Weekly Load Curve Simulation with Discrete Control Devices Representation for Voltage Control Performance Evaluation in a Large Scale System

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Presentation Summary

- Introduction
- Automatic Switching of Shunt Banks
- System Load Curve Simulation
- IEEE 14-bus Test System
- Large Scale System
- Conclusions
Introduction

- **System load curve simulation – ANAREDE**
  - Improve the system analysis
  - Evaluation of different conditions for load behavior
  - Representation of slow control devices

- **Use of automatic shunt switching**
  - There is availability of reactive shunt compensation
  - Keep the system voltage profiles within limits
  - Choice of the controlled bus voltage
  - Full Newton representation
Introduction

• Steady-State: system behavior evaluation
  ✓ Coordination with another control devices
    ▪ LTC’s Transformers
    ▪ FACTS
    ▪ Remote and Secondary Voltage Control
    ▪ Identification of critical settings
  ✓ Variation of power factor

• Generation balance
  ✓ Generator participation factor
    ▪ Base case settings
Automatic Shunt Compensation

\[
\begin{bmatrix}
\Delta P \\
\Delta Q \\
\Delta y
\end{bmatrix}
= \begin{bmatrix}
\frac{\partial P}{\partial \theta} & \frac{\partial P}{\partial V} & \frac{\partial P}{\partial b^{sh}} \\
\frac{\partial Q}{\partial \theta} & \frac{\partial Q}{\partial V} & \frac{\partial Q}{\partial b^{sh}} \\
\frac{\partial y}{\partial \theta} & \frac{\partial y}{\partial V} & \frac{\partial y}{\partial b^{sh}}
\end{bmatrix}
\cdot
\begin{bmatrix}
\Delta \theta \\
\Delta V \\
\Delta b^{sh}
\end{bmatrix}
\]

\(y\) - Control Mismatch Function
\(b^{sh}\) - Control Variable
System Load Curve Simulation

Basic algorithm:

1. **Cont = 0**
   - Base Case Solution

2. New Load and Generation Dispatch
   - **Cont = Cont + 1**

3. **Cont=1?**
   - Yes: Linear Load Flow Solution
   - No: Power Flow Solution

4. **Solution?**
   - Yes: Last Point?
     - Yes: End simulation
     - No: Go to Next Point
   - No: **Cont = 0**

- Linear Load Flow Solution
  - **Cont = 0**

- Power Flow Solution
  - **Cont = 0**

- Cont = 1?
  - Yes: Linear Load Flow Solution
  - No: Power Flow Solution
IEEE 14-bus Test System

• Topology
IEEE 14-bus Test System

- **Use of Optimal Power Flow - FLUPOT**
  - Use of maximum loadability objective function
  - Voltage limits for all buses
  - Minimum shunt allocation
    - 92% of load increase
- **Load modeling**
  - Constant-P
  - Invariant power factor
- **Participation factor for generators**
  - Swing bus
- **100% convergence**
### IEEE 14-bus Test System

#### System Configuration

<table>
<thead>
<tr>
<th>PV Buses</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuits</td>
<td>20</td>
</tr>
<tr>
<td>Active Load</td>
<td>497 MW</td>
</tr>
<tr>
<td>Active Generation</td>
<td>560 MW</td>
</tr>
</tbody>
</table>

#### Shunt Control Configuration

<table>
<thead>
<tr>
<th>Bus</th>
<th>Voltage Limits</th>
<th>Bank Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>4</td>
<td>0.950 p.u.</td>
<td>1.050 p.u.</td>
</tr>
<tr>
<td>5</td>
<td>0.950 p.u.</td>
<td>1.050 p.u.</td>
</tr>
<tr>
<td>9</td>
<td>0.950 p.u.</td>
<td>1.050 p.u.</td>
</tr>
</tbody>
</table>
IEEE 14-bus Test System

- Typical load curve during one week
  - Hourly Simulation? 168 points
IEEE 14-bus Test System

Voltage Profile – Bus 4

- Full Compensation
- Discrete Compensation

Voltage (p.u.)

