Day-Ahead and Short-Term Unit Commitment OPF with Voltage Stability Constraints

California ISO

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Introduction

- The California ISO (CAISO) (Folsom, CA) has developed as set of look-ahead tools with Bigwood Systems (BSI) (Ithaca, NY):
  - To run analysis on forecasted operating cases to anticipate voltage problems
  - To supply optimized enhancements using operational tools such as:
    - Reactive power compensating devices
    - Real generation
    - Reactive power generation
    - Load shedding to prevent collapse, worst case
Introduction (2)

- Voltage Stability Analysis and Enhancement – Day-Ahead (VSA-DA)
- Voltage Stability Analysis and Enhancement – Short-Term Unit Commitment (VSA-STUC)
- Voltage Stability Analysis and Enhancement – Look-Ahead (VSA-LA)
Background

- Voltage instability and fluctuations tend to occur much earlier than voltage collapse.
- As power systems become more stressed and the penetration of renewable energy increases, system operators need to analyze voltage security of the systems based on actual operating conditions, contingency and stressing of the system.
- Preventive steps taken before a potential voltage collapse scenario are valuable.
What is Needed?

- The ability to **anticipate problems** related to contingencies, unusual operating conditions, power transfers, etc.
- **Time** to prepare the system adjustments necessary for reliable operation of the grid
- A **longer forecast window** to provide the ISO the critical time necessary to identify voltage issues and prevent voltage collapse
Starting Points

- The ISO had in place BSI’s tools using the Energy Management System (EMS) data to supply:
  - 5-minute data to On-line VSA Real-Time (VSA-RT)
  - 2-hour forecasts to On-line VSA-Look-Ahead (VSA-LA)
On-line VSA&E

- Comprehensive power system modeling,
- Computation of P-V curves
  - load margin to voltage collapse
  - margin to voltage limit violation
  - margin to thermal limit violation
- CIM input
- Capability curves
- Large contingency lists
- Handling of state-based RAS/SPS
On-line VSA&E (2)

- The most advanced and patented methods are used to rapidly calculate the exact nose point and P-V, Q-V and P-Q-V curves and to perform fast contingency screening and ranking.

- When the load margin for the base case and limiting contingency is insufficient, VSA&E determines the effective preventive or enhancement control to increase load margin
Greater Reach

- The VSA&E-RT and the VSA&E-LA tools are vitally effective over the limited timeframe of the EMS source information.
- To greatly expand the forecast time horizon, the ISO developed new BSI applications to supplement the EMS-based VSA&E with market-based data.
- Executed on a periodic basis.
- Cases developed from forecasted market postings.
New Tools Introduced

- VSA-DA (24 hours ahead, hourly data)
- VSA-STUC (4.5 hours ahead, 15-minute data)
- Enhanced VSA Look-Ahead
- Employ market results to effectively supplement decision makers with a longer forecast time horizon
- Now running in production environment at the ISO
On-line Voltage Stability and Enhancement in the CAISO power market

• The day-ahead market (VSA&E-DA)
  • Processes cases for day-ahead+1 through day-ahead+6
  • Each day consists of 24 hourly cases
  • Update once per day
  • Preventive and Enhancement Control run as needed
On-line Voltage Stability and Enhancement in the CAISO power market

- The short-term unit commitment market (VSA&E-STUC)
  - Processes cases for next 4 and one-half hours
  - Each hour consists of 4 15-minute cases
  - Updated every hour with 18 cases
  - Preventive and Enhancement Control run as needed
System Architecture
Distributed, High Availability
On-line VSA&E Day-Ahead and STUC

- The daily payload of Market Data and the hourly payload of Market Data are processed by VSA&E immediately on receipt.
- The VSA&E model for each case is built directly using the Market data for the market areas internal to CAISO.
- For market areas external to CAISO the VSA&E model is built using the EMS Static CIM database and historical data (Load Distribution Factors, Generator Distribution Factors and relevant outage information).
On-line VSA&E-DA-STUC Base Cases

- A base model is assembled for the entire WECC system
- BSI’s power flow is run to create a base case for each time period in the batch to use in Day-Ahead Analysis and STUC Analysis
- These batched VSA&E cases and results available for display in their respective Viewer tool and for further analysis and inspection in the VSA&E Study Mode tool
On-line VSA&E User Interface
**Base Case**

