WECC Load Model Sensitivity Study

"An Analysis of the Sensitivity of WECC Grid Planning Models to Assumptions Regarding the Composition of Loads"

Task 1 Progress Update

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Agenda

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- Background
- Study Procedure
- Initial Parameter Lists and Value Ranges
- Summary of Initial Results
- Interesting Examples
- Proposed System Performance Criteria
- Proposed Metrics for Quantifying Sensitivities
- Presentation of Results

Background

- **Objectives**
  - Explore the sensitivity of WECC planning models to uncertainty in the composition and behavior of loads
  - Provide guidance for future planning studies
- **Task 1 work completed**
  - Develop list of parametric simulations to be conducted
  - Investigate sensitivities of initial parameter list
  - Run all contingencies for each transmission provider (TP)
  - Monitor all transmission bus voltages in each TP area
  - Monitor generation for loss of synchronism or excessive oscillation

Study Work

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- **Exploratory simulation runs performed**
  - PacifiCorp (PSS/E) – all contingencies
  - PG&E (PSLF) – initial runs on one contingency, others to follow
  - SCE (PSLF) – in progress
  - SRP (PSLF) – in progress
- **Initial focus on Motor D load parameters**
- **Sensitivity analysis procedure:**
  1. Dynamics data as given (no stalling): Phase 1 Base Case
  2. Set Tstall = 0.033 sec (typical): Phase 2 Base Case
  3. Vary one parameter in the Phase 2 Base Case
     - Two new cases: parameter set to minimum and maximum values
     - Total load is unchanged (same power flow case)

Initial Key Parameter List (Motor D)

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- Tstall, Stall time delay, sec.
- Vstall, Stall voltage, p.u.
- FmA, Motor A fraction of load P
- FmB, Motor B fraction of load P
- FmC, Motor C fraction of load P
- FmD, Motor D fraction of load P
- Fel, Electronic load fraction of P
- Vtr1, First under voltage trip level, p.u.
- Ttr1, First under voltage trip delay time, sec.
- Fuvr, Fraction of load with under voltage relay protection
- Frst, Fraction of load that can restart after stalling
- Vrst, Voltage at which restart can occur, p.u.
- Trst, Restart time delay
- Contactor settings (treated as a group):
  - Vc1off, Contactor voltage at which tripping starts, p.u.
  - Vc2off, Contactor voltage at which tripping is complete, p.u.
  - Vc1on, Contactor voltage at which reconnection starts, p.u.
  - Vc2on, Contactor voltage at which reconnection is complete, p.u.
- Tth, Motor D thermal time constant, sec.
- Th1t, Motor D thermal protection trip start level, p.u. temperature
- Th2t, Motor D thermal protection trip completion level, p.u. temperature

Initial Key Parameters (Motors A, B, C)

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- **Motor A, B, C parameters to be studied:**
  - Ls, Synchronous reactance, p.u.
  - Tpo, Transient open-circuit time constant, sec.
  - Ftr1, First low voltage trip fraction
  - Vrc1, First low voltage reconnection level, p.u. V
  - Trc1, First low voltage reconnection delay time, sec.
  - Vtr2, Second low voltage trip level, p.u.
  - Ttr2, Second low voltage trip delay time, sec.
  - H, Inertia constant, sec.

Parameter Value Ranges

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Ref. No.	Description of Parameter	Phase 1	Phase 2		
			Base Value as given in dyd/dyr	Minimum Value	Maximum Value
1	Vstall, Stall voltage, p.u.	0.5	0.5	0.3	0.8
2	Tstall, Stall time delay, sec.	9999	0.033	0.01667	0.25
3	Vc1off, Contactor voltage at which tripping starts, p.u.	0.5	0.5	0.3	0.7
4	Vc2off, Contactor voltage at which tripping is complete, p.u.	0.4	0.4	0.2	0.6
5	Vc1on – Contactor voltage at which reconnection is complete (pu)	0.6	0.6	0.4	0.8
6	Vc2on – Contactor voltage at which reconnection starts (pu)	0.5	0.5	0.3	0.7
7	Tth, Motor D thermal time constant, sec.	15	15	5	25
8	Th1t, Motor D thermal protection trip start level, p.u. temperature	0.7	0.7	0.4	0.9
9	Th2t, Motor D thermal protection trip completion level, p.u. temperature	1.2	1.2	1	3
10	FmA, Motor A fraction of load P	0.167	0.167	-20%	+20%
11	FmB, Motor B fraction of load P	0.135	0.135	-20%	+20%
12	FmC, Motor C fraction of load P	0.061	0.061	-20%	+20%
13	FmD, Motor D fraction of load P	0.113	0.113	-20%	+20%
14	Fel, Electronic load fraction of P	0.173	0.173	-20%	+20%
15	Vtr1, First under voltage trip level, p.u.	0.6	0.6	0.4	0.8
16	Ttr1, First under voltage trip delay time, sec.	0.02	0.02	0.01667	0.25
17	Fuvr, Fraction of load with under voltage relay protection	0.1	0.1	0	0.5
18	Frst, Fraction of load that can restart after stalling	0.2	0.2	0	1
19	Vrst, Voltage at which restart can occur, p.u.	0.95	0.95	0.5	1
20	Trst, Restart time delay	0.3	0.3	0.1	1

