**

**Life Impact**  The University of Adelaide
IEEE Simplified Model of the S-E Australian Power System

<table>
<thead>
<tr>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Generation</td>
</tr>
<tr>
<td>○ Load</td>
</tr>
<tr>
<td>▼ Static Var Compensator (SVC)</td>
</tr>
</tbody>
</table>

QLD – Queensland
SA – South Australia
VIC – Victoria
NSW – New South Wales

500 km  Approx. Scale
Study Cases: Sear

Case #1 – 500MW VIC → SA, CCT search
3 phase fault applied, at Bus 305 end, circuit #1 (F1)
Fault clearance: tripping the #1 circuit

Case #2 – 500MW VIC → SA, CCT search
3 phase fault applied, at Bus 507 end, circuit #1 (F2)
Fault clearance: tripping the #1 circuit

Case #3 – CT = 120ms, PTL search (VIC → SA)
3 phase fault applied, at Bus 507 end, circuit #1 (F2)
### Summary & Comparison of Search Results

<table>
<thead>
<tr>
<th>Case</th>
<th>Binary-SIME Search</th>
<th>Binary search</th>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>28.42 &lt; 41.20</td>
<td></td>
<td>Fast convergence to first swing limit, but binary search required to locate multi-swing limit</td>
</tr>
<tr>
<td>#2</td>
<td>62.56 &gt; 55.79</td>
<td></td>
<td>Search diverged. Repetition of SIME steps</td>
</tr>
<tr>
<td>#3</td>
<td>59.78 = 59.78</td>
<td></td>
<td>SIME limit prediction never attempted</td>
</tr>
</tbody>
</table>
Back Swing instability, Case 2 with $CT = 193\text{ms}$ (Fault at SA end)

SVC limit reached

Machine cannot return to synchronous

$V_{ref}$

$t_\alpha = 1.84\text{ s}$

$t_\beta = 2.70\text{ s}$

$t_\delta = 3.63\text{ s}$

$W$ – rotor vel. SA machines

$V$ – voltage at Bus 509

$B$ – SVC susceptance

$P$ – Power transfer VIC $\rightarrow$ SA

VIC-SA interconnection

SA system

507

509

VIC system

305

$\text{SVC}$

$\text{500MW}$

$t_{clr} = 1.193\text{ s}$

Time (s)
Conclusions

- Enhanced Binary-SIME algorithm
  - provides fast & robust approach to TSL search
- Implementation with PSS/E™ software enables algorithm to be applied for assessment of real systems
- Results
  - potential savings in the simulated search time
  - Complications due to backswing phenomena on the simplified model of the SE Australian Power system
- Further investigations
  - Adjustments to ESC for early occurrence of back-swing instability
  - Compatibility of forward- and back-swing instability margins
  - Additional enhancements to the algorithm
  - More tests on the Simplified SE Australian system & other system models.