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

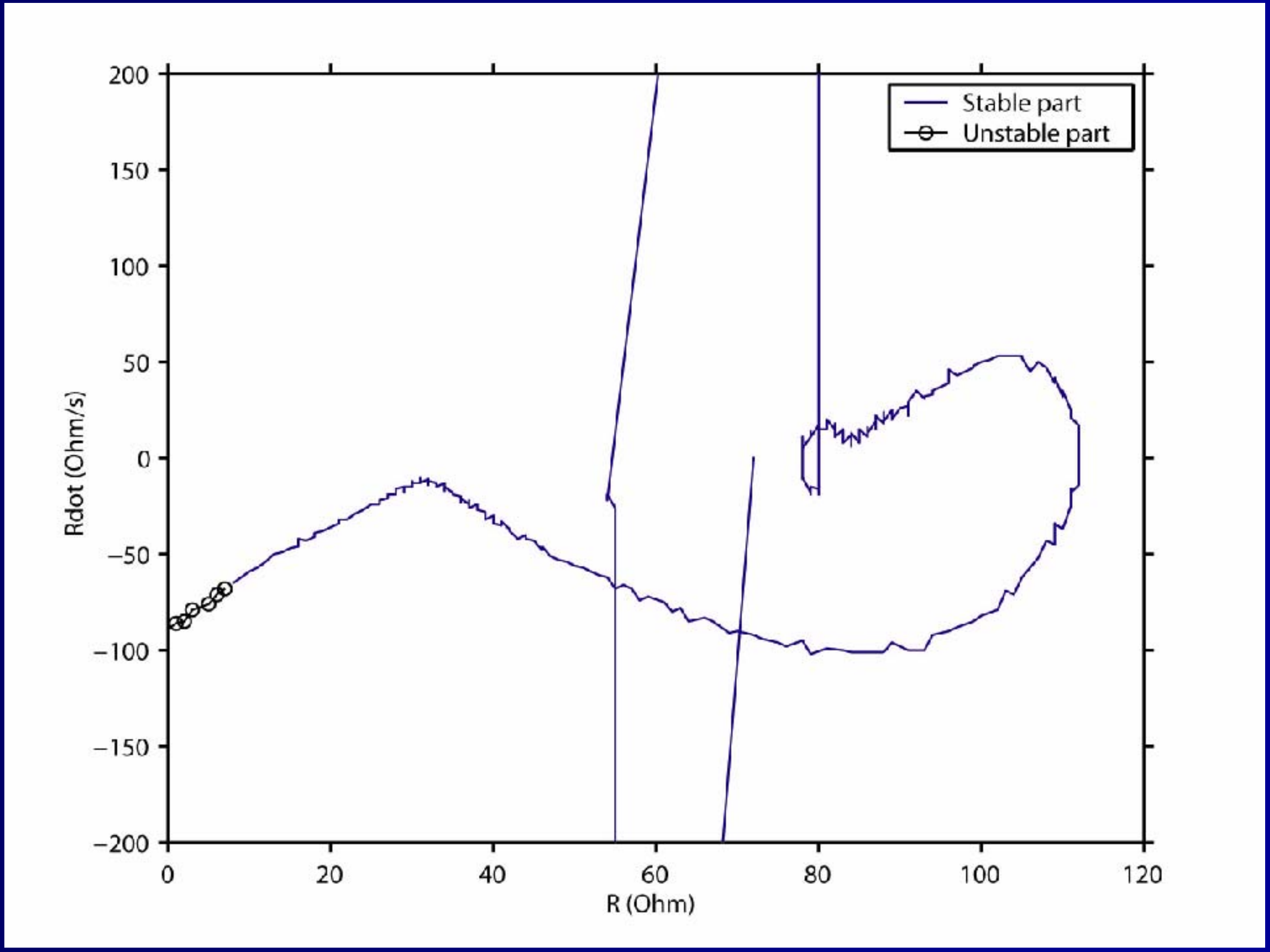
- Open-loop discrete-event
- Feed-forward discontinuous
- Many controls one-shot by nature
  - generator tripping
  - load shedding
- Other controls maybe one-shot by design: HVDC fast power changes