Summary of Initial Results

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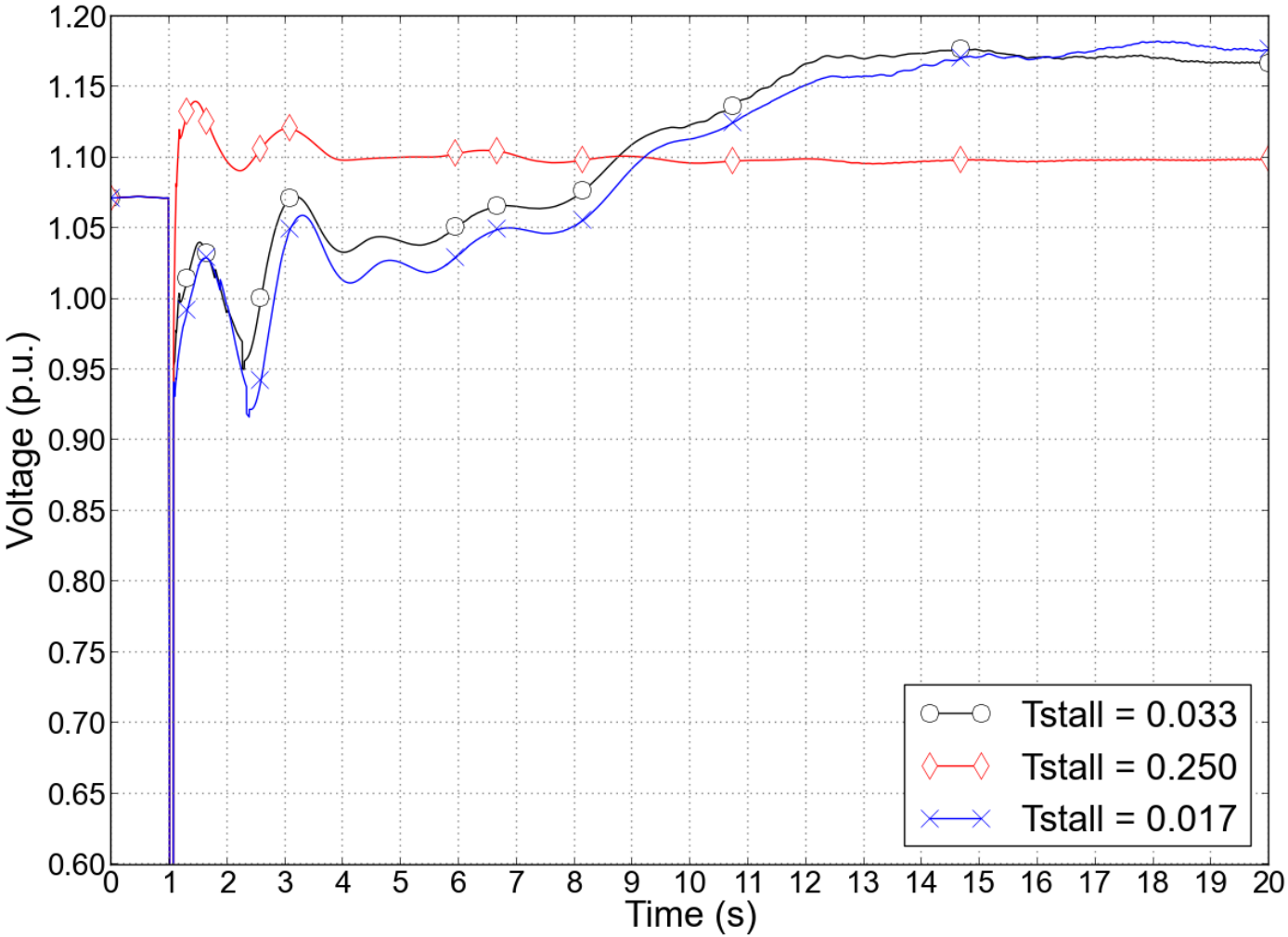
- Initial runs to 10 sec (PacifiCorp), 20 sec (PG&E)
  - Further simulations will run to 30 sec
- Most important parameters:
  - Tstall
  - Vstall
  - Contactor settings (Vc1on, Vc2on, Vc1off, Vc2off)
  - Fuvr – fraction of Motor D loads with undervoltage relay protection
  - FmD – Motor D load fraction of total load
  - Motor D thermal protection
    - Tth – thermal time constant
    - Th1t and Th2t – thermal protection levels
  - Vrst – voltage level at with restart can occur

