Synchronized Phasor Measurements for Response-Based One-Shot Control

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Automate Design of Wide-Area Stability Controls

- Uses large amounts of simulation data to develop the controls
- Uses pattern recognition tools such as decision trees and neural networks
- Not necessarily optimal
- Demonstrate net improvement
Work in Progress

- Present results that use R-Rdot
- Kejun Mei, and S.M. Rovnyak, "Response-Based Decision Trees to Order Stabilizing Control," *IEEE Transactions on Power Systems*, pp. 531-537, February 2004
- Plan results that use PMUs – Kejun Mei
One-Shot Stability Control

- Open-loop discrete-event
- Feed-forward discontinuous
- Many controls one-shot by nature
  - generator tripping
  - load shedding
- Other controls maybe one-shot by design: HVDC fast power changes
Event-Based Control

- Event-based controls very common:
  - Remedial action schemes (RAS)
- Controls are predetermined for specific events through off-line simulation
- Typically consist of generator tripping and reactive switching
- Load shedding also possible
Simulations for Response-Based Control
Converting Simulations to Input-Output Pairs

- PACI = Tesla phase angle - John Day phase angle
- Input Vector = \{ R, Rdot \}
- Desired Output = Trip if \( \text{PACI} < -120 \)

<table>
<thead>
<tr>
<th>Time</th>
<th>R</th>
<th>Rdot</th>
<th>PACI</th>
<th>Desired Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.833</td>
<td>17.64</td>
<td>-26.77</td>
<td>-112.10</td>
<td>0 (No Action)</td>
</tr>
<tr>
<td>4.850</td>
<td>16.89</td>
<td>-44.70</td>
<td>-114.16</td>
<td>0 (No Action)</td>
</tr>
<tr>
<td>4.867</td>
<td>16.16</td>
<td>-44.02</td>
<td>-116.32</td>
<td>0 (No Action)</td>
</tr>
<tr>
<td>4.883</td>
<td>15.40</td>
<td>-45.51</td>
<td>-118.59</td>
<td>0 (No Action)</td>
</tr>
<tr>
<td>4.917</td>
<td>13.84</td>
<td>-44.50</td>
<td>-123.51</td>
<td>1 (Take Action)</td>
</tr>
<tr>
<td>4.933</td>
<td>12.72</td>
<td>-64.78</td>
<td>-126.16</td>
<td>1 (Take Action)</td>
</tr>
</tbody>
</table>
Training Data for Response-Based Control
Decision Region for Response-Based Control
Decision Region for Response-Based Control
Different Regions for Different Purposes

Kejun Mei, and S.M. Rovnyak, "Response-Based Decision Trees to Order Stabilizing Control," *IEEE Transactions on Power Systems*, February 2004
Trajectories with and without Control
Step 1: Train DT to Detect or Predict Stability

- Run training simulations
- Convert data to input-output pairs
- Each input vector represents a simulated measurement instant
- Desired output = 0 or 1 depending on stability at the measurement instant
Step 1: Train DT to Detect or Predict Stability

- Specify relative misclassification costs for DT training software
- Affect the relative number of errors
  - Errors when desired output = 1
  - Errors when desired output = 0
- Affect size of the decision region
- Choose parameter values & train DT
Step 2: Find a good combinations of controls

- Choose one specific combination of one shot controls (let's call this a "Trial Combo")
- Re-run training simulations
- Trigger the "Trial Combo" the first time during a simulation that a set of measurements results in a DT output 1 (Take Action)
- Choose different "Trial Combo" and repeat
Step 2: Find a good combinations of controls

- Each “Trial Combo” evaluated over all the training simulations
- Objective function approach
  - Add 1 point for each simulation stabilized by the control
  - Subtract 3 points for each simulation destabilized by the control
Step 2: Find a good combinations of controls

- Combinatorial search for the best “Trial Combo” is time consuming when considering different control amounts like how many MW of load to trip.
- Would like to try changing the amounts of several controls between “Trial Combos”.
- In any case, settle on the best “Trial Combo” in Step 2 and call it “The Final Control Combination”.
Step 3: Evaluate DT to Trigger “The Final Control Combo” on New Simulations

- Run a test set of simulations
- Trigger the “The Final Control Combo” the first time during a simulation that a set of measurements results in a DT output 1 (Take Action)
- Evaluate results over all the test simulations
Simulation Study

- 176-bus simplified model of WECC
- 29 generator buses
- 385 training simulations
- 1600 test set simulations
- Wide variety of events in simulations
  - Various fault locations and durations
  - Single line to ground and 3 phase faults
  - Double contingency outages
Simulation Study

- R-Rdot measured middle of PACI
- Final Control Combo consists of three simultaneous one-shot controls
- 2 HVDC fast power changes and one generator tripping = “3-Bang control”
- “Take Action” in 116 of 385 train sims
- “Take Action” in 491 of 1600 test sims
Stability Criterion is Loss of Synchronism Across PACI

- Control in 116 train simulations
- Control in 491 test simulations

<table>
<thead>
<tr>
<th></th>
<th>Train Set</th>
<th>Test Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stabilized</td>
<td>46</td>
<td>253</td>
</tr>
<tr>
<td>Stable</td>
<td>61</td>
<td>185</td>
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<tr>
<td>Unstable</td>
<td>9</td>
<td>53</td>
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<tr>
<td>Destabilized</td>
<td>0</td>
<td>0</td>
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</table>
Stability Criterion is Network-Wide Synchronism

- PACI Angle Still Used as Stability Criterion for Step 2 Objective Function

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<tbody>
<tr>
<td>Stabilized</td>
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<td>19</td>
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<tr>
<td>Stable</td>
<td>59</td>
<td>103</td>
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<tr>
<td>Unstable</td>
<td>52</td>
<td>369</td>
</tr>
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Step 2 Objective Function is PACI Synchronism

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<td>Stabilized Over PACI</td>
<td>46</td>
<td>253</td>
</tr>
<tr>
<td>Stabilized Network-Wide</td>
<td>5</td>
<td>19</td>
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Step 2 Objective Function is Network-Wide Synchronism

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<tr>
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<tbody>
<tr>
<td>Stabilized Over PACI</td>
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<td>74</td>
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<tr>
<td>Stabilized Network-Wide</td>
<td>17</td>
<td>1</td>
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## Comparison

<table>
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<tr>
<th>PACI Objective</th>
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<tr>
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Extension to Synchronized Phasor Measurements

- Input vector contains phase angle measurements and rates of change
- Desired output = “Take Action” if any generator losing synchronism
  - i.e. network-wide stability
- Objective function in Step 2 is network-wide stability
Extension to Synchronized Phasor Measurements

- Hope to use large-scale simulation
- Hope to vary multiple parameters while searching the space of “Trial Combos” like gradient descent
- May use continuous objective function

\[ J = \int_0^T \sum_i \frac{1}{M_{total} T} M_i \left( \delta_i(t) - \delta_{coa}(t) \right)^2 \, dt \]
Extension to Synchronized Phasor Measurements

- ISGA reference

- Gradient descent to find combo of one-shot controls for one event

- Straightforward adaptation to use gradient descent for multiple events