Complexity Analysis for PMU Measurement-based Load Modeling

Power & Energy Systems Group
Dept. of Electrical & Computer Engineering
University of Illinois, Urbana-Champaign

Acknowledgements: Siming Guo (UIUC), and PSERC
Motivation

- **Transient stability** is key in many current analyses, and is being proposed to replace steady state contingency analysis
  - **Operations**: accurate dynamic models will be needed that reflect the current grid state in real time so operators can perform appropriate controls to ensure grid stability
  - **Planning**: fast models needed to reduce computation time and allow case studies with more dimensions

- Load models have traditionally been neglected
- Many dynamic studies attribute uncertainty of their solutions to load models

Source: wikipedia
Measurement-based load modeling

- **Goal:** accurate dynamic load models for transient stability studies
- Increasing interests in a measurement-based load modeling framework
- Thanks to wide deployment of PMUs and other DFRs, it is possible to fit the recorded fault data to parameterized dynamic load models
- Fault-induced delayed voltage recovery (FIDVR) events of particular interest

[Source: LNBL 2010 report]
Challenges

- Loads cannot be separately tested and have to be determined while on-line.

- Existing aggregated load models are complicated and highly non-linear.
  - include diverse components, such as transformers, power electronics, and motors.
  - account for switching events.

- Difficult to validate the results as loads are constantly changing.

- Our contributions: develop the analytical framework to address the adequacy or necessity of existing dynamic load models.
# Complexity analysis

- Extremely large number of parameters; 100+ for the WECC CMPLDW
- Some parameters more **significantly** affect dynamic responses

<table>
<thead>
<tr>
<th>Bass</th>
<th>0</th>
<th>Vd2</th>
<th>0.65</th>
<th>CompPF D</th>
<th>0.97</th>
<th>VdrD</th>
<th>0.9</th>
<th>Trq2D</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rfrd</td>
<td>0.04</td>
<td>Frce1</td>
<td>0.23</td>
<td>LsA</td>
<td>1.8</td>
<td>EtrqA</td>
<td>0</td>
<td>Fu2A</td>
<td>0.47</td>
</tr>
<tr>
<td>Xfrd</td>
<td>0.03</td>
<td>pfe</td>
<td>-0.99</td>
<td>Lsb</td>
<td>1.8</td>
<td>EtrqB</td>
<td>2</td>
<td>Fu2B</td>
<td>0.3</td>
</tr>
<tr>
<td>fo</td>
<td>0.75</td>
<td>P1e</td>
<td>2</td>
<td>Lsc</td>
<td>1.8</td>
<td>EtrqC</td>
<td>2</td>
<td>Fu2C</td>
<td>0.3</td>
</tr>
<tr>
<td>Xxf</td>
<td>0.06</td>
<td>P1c</td>
<td>0.54546</td>
<td>VstallD</td>
<td>0.6</td>
<td>Trsd</td>
<td>0.4</td>
<td>Vr1A</td>
<td>0.9</td>
</tr>
<tr>
<td>Tfixls</td>
<td>1</td>
<td>P2c</td>
<td>1</td>
<td>Lpa</td>
<td>0.1</td>
<td>Fr1A</td>
<td>0.2</td>
<td>Vr1B</td>
<td>0.65</td>
</tr>
<tr>
<td>Tfixls</td>
<td>1</td>
<td>P2c</td>
<td>1</td>
<td>Lpb</td>
<td>0.16</td>
<td>Fr1B</td>
<td>0.2</td>
<td>Vr1C</td>
<td>0.65</td>
</tr>
<tr>
<td>ltc</td>
<td>1</td>
<td>Pfq</td>
<td>0</td>
<td>Lpc</td>
<td>0.16</td>
<td>Fr1C</td>
<td>0.2</td>
<td>Vr20fD</td>
<td>0.4</td>
</tr>
<tr>
<td>Tmn</td>
<td>0.9</td>
<td>Q1e</td>
<td>2</td>
<td>LppA</td>
<td>0.083</td>
<td>FvrD</td>
<td>0.17</td>
<td>Vr1A</td>
<td>0.75</td>
</tr>
<tr>
<td>Tmxmax</td>
<td>1.1</td>
<td>Q1c</td>
<td>-0.5</td>
<td>LppB</td>
<td>0.12</td>
<td>Vr1B</td>
<td>0.5</td>
<td>Trc1A</td>
<td>9999</td>
</tr>
<tr>
<td>step</td>
<td>0.00625</td>
<td>Q2e</td>
<td>1</td>
<td>LppC</td>
<td>0.12</td>
<td>Vr1C</td>
<td>0.5</td>
<td>Trc1B</td>
<td>0.6</td>
</tr>
<tr>
<td>Vmin</td>
<td>1</td>
<td>Q2c</td>
<td>1.5</td>
<td>XstallD</td>
<td>0.1</td>
<td>Vr1D</td>
<td>0.5</td>
<td>Trc1C</td>
<td>0.6</td>
</tr>
<tr>
<td>Vmax</td>
<td>1.02</td>
<td>Q3e</td>
<td>-1</td>
<td>Tpso</td>
<td>0.092</td>
<td>Tr1A</td>
<td>0.65</td>
<td>Vr20aD</td>
<td>0.45</td>
</tr>
<tr>
<td>Tdcl</td>
<td>30</td>
<td>MvpA</td>
<td>2</td>
<td>Tpso</td>
<td>0.092</td>
<td>Tr1B</td>
<td>0.02</td>
<td>Trc2A</td>
<td>0.639</td>
</tr>
<tr>
<td>Ttap</td>
<td>5</td>
<td>MvpB</td>
<td>2</td>
<td>Tpso</td>
<td>0.092</td>
<td>Tr1C</td>
<td>0.02</td>
<td>Trc2B</td>
<td>9999</td>
</tr>
<tr>
<td>Rcmp</td>
<td>0</td>
<td>MvpC</td>
<td>2</td>
<td>Tpso</td>
<td>0.092</td>
<td>Tr1D</td>
<td>0.02</td>
<td>Trc2C</td>
<td>99999</td>
</tr>
<tr>
<td>Xcmp</td>
<td>0</td>
<td>MvpD</td>
<td>1</td>
<td>TstallD</td>
<td>0.02</td>
<td>Vr2A</td>
<td>0.5</td>
<td>Trc2D</td>
<td>0.73</td>
</tr>
<tr>
<td>FmA</td>
<td>0.17</td>
<td>Lfma</td>
<td>0.7</td>
<td>Tptoa</td>
<td>0.002</td>
<td>Vr2B</td>
<td>0.7</td>
<td>Vr2C</td>
<td>0.7</td>
</tr>
<tr>
<td>FmB</td>
<td>0.1</td>
<td>Lfmb</td>
<td>0.8</td>
<td>Tptob</td>
<td>0.0026</td>
<td>Vr2C</td>
<td>0.7</td>
<td>Vr2D</td>
<td>0.9</td>
</tr>
<tr>
<td>Fmc</td>
<td>0.05</td>
<td>Lfmc</td>
<td>0.8</td>
<td>Tptoc</td>
<td>0.0026</td>
<td>FrsD</td>
<td>0</td>
<td>ThkD</td>
<td>39</td>
</tr>
<tr>
<td>Fmd</td>
<td>0.23</td>
<td>Lfmd</td>
<td>1</td>
<td>Tptoa</td>
<td>0.002</td>
<td>H A</td>
<td>0.05</td>
<td>Th1tD</td>
<td>0.3</td>
</tr>
<tr>
<td>Fel</td>
<td>0.1</td>
<td>RaA</td>
<td>0.04</td>
<td>H B</td>
<td>1</td>
<td>Tr2A</td>
<td>0.02</td>
<td>Th2D</td>
<td>2.05</td>
</tr>
<tr>
<td>Pfel</td>
<td>1</td>
<td>RaB</td>
<td>0.03</td>
<td>H C</td>
<td>0.1</td>
<td>Tr2B</td>
<td>0.02</td>
<td>Tvd</td>
<td>0.025</td>
</tr>
</tbody>
</table>