Tstall Example, 500 kV (PG&E)



Vstall Example, 345 kV (PacifiCorp)

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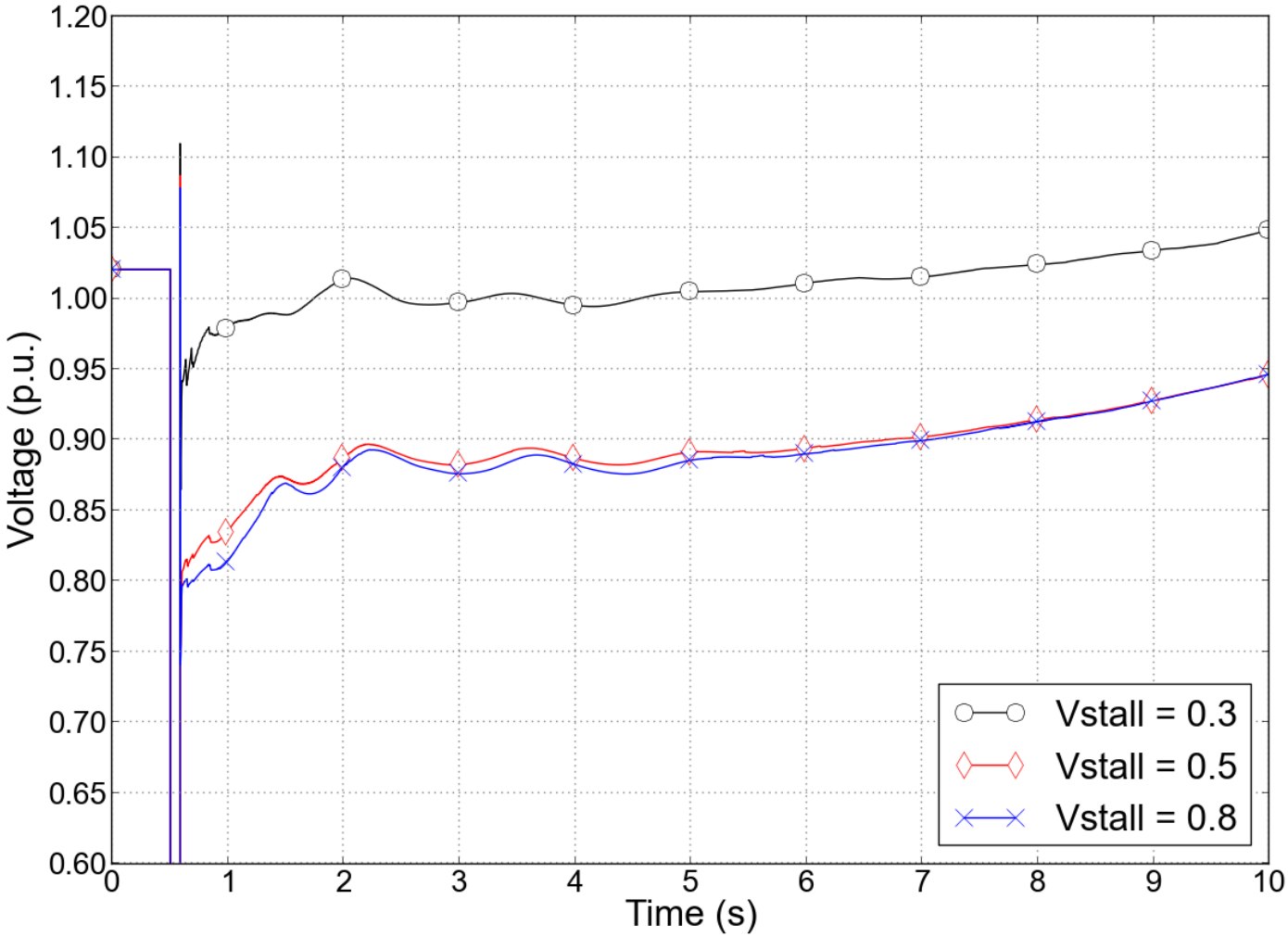
