Load Modeling Methodologies for Cascading Outage Simulation Considering Power System Stability

Jiajia Song, Eduardo Cotilla-Sanchez, Ted K.A. Brekken

Oregon State University
Outlines

• Cascading outage
  • Definition, impacts, analysis methods
• Load modeling
  • Importance of load modeling
  • Methodologies for load modeling
• Current work and future objectives
• Summary
Cascading outage

- **Definition**: a sequence of dependent failures of individual components, triggered by initial events, that successively weaken the power system.
## Major blackouts

<table>
<thead>
<tr>
<th>Date</th>
<th>Area</th>
<th>Impacts</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aug 14, 2003</td>
<td>North America (NE)</td>
<td>61,800 MW, 50M people</td>
<td>2+ days</td>
</tr>
<tr>
<td>Sep 28, 2003</td>
<td>Italy</td>
<td>27,000 MW, 57M people</td>
<td>5-12 hrs</td>
</tr>
<tr>
<td>Sep 23, 2003</td>
<td>Sweden &amp; Denmark</td>
<td>6,550 MW, 5M people</td>
<td>5 hrs</td>
</tr>
<tr>
<td>Nov 4, 2006</td>
<td>Europe</td>
<td>&gt;64,000 MW, 15M households</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Nov 10, 2009</td>
<td>Brazil &amp; Paraguay</td>
<td>17,000MW, 80M people</td>
<td>7 hrs</td>
</tr>
<tr>
<td>Feb 4, 2011</td>
<td>Brazil</td>
<td>53M people</td>
<td>4 hrs</td>
</tr>
<tr>
<td>Sep 8, 2011</td>
<td>US &amp; Mexico (S-W)</td>
<td>4,300MW, 5M people</td>
<td>12 hrs</td>
</tr>
<tr>
<td>Jul 30-31, 2012</td>
<td>India</td>
<td>32,000MW, 620M people</td>
<td>2+ days</td>
</tr>
</tbody>
</table>

The **highlighted events** in the list are caused by cascading outages.
Approaches for cascading outage analysis

- Steady state (or Quasi-steady state) modeling based analysis
  - Regular N-x contingency analysis.
- High level probabilistic models
- Other new methodologies
  - Bifurcation theory based models, Phasor technology, High performance computing, Graphic theory (or topological theory) based models, Data mining and advanced visualization.

➤ Majority of them don’t consider this problem from stability perspective, especially from the load complexity point of view, which could be an issue.
Load modeling

• Load: the aggregated power demand at a feeder or substation.
• Immense uncertainty.

• Traditionally, load models includes:
  • Static Load Models
  • Dynamic Load Models
• ZIP static model:  \[ P_L = P_0 \left[ p_1 \left( \frac{V}{V_0} \right)^2 + p_2 \left( \frac{V}{V_0} \right)^1 + p_3 \right] \]

• Exponential static model:  \[ P_L = P_0 \left( \frac{V}{V_0} \right)^{K_{pV}} \]

• PSS/E static model:  \[ P_L = P_0 \left[ p_1 \left( \frac{V}{V_0} \right)^{n_1} + p_2 \left( \frac{V}{V_0} \right)^{n_2} + p_3 \left( \frac{V}{V_0} \right)^{n_3} \right] \left(1 + K_{pf} \Delta f\right) \]

• EPRI static model:  \[ P_L = P_0 \left[ p_{a1} \left( \frac{V}{V_0} \right)^{K_{pV1}} \left(1 + K_{pf} \Delta f\right) + \left(1 - P_{a1}\right) \left( \frac{V}{V_0} \right)^{K_{pV2}} \right] \]

• ZIPE static model:  \[ P_L = P_0 \left[ K_{pz} \left( \frac{V}{V_0} \right)^2 + K_{pi} \left( \frac{V}{V_0} \right)^1 + K_{pc} + K_{p1} \left( \frac{V}{V_0} \right)^{n_{pv1}} \left(1 + K_{pf1} \Delta f\right) \right. \]
\[ \left. + K_{p2} \left( \frac{V}{V_0} \right)^{n_{pv2}} \left(1 + K_{pf2} \Delta f\right) \right] \]

• Other static model
Dynamic load models

- Physical Dynamic Load Model:
  - 1st or 3rd order induction motor
  - Composite load model
Dynamic load models

• Input-Output Dynamic Model:
  • Neural-Network
  • Differential equation
  • Transfer function
Dynamic load models

• Other Dynamic Load Models for Specific Applications:
  • For distributed generation (wind, solar)
  • For thermalstatically controlled load
  • For power electronics load
Which is the best candidate for cascading outage analysis?

‘Wishlist’:

• Simple, but not compromise its ability of representing the dynamics of power system.

• Be easily adapted into existing computer programs.

• A composite load (ZIPE + IM) is selected in our current research.
Current work and future objectives

1. Apply the candidate load model into a benchmarking case for cascading failure study.
   • Currently, a Matlab based dynamic simulator for cascading outage analysis is under development.
Current work and future objectives

2. Adapt some algorithms (e.g. random chemistry [Paul. H 2012]) that identifies collections of multiple contingencies that initiates cascading outages.

3. Implement contingency analysis.
Current work and future objectives

4. The power law relationship is a good benchmark to verify our simulation results.
Summary

• Cascading outages mechanisms usually lead to very large blackouts, and they are challenging to understand.

• Inappropriate load model may miss the associated dynamic responses that possibly lead to cascading outages or change their expected sequence.

• A composite load (ZIP + induction motor) could be a good candidate for cascading outage analysis.
Tell me why.

Oh, No!