Hours

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IEEE 14-bus Test System

Voltage Profile – Bus 5

- Full Compensation
- Discrete Compensation

Voltage (p.u.) vs Hours

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IEEE 14-bus Test System

Voltage Profile – Bus 9

Voltage (p.u.) vs. Hours

Full Compensation

Discrete Compensation

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IEEE 14-bus Test System

Shunt Switching

Shunt Banks (Mvar)

<table>
<thead>
<tr>
<th>Bus 4</th>
<th>Bus 5</th>
<th>Bus 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>120</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>100</td>
<td>80</td>
<td>80</td>
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<tr>
<td>80</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>40</td>
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<tr>
<td>40</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Hours

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Large Scale System

• North-south Brazilian interconnected system
  ✓ Configuration of April 2003 – Heavy Load (ONS)
  ✓ Evaluation of Rio Area

• System Configuration

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Buses</strong></td>
<td>2485</td>
</tr>
<tr>
<td><strong>Circuits</strong></td>
<td>3563</td>
</tr>
<tr>
<td><strong>Generators / Remote Control / SVC´s</strong></td>
<td>242 / 10 / 5</td>
</tr>
<tr>
<td><strong>Transformers / LTC´s</strong></td>
<td>1064 / 544</td>
</tr>
<tr>
<td><strong>Active Load – System</strong></td>
<td>42 923 MW</td>
</tr>
<tr>
<td><strong>Active Load – Rio Area</strong></td>
<td>7 100 MW</td>
</tr>
</tbody>
</table>

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Large Scale System

• Rio Area
  ✓ Big load center
  ✓ Coordination between control devices

• Load modeling
  ✓ Constant-P and invariant power factor

• Participation factor for generators
  ✓ The same of base case for major generation plants

• System simulation
  ✓ Large variations of load (max: -40 %)
  ✓ Discrete compensation
Large Scale System

- Rio Area
  Simplified Diagram

Legend

- 765 kV
- 500 kV
- 345 kV
Large Scale System

- Typical load curve during one week – April 2003
  - Intervals of 30 minutes? 336 points
## Large Scale System

### Shunt Banks: Main Devices

<table>
<thead>
<tr>
<th>Bus Name</th>
<th>Number of Banks</th>
<th>Configuration (Mvar)</th>
<th>Bus Name</th>
<th>Number of Banks</th>
<th>Configuration (Mvar)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVAIPO-R550</td>
<td>3</td>
<td>-180</td>
<td>CAMPOS----138</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>IVAIPO-R540</td>
<td>3</td>
<td>-180</td>
<td>CM-TER1-3C10</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>T.PRETO--345</td>
<td>8</td>
<td>200</td>
<td>CM-TER1-2R25</td>
<td>2</td>
<td>-25</td>
</tr>
<tr>
<td>TPRE-69-R360</td>
<td>2</td>
<td>-180</td>
<td>CM-TER2-3C10</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>PCAL13.8-R50</td>
<td>2</td>
<td>-25</td>
<td>CM-TER2-2R25</td>
<td>2</td>
<td>-25</td>
</tr>
<tr>
<td>CAMP13.8-R50</td>
<td>2</td>
<td>-25</td>
<td>VITORIA--345</td>
<td>2</td>
<td>-60</td>
</tr>
<tr>
<td>CAM13.8-R100</td>
<td>2</td>
<td>-50</td>
<td>V.REDONDA138</td>
<td>2</td>
<td>67,5</td>
</tr>
<tr>
<td>MAR13.8-R100</td>
<td>2</td>
<td>-50</td>
<td>Z.INDUSTRIAL</td>
<td>1</td>
<td>67,5</td>
</tr>
<tr>
<td>C.PAULIS-500</td>
<td>1</td>
<td>-136</td>
<td>PALMARES-138</td>
<td>2</td>
<td>67,5</td>
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<tr>
<td>C.PAULIS-138</td>
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<td>75</td>
<td>MAGE---------69</td>
<td>2</td>
<td>14,4</td>
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<tr>
<td>PCA13.8-R100</td>
<td>2</td>
<td>-50</td>
<td>R.LEAO----138</td>
<td>3</td>
<td>1x37,2+1x23,3+1x30,0</td>
</tr>
<tr>
<td>ADRIANO--500</td>
<td>1</td>
<td>-136</td>
<td>TERESOPOL138</td>
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<td>16,4</td>
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<tr>
<td>ITUTINGA-345</td>
<td>1</td>
<td>200</td>
<td>UTEC---------69</td>
<td>1</td>
<td>13,3</td>
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<tr>
<td>ADRIANO--345</td>
<td>2</td>
<td>162,5</td>
<td>CMP.DIST.-69</td>
<td>1</td>
<td>19,7</td>
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<tr>
<td>S.JOSE---138</td>
<td>2</td>
<td>250</td>
<td>ITALVA---------</td>
<td>1</td>
<td>26</td>
</tr>
<tr>
<td>JACAREP--138</td>
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<td>100</td>
<td>ALAGE-1-34.5</td>
<td>2</td>
<td>10,8</td>
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<tr>
<td>ADRIAN-T-T1B</td>
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<td>40</td>
<td>BFERREIR-138</td>
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<tr>
<td>ADRIAN-T-T2A</td>
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<td>CACHOEIRO138</td>
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<tr>
<td>JAC-13.8-R30</td>
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<td>JAC-13.8-R30</td>
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<td>ADR-13.8R100</td>
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<td>-50</td>
<td>J.NEIVA--138</td>
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<tr>
<td>CAMPOS---345</td>
<td>2</td>
<td>-60</td>
<td>N.VENECTA138</td>
<td>1</td>
<td>26,7</td>
</tr>
<tr>
<td>CAMP-CAP-345</td>
<td>2</td>
<td>60</td>
<td>PITANGA--138</td>
<td>2</td>
<td>26,7</td>
</tr>
</tbody>
</table>
Large Scale System