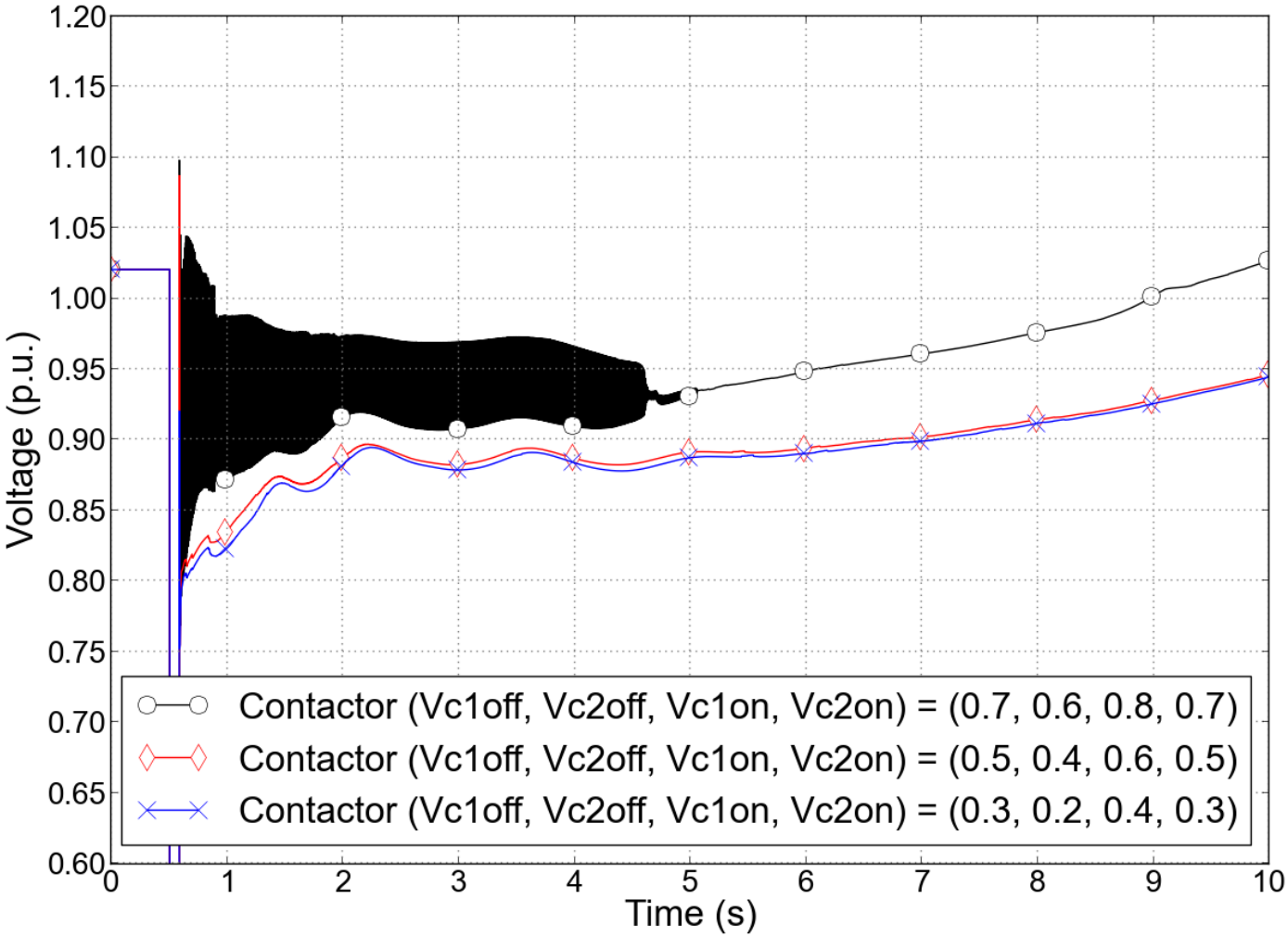
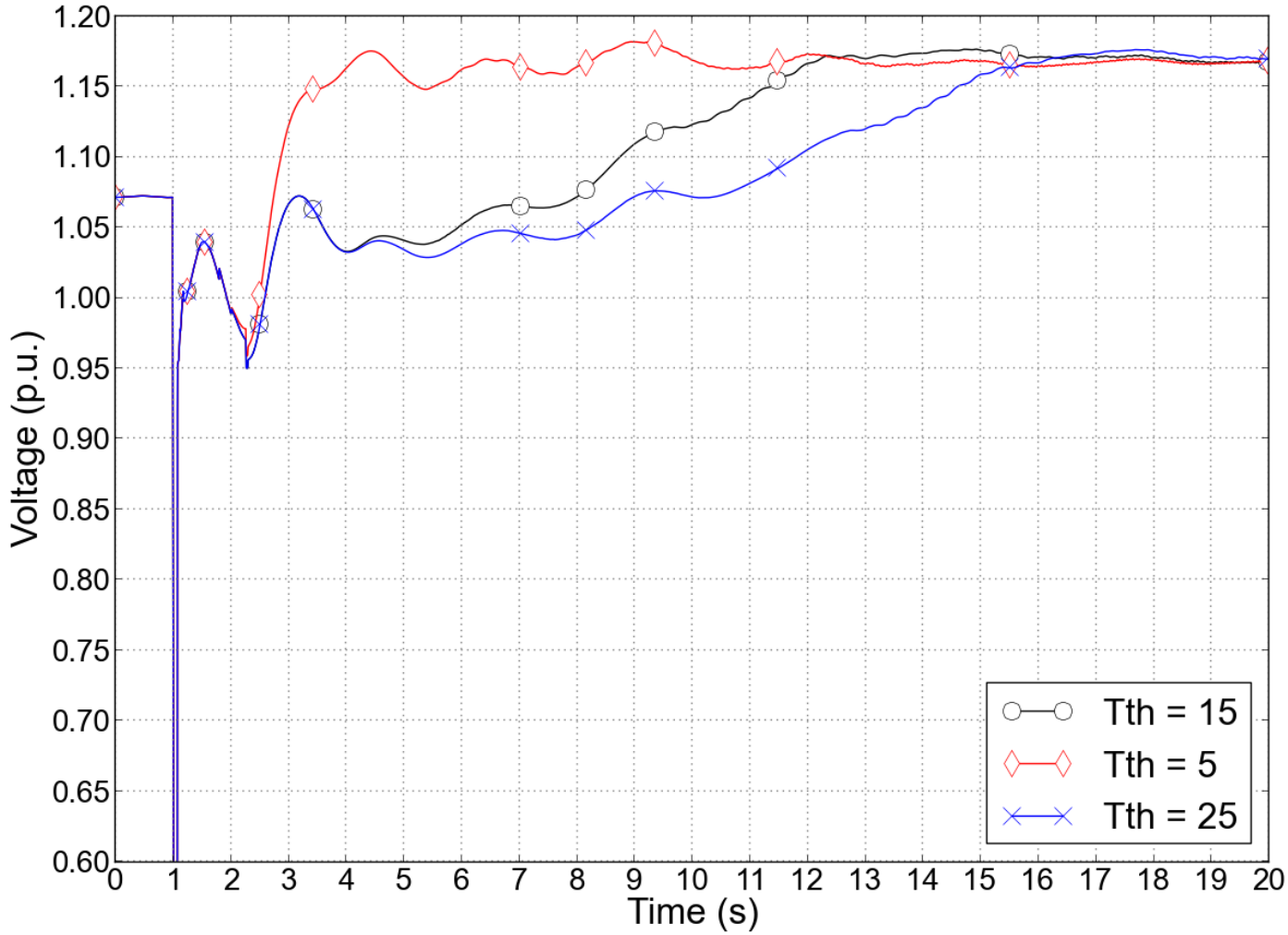