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 PACI < - 120
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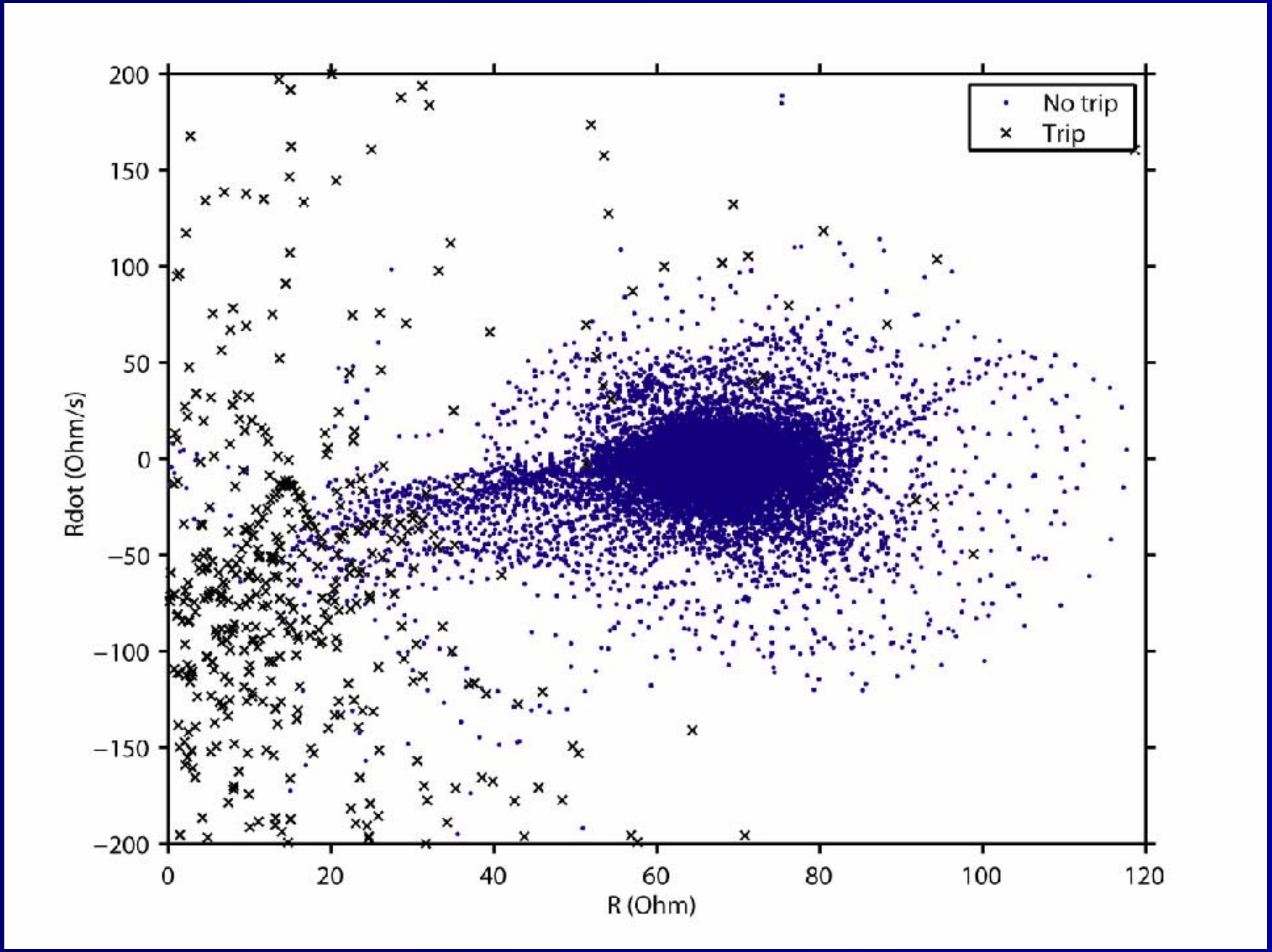
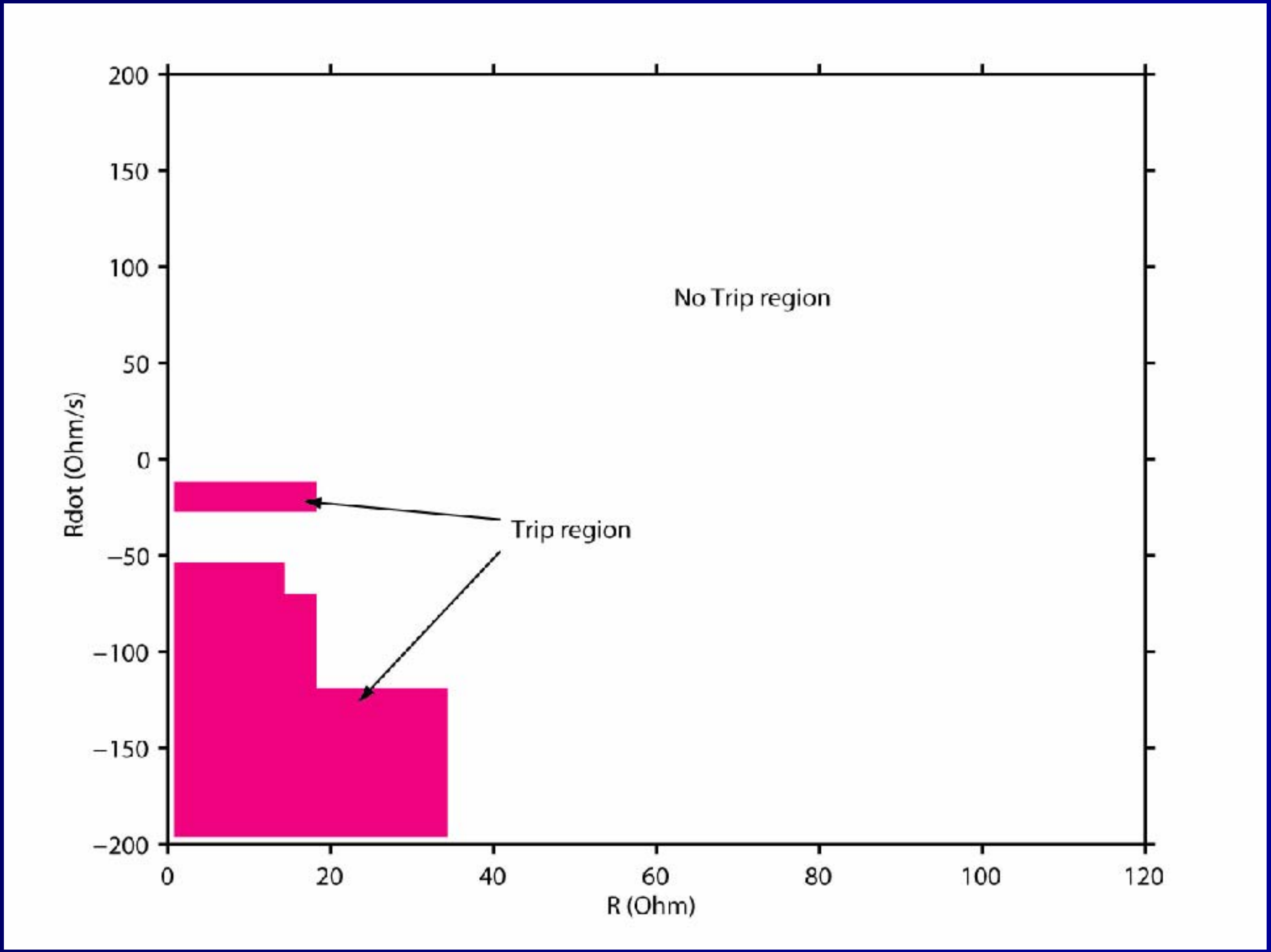
Time	R	Rdot	PACI	Desired Output
4.833	17.64	-26.77	-112.10	0 (No Action)
4.850	16.89	-44.70	-114.16	0 (No Action)
4.867	16.16	-44.02	-116.32	0 (No Action)
4.883	15.40	-45.51	-118.59	0 (No Action)
4.900	14.58	-48.93	-120.99	1 (Take Action)
4.917	13.84	-44.50	-123.51	1 (Take Action)
4.933	12.72	-64.78	-126.16	1 (Take Action)