Voltage Profile for major 765 kV Buses

Voltage (p.u.)

<table>
<thead>
<tr>
<th>Voltage Profile for major 765 kV Buses</th>
</tr>
</thead>
<tbody>
<tr>
<td>V, 62 IV-FOZ-1-765</td>
</tr>
<tr>
<td>V, 64 IV-FOZ-3-765</td>
</tr>
</tbody>
</table>

Hours

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Large Scale System

Voltage Profile for major 500 kV Buses

Voltage (p.u.)

Hours

May - 23rd to 27th – 2004 – Rio de Janeiro (RJ) - BRASIL
Large Scale System

Voltage Profile for major 345 kV Buses

- V, 138 ITUTINGA-345
- V, 140 ADRIANO--345
- V, 147 CAMPOS---345
- V, 149 VITORIA--345

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Large Scale System

Voltage Profile for major 138 kV Buses

Voltage (p.u.)

Hours

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Large Scale System

Shunt Switching – 765 kV Transmission System

- Shunt Banks (Mvar)
- Hours

- Blue line: Bs, 57 IVAIPOR-R540
- Red line: Bs, 78 T.PRETO-345
- Black line: Bs, 67 IVAIPOR-R540
- Gray line: Bs, 79 TPRE-69-R360

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Large Scale System

Shunt Switching – Rio Area

![Shunt Switching Graph]

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Large Scale System

Shunt Switching – Espírito Santo Area

Shunt Banks (Mvar)

<table>
<thead>
<tr>
<th>Shunt Banks</th>
<th>Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bs, 147 CAMPOS--345</td>
<td>1</td>
</tr>
<tr>
<td>Bs, 149 VITORIA--345</td>
<td>49</td>
</tr>
<tr>
<td>Bs, 157 CAMP-CAP-345</td>
<td>97</td>
</tr>
<tr>
<td>Bs, 175 CAMPOS--138</td>
<td>145</td>
</tr>
</tbody>
</table>

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Conclusions

• Critical settings of control devices
  ✓ Better voltage regulation
  ✓ Control devices hierarchy

• Robust convergence
  ✓ Full Newton representation

• Automatic switching of capacitor/reactor banks
  ✓ More realistic representation of the system

• Better adjustment of base case
  ✓ Different scenarios

• Representation of large shunt banks