*Motor Fraction Parameters (%)*

*Thermal Protection Parameters*
Simpler CLOD model

- Parameters: percentage level of
  - Large Motors (LM)
  - Small Motors (SM)
  - Discharge Lighting (DL)
  - Transformer Saturation (TS)
  - Voltage-dependent Loads (VL)

- Use PowerWorld generator playback function to input real voltage data recorded during FIDVR disturbances
CLOD output
Sparse principal component analysis (S-PCA)

- Without sparsity, PCA is related to SVD matrix decomposition
- Sparsity is advocated to further explore hidden data structure/redundancy for noisy measurements or missing data

\[ A = U \cdot W \cdot V^T \]
Preliminary studies

- Both real and reactive power mismatch matrices are almost of rank 1

- The first principal component for Pmat is 
  \[ [0.7020, 0.7122, 0.0000, 0.0000] \]
  - Only changes of LM or SM would affect dynamic response
  - It is the aggregated LM and SM percentages would matter

- The first two principal components for Qmat are 
  \[ [0.6212, 0.7627, -0.1800, 0.0000] \]
  \[ [0.6886, -0.4216, 0.5900, 0.0000] \]
  - Q response would depend on DL percentage
Conclusions

- Load models are crucial for accurate transient stability studies

- PMUs provide high resolution for measurement-based load models, but it is important to first understand the adequacy or redundancy of models itself
  - Preliminary studies point out parameter identifiability issues
  - (Sparse) PCA method offers the analytical solution to characterize this effect

- Ongoing work
  - Test Sparse PCA for the WECC load model
  - Characterize the dependence on loading conditions
  - Leverage the complexity analysis results to facilitate load estimation in real time