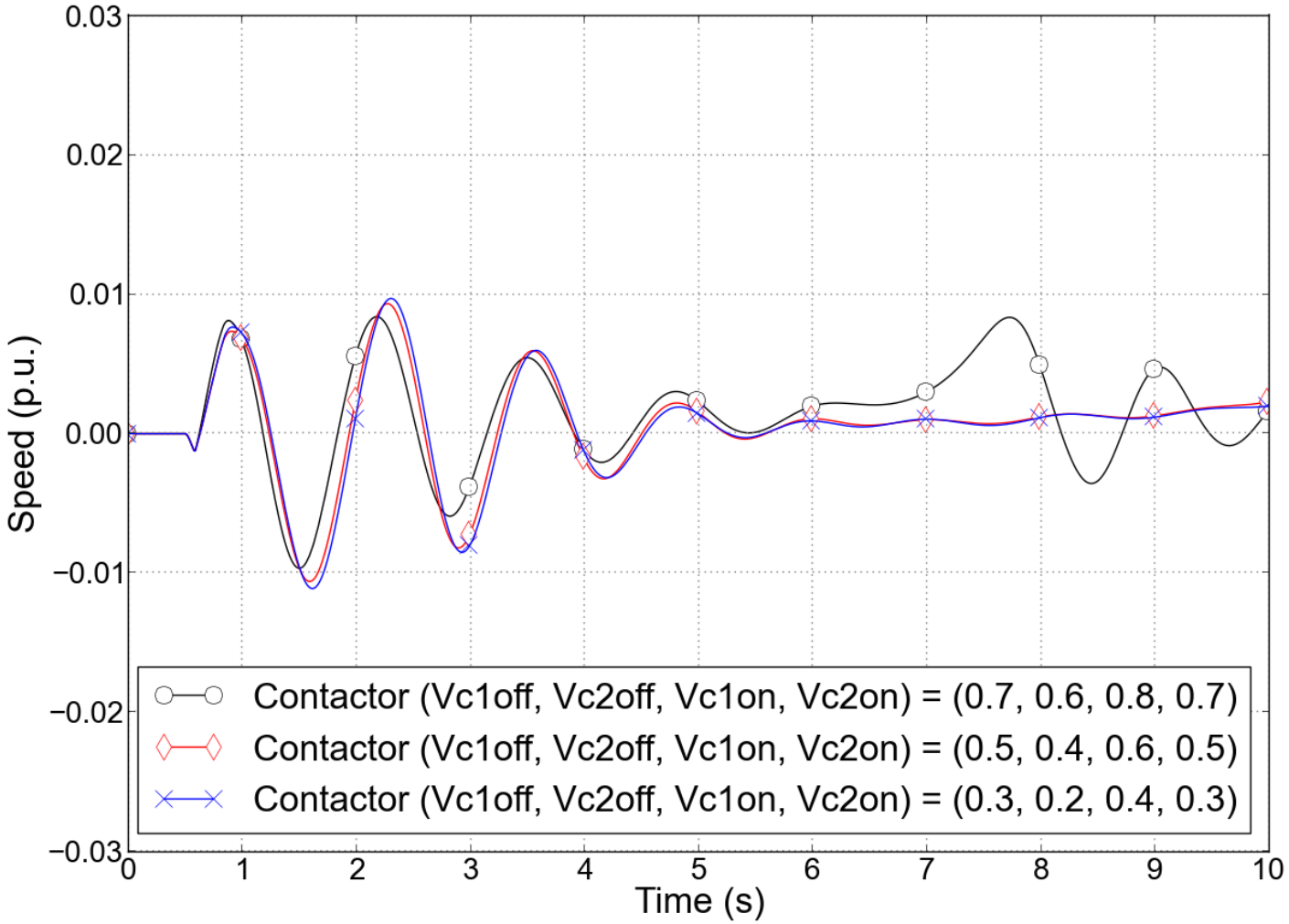
Contactor Example, 345 kV (PacifiCorp)