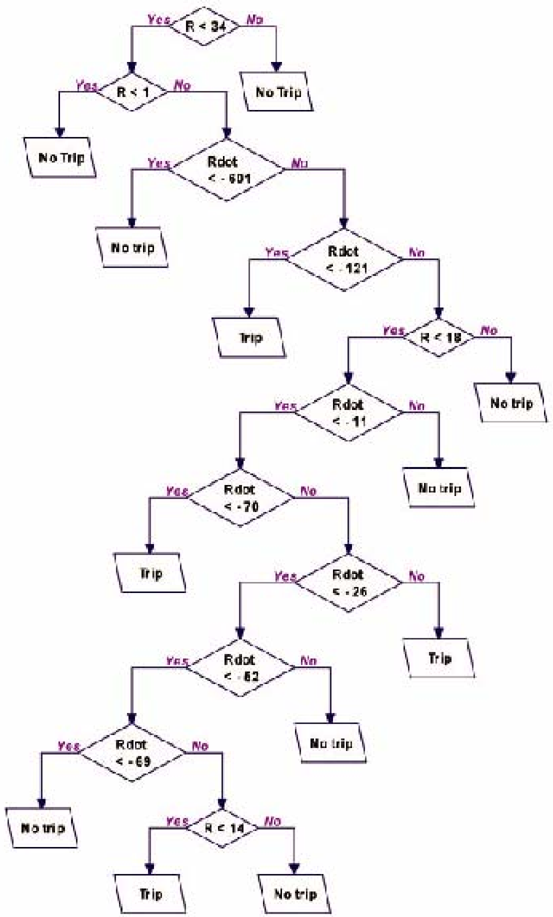
Training Data for Response-Based Control



