In Pursuit of Reuseable, Electric Power System Models: Breaking Down Barriers

Time-Series, Automated Analysis and Design with Large Measurement Sets

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Integrated System Modeling: Research Circuits
**Graph Trace Analysis:** Generic Programming, Edge-Edge Graphs, Topology Iterators

- **Initialize iterators:** Add, connect
- **Update iterators:** Insert, delete, operate, fail
- **Generic:** Attach any algorithm, measurement set
- **Algorithms:** Sorting, continuation methods (robustness)

**quadruply linked list**

\[
\begin{cases}
    p[f] \\
p[b] \\
p[fp] \\
p[ct]
\end{cases}
\]

doubly linked list

**connectivity**

\[
S \rightarrow BT_s \rightarrow \{ i[p] = 0 \mid i[p] += i_L[p] + i[p[ct]], i[p[fp]] += i[p] \}
\]

\[
CT \rightarrow LT_{ct} \rightarrow \{ v_{sum} = 0 \mid v_{sum} += v[p[fp]] - v[p] \}
\]
<table>
<thead>
<tr>
<th>Traditional Analysis</th>
<th>GTA</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Node-edge graph</td>
<td>Edge-edge graph</td>
<td>Rapid topology management</td>
</tr>
<tr>
<td>Uses topology up front in algorithms to create matrices</td>
<td>Continuously uses topology in traces throughout algorithm</td>
<td>Topology management enables rapid development of complex algorithms – schematics, design, weather analysis, ...</td>
</tr>
<tr>
<td>Time to manage topology changes increases as size of system grows</td>
<td>Time to manage topology changes is independent of system size</td>
<td>Configuration changes on systems with millions of components can be managed</td>
</tr>
<tr>
<td>Different analysis algorithms use different simplified models</td>
<td>All analysis algorithms run on same model and exchange results through the model</td>
<td>Algorithms can work together as a team to solve complex problems</td>
</tr>
<tr>
<td>Each analysis algorithm gets its own copy of measurements</td>
<td>All analysis algorithms share measurements through the same model</td>
<td>Do not have multitude of measurement interfaces to create and maintain</td>
</tr>
<tr>
<td>Multi-domain system analysis is complicated</td>
<td>Can write common algorithms that run across multi-domain systems (solves TSD together)</td>
<td>Do not have to write separate software for different engineering domains</td>
</tr>
<tr>
<td>Optimization suffers from curse of dimensionality</td>
<td>Traces are used to determine space of possible solutions</td>
<td>Optimization of large scale systems is practical</td>
</tr>
<tr>
<td>Special computer hardware required for parallel processing</td>
<td>Distribute calculations across processors by distributing model</td>
<td>Do not need to invest in expensive computer equipment</td>
</tr>
</tbody>
</table>
GTA-Based Time-Series Analysis Validations

**SVP Transmission System Validation**

**Entergy Load Model Validation**
Mount Valley Sub, 2977 customers

**Amps Crew Phase Balancing Operation**

**ORU Phase Balancing Validation**

Largest voltage deviation: 1.1 %  
Average: 0.5 %

Largest current deviation: 3.9 %  
Average: 2.8 %

Largest pf deviation: 5.7 %  
Average: 2.7 %

**NREL Validation on DTE 16 MVA Feeder with 1 MW DG**
DOE Sponsored ISM Survey

BARRIERS

“The technical challenges do not appear to be as great as the interpersonal challenges, which include bringing together silos of responsibility, where the silos often do not speak the same language.” NISC

“Very experienced personnel can be naysayers, and often an experience is needed to get their attention and change their perspective.” NISC

“Getting processes in place to insure ISM stays accurate and in synch with field conditions.” ORU, CHGE, PHI

BENEFITS

“Provides situational awareness for the whole system” ORU

“First line of defense in finding inaccurate meters” ORU

“Allows utility to become proactive in problem solutions” CHGE

“Once an ISM is achieved model maintenance is more efficient” NISC

“Without an ISM the understanding of system behavior is limited to a few operators and engineers” SVP

“With an ISM Automated analysis becomes possible” PHI

“As opposed to data analytics, ISM solutions cover the entire range of operations” OSIsoft

Model-Centric Life-Cycle Process using a Generic, Manufactured, Living Model providing Proactive, Holistic Solutions
ISM Over Google Earth Showing Secondary Circuits, Loads, and PV
Simplified Versus Detailed Secondary Circuit Models

PV Penetration Analysis Approach Comparisons

<table>
<thead>
<tr>
<th>Method</th>
<th>Max PV Penetration (% of load)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Secondary Using Step Change and IEEE 1453-1992</td>
<td>23</td>
</tr>
<tr>
<td>Detailed Secondary Using Step Change and IEEE 1453-1992</td>
<td>18</td>
</tr>
</tbody>
</table>
Is the secondary circuit just a load on the distribution transformer bus?