- Display On-line
- Browser Mode data
Limiting Contingency Case

- Display On-line or
- Browser Mode data

---

**STUC VSA Calculations (Limiting Contingency)**

<table>
<thead>
<tr>
<th>Case</th>
<th>Lead Margin (MW)</th>
<th>Confident Margin</th>
<th>WE Margin</th>
<th>Q Margin</th>
<th>Safety Margin</th>
<th>Base Inf Limit</th>
<th>Base Inf PF</th>
<th>Cont Inf Limit</th>
<th>Cont Inf PF</th>
<th>Limiting Contingency</th>
<th>Weakest Bus</th>
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</tbody>
</table>

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**Graph**: Line diagrams showing voltage stability over time.
Renewable Energy Handling - Why Is it Required

- Modern Power system operates close to capacity
- Proliferation of stochastic renewable energy sources e.g. Wind & solar
- Increases uncertainty in the power system and hence possible violation of systems limitations
- No existing tools for assessing the stability of power system exposed to this danger
Renewable Energy Handling - How it Works

- Historical Random Power Injection
- Forecasted Power Injection
- Correlation Matrix
- Marginal Distribution
- Forecasted Power Injection
- Location of Renewable Units
- Data Bridge
- Critical Contingencies & Probabilistic Power Flow Results
- Load Margin Statistics, Mean, Variance, Skewness, High Probabilistic Load Margin, Low Probability Load Margin
- VSA With Renewable Energy
- Power Flow Data
- Database Manager
- California ISO
- BSI
- Shaping a Renewed Future
Load Margin Distribution for Renewable Scenario
VSA&E Generated Nomogram

- Black nomogram curve represents the calculated curve.
- Red nomogram curve represents the analytical representation of the nomogram.
VSA&E – Study Mode

- VSA&E study tools for off-line analysis of:
  1. Current RT or LA case
  2. RT/LA/DA/STUC archived cases
  3. Imported off-line operations planning studies
  4. VSA studies built in the tool from any power flow case
VSA&E Control

- **Preventive Control for Insecure Contingencies** – VSA&E determines effective preventive controls to the base case such that insecure contingencies are eliminated by exercising all available control actions before resort to load shedding.

- **Enhancement Control** – Determines effective enhancement controls to selected base case/contingency for desired load margins by exercising all available control actions and load shedding by applying the user design.
Contingency Ranking & Estimated Margins

Session: __buildin.ses  Conting. List: __buildin.ses  Run Date: 6/6/06 18:00

<table>
<thead>
<tr>
<th>Rank</th>
<th>Number</th>
<th>Contingency</th>
<th>Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>18550</td>
<td>Cayuga Park-Buttermilk Mill (138/01) 138 kV line</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>18520</td>
<td>Hickory Hollow-Buttermilk Mill (138/02) 138 kV line</td>
<td>0.000</td>
</tr>
<tr>
<td>3</td>
<td>6820</td>
<td>Reuben-Quarry 115 LINE</td>
<td>0.000</td>
</tr>
<tr>
<td>4</td>
<td>18180</td>
<td>Taughannock#1 230/115 kV Transformer</td>
<td>0.000</td>
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<tr>
<td>5</td>
<td>18250</td>
<td>Applegate-Enfield &amp; Ulysses-Swamp College</td>
<td>2429.753</td>
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<tr>
<td>6</td>
<td>18010</td>
<td>Ludlowville (8789) &amp; Groton 1181</td>
<td>2579.699</td>
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<tr>
<td>7</td>
<td>6780</td>
<td>Van Etten-Spencer 230 LINE</td>
<td>2658.051</td>
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<tr>
<td>8</td>
<td>18730</td>
<td>Tioga-George-Junior 230kV &amp; Junior Units 1,2&amp;3</td>
<td>3062.834</td>
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<tr>
<td>9</td>
<td>18020</td>
<td>Virgil-Jacksonville 500 kV line &amp; Genoa CTs</td>
<td>3081.472</td>
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</tbody>
</table>