Motor D Thermal Protection Example, 500 kV (PG&E)



Loss of Synchronism Example



System Performance Criteria

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- Transient voltage dips will be monitored and recorded for dips that exceed:
  - 25% at load buses and 30% at non-load buses
  - 20% for more than 20 cycles at load buses
- Frequency oscillations will be monitored and recorded for dips below 59.6 Hz for 6 cycles or more at load buses
- Post-transient voltage deviations exceeding 5% at any bus
- Voltage recovery to 70% in 1 second, 80% in 3 seconds, 90% in 5 seconds
- Power, angle, or voltage magnitude oscillations will be monitored and recorded for 5% damping from the first swing peak to the 3rd swing peak
- Voltage overshoot will be monitored
  - Greater than 1.05 p.u. for 5 seconds or longer. Voltage overshoot over 1.1 p.u.
- Any non-consequential load loss (total load loss to be calculated)
- Any generator that loses synchronism

Metrics for Quantifying Sensitivities

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- Compare performance to base case, e.g., Phase 2 Base Case
- Number of violations of performance criteria
- Examine voltage response:
  - Entire simulation run
  - Time scales, e.g., 0-1 sec, 1-6 sec, 6-30 sec after fault clearing
    - Which parts of the response are affected by each parameter
  - Type of fault, e.g, three-phase w/ normal clearing, stuck breaker, etc.
- Exploring machine learning approaches
  - Machine learning rules, unsupervised learning
  - Classification and clustering
  - Measure of similarity voltage responses, e.g., Euclidean distance, dynamic time warping

Example Results Table

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Ref. No.	Contingency Type	Load Parameter Varied	Load Parameter Value	Observations in Number of Buses			
				Voltage dip exceeds 25% (load buses)	Voltage dip exceeds 30% (non-load buses)	Frequency dip below 59.6 Hz (>6 cycles)	Post-transient voltage deviation (>5%)
1	3-PH Single Line Outage	Tstall	0.01667	4	3	7	2
2	1-PH Stuck Breaker	Tstall	0.01667	7	10	12	25
3	3-PH Single Line Outage	Tstall	0.25	0	0	0	0
4	3-PH Single Line Outage	Vstall	0.3	0	0	0	0
5	3-PH Single Line Outage	Vstall	0.8	34	34	12	32

Ref. No.	Contingency Type	Load Parameter Varied	Load Parameter Value	Observations in Number of Buses				
				Voltage recovery			Voltage Overshoot	
				70% - 1 sec	80% - 3 secs	90% - 5 sec	Above 1.05 p.u. > 5 sec	Above 1.1 p.u.
1	3-PH Single Line Outage	Tstall	0.01667	1	2	7	2	7
2	1-PH Stuck Breaker	Tstall	0.01667	3	12	18	9	12
3	3-PH Single Line Outage	Tstall	0.25	0	0	0	0	0
4	3-PH Single Line Outage	Vstall	0.3	0	0	0	0	0
5	3-PH Single Line Outage	Vstall	0.8	20	30	40	10	20

Example Results Table (continued)

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Ref. No.	Contingency Type	Load Parameter Varied	Load Parameter Value	Generator angle swings - Damping <5%	Non-consequential Load Loss (MW)	Generators pulled out of synchronism
1	3-PH Single Line Outage	Tstall	0.01667	0	35	1
2	1-PH Stuck Breaker	Tstall	0.01667	0	65	2
3	3-PH Single Line Outage	Tstall	0.25	0	0	0
4	3-PH Single Line Outage	Vstall	0.3	0	0	0
5	3-PH Single Line Outage	Vstall	0.8	20	100	5

Presentation of Results

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- **Final Report and Presentation**
  - **Report Outline (not including figures and tables)**
    - Executive Summary (2-3 pages)
    - Introduction and Background (2 pages)
    - Objective and Approach (1 page)
    - Types of Contingencies Studied (1 page)
    - CMPLDW Load Model Discussion (2-3 pages)
    - Results for each TP (5 pages each, 20 pages total)
    - Overall Conclusions (2-3 pages)
    - Recommendations (1-2 pages)
  - **Results Tables**
    - Summarize observations from sensitivity analysis
    - Breakdown by fault type and load model parameter
  - **Figures**
    - For each TP, one figure for each load parameter studied as an example
    - Additional figures as needed to demonstrate specific phenomena
- **Peer-reviewed journal article**

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QUESTIONS?