Largest voltage variation is always at service point with PV

PV and customer information part of simple secondary model

PV and customer information contained in database tables

3 feeders modeled to distribution transformer with one load bus, ~3500 components, 633 load busses, 74 PV

secondary circuit builder

same 3 feeders with detailed secondary models, ~35000 components, 6912 load busses, 812 PV

Secondary voltage variations can trump primary voltage variations
Common approach is distribution feeders are analyzed one-by-one, transmission system is analyzed separately, and substation is not included in analysis at all.*
Pretending Transmission
Lines are Transposed

\[
\begin{bmatrix}
0.18 + j 1.27 & 0.13 + j 0.53 & 0.14 + j 0.44 \\
0.13 + j 0.53 & 0.19 + j 1.26 & 0.14 + j 0.52 \\
0.14 + j 0.44 & 0.14 + j 0.52 & 0.21 + j 1.24 \\
0.054 + j 0.75 & 0 & 0 \\
0 & 0.054 + j 0.75 & 0 \\
0 & 0 & 0.054 + j 0.75
\end{bmatrix}
\]
$P_X = \text{for a 10 minute interval, voltage change level that is exceeded X\% of the time}$

$$P_{st} = \sqrt{0.0314P_{0.1} + 0.0525P_{15} + 0.0657P_{3s} + 0.28P_{10s} + 0.08P_{50s}}$$

**Short term flicker factor**

$$P_{1s} = \frac{P_{0.7} + P_1 + P_{1.5}}{3}$$

$$P_{3s} = \frac{P_{2.2} + P_3 + P_4}{3}$$

**Smoothed values**

$$P_{10s} = \frac{P_6 + P_8 + P_{10} + P_{14} + P_{17}}{5}$$

$$P_{50s} = \frac{P_{30} + P_{50} + P_{80}}{3}$$

<table>
<thead>
<tr>
<th>Flicker severity level</th>
<th>Compatibility Limits - LV</th>
<th>Planning—MV</th>
<th>Planning—HV and EHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>P&lt;sub&gt;st&lt;/sub&gt; [10-min]</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>P&lt;sub&gt;lt&lt;/sub&gt; [120-min]</td>
<td>0.8</td>
<td>0.7</td>
<td>0.6</td>
</tr>
</tbody>
</table>
Cloud Motion PV Analysis

Max load ~ 14 MW, Max PV ~ 2 MW, PV Penetration ~ 14%

Evaluate installation of 7.3 MW PV, covering 44 acres, approximately square (about 6 acres per MW)
44 ft/sec cloud takes about 31 seconds to travel across PV generator

Voltage Change

Point Model Evaluation – installation not approved

Distributed Model Evaluation – installation approved
Relating Radar Weather to ISM - Weather Boxes

<table>
<thead>
<tr>
<th>WB0</th>
<th>WB1</th>
<th>WB2</th>
<th>WB3</th>
</tr>
</thead>
<tbody>
<tr>
<td>WB4</td>
<td>WB5</td>
<td>WB6</td>
<td>WB7</td>
</tr>
<tr>
<td>WB8</td>
<td>WB9</td>
<td>WB10</td>
<td>WB11</td>
</tr>
<tr>
<td>WB12</td>
<td>WB13</td>
<td>WB14</td>
<td>WB15</td>
</tr>
</tbody>
</table>

Weather boxes and measurements:
1-6500 measurements per weather box per radar scan
2-Approximately 85000 measurements per radar scan for ORU service territory
3-Approximately 1,275,000 measurements per hour

For each weather box store max and average for:
1-Reflectivity (dbz)
2-Wind speed (knots)
3-Accumulated precipitation (inches)
GTA Analysis Embedded In or Synched with ESRI

Power flow runs in GIS system with towers, poles, manholes, ...
Today: NISC Cloud Automation

Example ISMs

Analyzing every measurement, every day
Automated Voltage Profile Control Design

<table>
<thead>
<tr>
<th>Average Voltage Reduction % (% Voltage Dependency Factor = -0.15)</th>
<th>Base/New Annual Load Mwh</th>
<th>Annual Savings ($0.14/ kWh)</th>
<th>Base/New Annual Loss Mwh</th>
<th>Base/New % Loss Decrease</th>
<th>Base/New Peak Kw</th>
<th>Increase in Hosting Capacity (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.81</td>
<td>25391</td>
<td>$60420</td>
<td>662</td>
<td>659</td>
<td>4437</td>
<td>1061</td>
</tr>
<tr>
<td></td>
<td>24960</td>
<td></td>
<td>1.70</td>
<td>0.48</td>
<td>4337</td>
<td></td>
</tr>
</tbody>
</table>

**Base**

**New**
Open Source DEW Simulator

Program in four languages:
- C++
- C#
- Visual Basic
- F#

3 measurement types:
- Fixed sample rate
- Event driven
- Random sample
Summary: Modeling Philosophy

Analysis Readiness Levels

Level 1: What happened and why did it happen?
Hindsight – reactive, diagnostic, operating seat-of-the-pants, no architecture for performance

Level 2: What will happen?
Insight – predictive, scenario driven

Level 3: What is a good way to make it happen?
Foresight – proactive, operating with analysis based decisions, architecture for performance

Model-Centric Life-Cycle Process with a Generic, Manufactured, Living Model providing Proactive, Holistic Solutions