Contingency Ranking Report showing the first 9 in the ranking, including 4 insecure, ranked 1-4
Preventive Control Scenario

 hade BUILDIN EAST Preventive Control Table

Session: __buildin.ses Conting. List: __buildin.ses Run Date: 6/7/06 14:00

<table>
<thead>
<tr>
<th>Insecure Contingency Name</th>
<th>Margin for Pre-control System (MW)</th>
<th>Margin for Post-control System (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vanness-Bethesda-Bells Mill (13812) 138 kV line</td>
<td>0.000</td>
<td>839.510</td>
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<tr>
<td>OStreet-Bethesda-Bells Mill (13816/02) 138 kV line</td>
<td>0.000</td>
<td>1571.389</td>
</tr>
<tr>
<td>PORTLAND-PEQUEST RIVER 115 LINE</td>
<td>0.000</td>
<td>424.444</td>
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<tr>
<td>Lewistown #3 230/115 kV Transformer</td>
<td>0.000</td>
<td>2832.650</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Num</th>
<th>Location</th>
<th>Area</th>
<th>Type</th>
<th>Original Amount</th>
<th>Control Amount</th>
<th>Final Amount</th>
<th>Upper Limit</th>
<th>Lower Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GILBERT 230.0/110</td>
<td>JC</td>
<td>LTC</td>
<td>1.00000</td>
<td>-0.08125</td>
<td>0.91875</td>
<td>1.50000</td>
<td>0.51000</td>
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<tr>
<td>2</td>
<td>GILBERT 34.0/1003</td>
<td>JC</td>
<td>LTC</td>
<td>1.01910</td>
<td>-0.03750</td>
<td>0.98160</td>
<td>1.50000</td>
<td>0.51000</td>
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<tr>
<td>3</td>
<td>GILBERT 34.0/1094</td>
<td>JC</td>
<td>LTC</td>
<td>1.01910</td>
<td>-0.03750</td>
<td>0.98160</td>
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<td>0.51000</td>
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<tr>
<td>4</td>
<td>HOOVERSV 11.1433</td>
<td>PN</td>
<td>LTC</td>
<td>1.01510</td>
<td>0.11169</td>
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<td>BELLSMIL 138.1577</td>
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<td>0.16325</td>
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<td>1.15000</td>
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Enhancement Control Scenario

- For user request of 200 MW, the 4 recommended control actions will enhance the load margin by 207 MW increasing the load margin from 2710 MW to 2917 MW.

Enhancement Control Table

<table>
<thead>
<tr>
<th>Num</th>
<th>Location</th>
<th>Area</th>
<th>Type</th>
<th>Original Amount</th>
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<th>Final Amount</th>
<th>Upper Limit</th>
<th>Lower Limit</th>
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</thead>
<tbody>
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<td>1</td>
<td>EDGEMOOR 21926 EDGEMOOR 138.0kV</td>
<td>DPL</td>
<td>LTC</td>
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<td>-0.0500</td>
<td>0.9500</td>
<td>1.0500</td>
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<tr>
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<td>DPL</td>
<td>LTC</td>
<td>1.0000</td>
<td>-0.03750</td>
<td>0.9625</td>
<td>1.5000</td>
<td>0.51000</td>
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<td>3</td>
<td>REDLION 5002044 REDLION 230.0kV</td>
<td>DPL</td>
<td>LTC</td>
<td>1.03120</td>
<td>-0.00625</td>
<td>1.02495</td>
<td>1.19000</td>
<td>0.90000</td>
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<td>4</td>
<td>EDGEMOOR 19.0kV</td>
<td>DPL</td>
<td>Gen_Q</td>
<td>1.00180</td>
<td>0.01494</td>
<td>1.01674</td>
<td>1.05072</td>
<td>0.94928</td>
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</tbody>
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Steele-Vienna & Ind River-Milford

- 2710.52002
- 2917.33008
- 200.00000
- 206.81000
CAISO VSA&E/DA/STUC: On the Drawing Board

- **Renewable Energy Engine Enhancement**
  - Implement Novel Scenario Generation and Reduction Schemes and Enhance Parallel Computation Engine for VSA/DA/STUC/Renewable

- **Toward Reliable Solver Engines for Power Networks under Renewables: Solutions and Incorrect Data Detection**
  - Improved reliable power flow solver to replace the current flat start power flow solver

- **Renewable Energy: Worst Renewable Scenario**
  - Computing the worst-ranked case scenarios and their associated load margins, in addition to the current confident margin, expected margin and probability distribution bar chart.
Thank You

California ISO
Dr. Khaled Abdul-Rahman
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