Power Plant Model Validation and Calibration

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The same power plant tested by two consultants

Which data is correct?
You do not know unless you have an independent way of verifying
Using PMU Data for Model Validation

• BPA has installed PMUs at power plant POIs
• BPA developed Power Plant Model Validation (PPMV) application using PMU data

Record:
- POI bus voltage
- POI bus frequency
- Power plant MWs and MVARs
Turned out neither consultant was right

Consultant A

Consultant B

Reality
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>WSCC BOT required that all generators &gt; 10 MVA to be tested for model validation</td>
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<tr>
<td>2000</td>
<td>BPA project on using disturbance data for plant model validation</td>
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<tr>
<td>2001</td>
<td>Using disturbance recordings for validation of governor models</td>
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<tr>
<td>2006</td>
<td>WECC approves Generating Unit Model Validation Policy which allows use of disturbance recordings for power plant model validation</td>
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<tr>
<td>2007</td>
<td>NERC starts development of model validation standards MOD-025/026/027, expected to become in effect in 2013</td>
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<td>2008</td>
<td>BPA TIP 52: develop production-grade model validation application using PMU data</td>
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<td>2011</td>
<td>BPA baselines models using Power Plant Model Validation app</td>
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<tr>
<td>2012</td>
<td>BPA collaborates with DOE on model calibration research</td>
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Modeling Governor Response

- PMU data was very instrumental in identifying frequency response characteristics of power plants

**BEFORE**

Four Corners Plant Outage on December 25, 1999

**AFTER**

Four Corners Plant Outage on December 25, 1999

Blue = actual, Red = model
Power Plant Model Validation

• What a good models looks like:

Voltage and frequency are inputs
Active and reactive power are “measures of success”

Blue line = actual recording
Red line = model
Power Plant Model Validation

• What a bad model looks like:

Voltage and frequency are inputs
Active and reactive power are “measures of success”

Blue line = actual recording
Red line = model
BPA Modeling Baseline

<table>
<thead>
<tr>
<th>Plant</th>
<th>Active Power</th>
<th>Reactive</th>
</tr>
</thead>
<tbody>
<tr>
<td>H1(14)</td>
<td>Passable</td>
<td>Needs Review</td>
</tr>
<tr>
<td>H2(18)</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
<tr>
<td>H3(16)</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
<tr>
<td>H4(12)</td>
<td>Flawed, Needs Re-test</td>
<td>Needs Review</td>
</tr>
<tr>
<td>H5(27)</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
<tr>
<td>T1(1)</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
<tr>
<td>T2(2)</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
<tr>
<td>T3(3)</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
<tr>
<td>T4(1)</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
<tr>
<td>W1</td>
<td>Good</td>
<td>Needs Review</td>
</tr>
</tbody>
</table>
BPA Experience with Disturbance-Based Model Validation

• Most common model issues:
  – Power System Stabilizer models
  – Turbine control mode of operation / governor models
  – Generator inertia
  – Deficiencies in model structure

• Other reasons for model mismatch
  – Automatic Generation Controls
  – UEL

• “Clinical” experience:
  – Plants with modern digital systems have good models that stay accurate over time
  – Plants with legacy analog controls have most errors and tend to change in time
Performance Monitoring and Detecting Generator Control Failures

- Once a good baseline is developed, PMU is used for “clinical” assessment of power plant performance

- Controller status at the generator was indicating normal state
- PMU disturbance data indicated actual response very different from what was expected
- Power plant was contacted, controls inspected, found internal failure
Benefits of PMU-based Model Validation

- Disturbance recordings can complement the baseline model development (e.g. TransAlta – BPA work at Centralia)
- PMU-based model validation is an acceptable method for GOs to comply with NERC MOD-026,-027
  - assuming a correct baseline model is developed
- PMU-based model validation can be used by TPs to independently verify that the models provided by GOs are accurate
  - BPA experience suggests that 60 to 70% of models did not match disturbance recordings even after the baseline test was performed
  - TPs need independent method of model verification – it is difficult to police traffic if you do not have a speed radar
- PMU-based model validation allows more frequent model verification and detection of control failures (e.g. Grand Coulee and Colstrip) than once every 10 years (per NERC) or 5 years (per WECC)
Model Calibration
Model Calibration

• Initially, BPA use of the PMU data has been limited to validating dynamic models of power plants:
  – used for pass / fail checking
  – no model adjustments are made should the model be wrong
Model (in)Validation

Simulations done using a model from WECC dynamic data base

Blue = actual
Red = simulated
Model Calibration

• DOE is funding several researchers to do work on power plant model calibration using PMU data
  – PNNL (Kalman filter)
  – Sakis Meliopolis, Georgia Tech (super-calibrator)
  – Bernard Lesieutre, University of Wisconsin (pattern matching)
  – Wei-Jen Lee, University of Texas (particle swarm optimization and non-linear optimization)

• EPRI is also working on PMU-based model calibration

• BPA has worked with Bernie Lesieutre to perform model calibration for CGS and Colstrip
Model Calibration

Simulations done using a calibrated model

Blue = actual
Red = simulated
Model Calibration

Simulations done using a calibrated model

Blue = actual
Red = simulated
Model Calibration Test Cases

- BPA prepared test cases:
  - 12 disturbances (voltage and frequency) are played through a known model to get active and reactive power responses

- Researchers received:
  - 6 data sets (voltage, frequency, active and reactive power) simulated above
  - A distorted model of a generator (H, AVR, PSS, Governor)

- Researchers performed model calibration and gave a re-calibrated model to BPA

- BPA used additional 6 data sets to check how well they did
Observations

• Generator inertia – both PNNL and UW did well
• AVR parameters – transient performance right on, steady-state OK
• PSS – UW did better job finding PSS
• Governor – UW had excellent match of MW responses with parameters off by as much as 25 to 30%
  – Governor response was slow, possibly faster dynamics are not observable, which potentially leads to non-uniqueness in model data sets matching the curve
  – Can we find the data from “baseline tests”? 
Baseline Test and Model Development
Baseline Test and Model Development
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