Decision Region for Response-Based Control

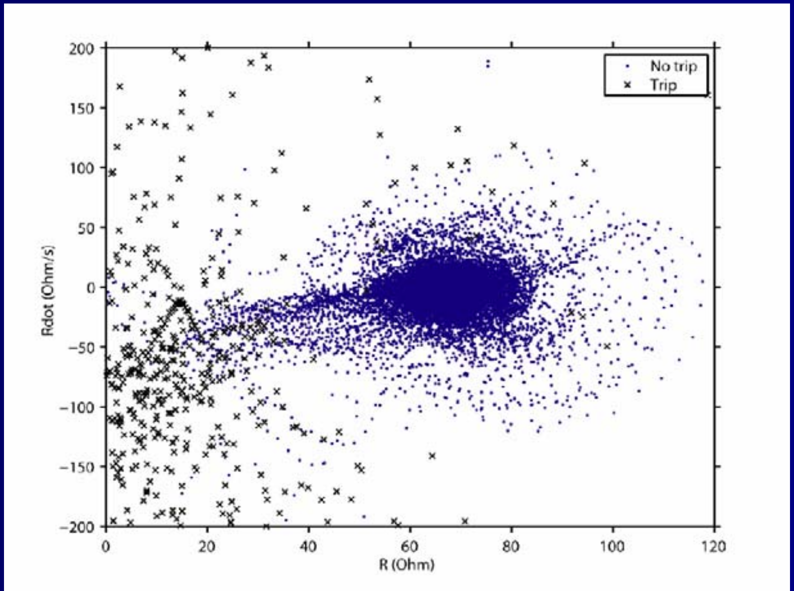


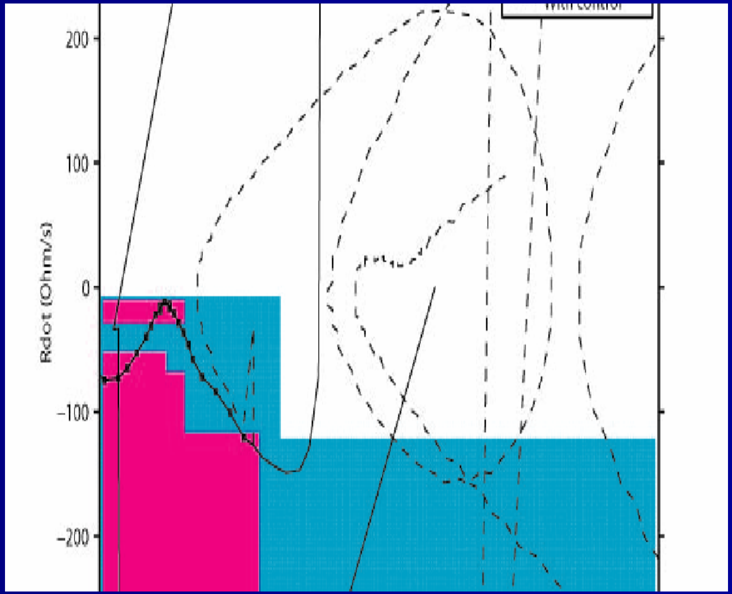
Decision Region for Response-Based Control



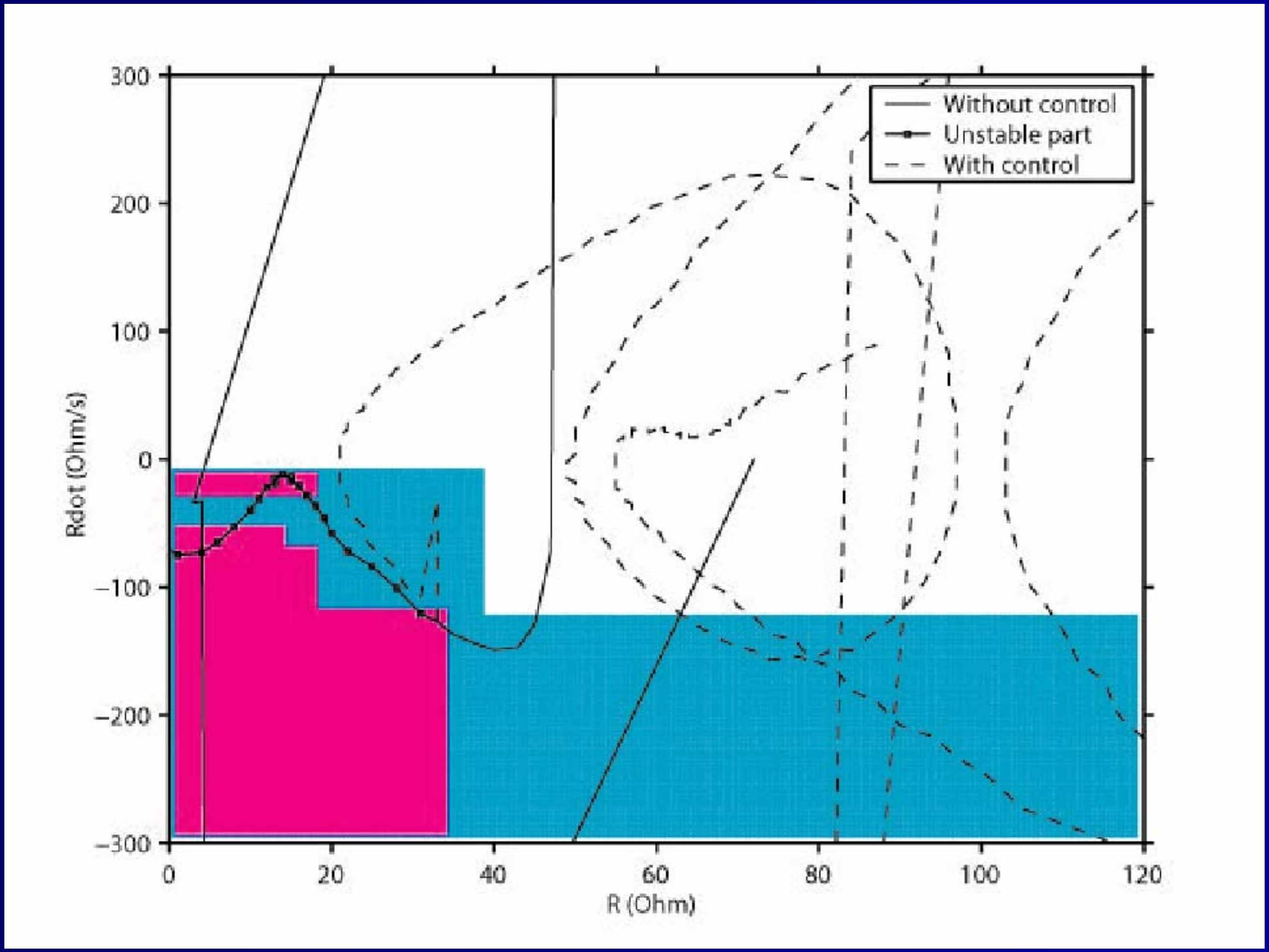
Different Regions for Different Purposes

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 (lets 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

	Train Set	Test Set
Stabilized	46	253
Stable	61	185
Unstable	9	53
Destabilized	0	0

Stability Criterion is Network-Wide Synchronism

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

	Train Set	Test Set
Stabilized	5	19
Stable	59	103
Unstable	52	369
Destabilized	0	0

Step 2 Objective Function is PACI Synchronism

	Train Set	Test Set
Stabilized Over PACI	46	253
Stabilized Network-Wide	5	19

Step 2 Objective Function is Network-Wide Synchronism

	Train Set	Test Set
Stabilized Over PACI	10	74
Stabilized Network-Wide	17	1

Comparison

PACI Objective	Train Set	Test Set
PACI Stabilized	46	253
Net-Wide Stabilized	5	19

Network-wide Objective	Train Set	Test Set
PACI Stabilized	10	74
Net-Wide Stabilized	17	1

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
  - Guang Li, and S.M. Rovnyak, "Integral Square Generator Angle Index for Stability Ranking and Control," *IEEE Trans on Power Systems*, May 2005
- Gradient descent to find combo of one-shot controls for one event
- Straightforward adaptation to use gradient descent for multiple events