

Composite Load Model Sensitivity Study

***“An Analysis of the Sensitivity of WECC Grid Planning
Models to Assumptions Regarding the Composition of Loads”***

**NERC/DOE FIDVR Workshop
Alexandria, VA**

September 30 – October 1, 2015

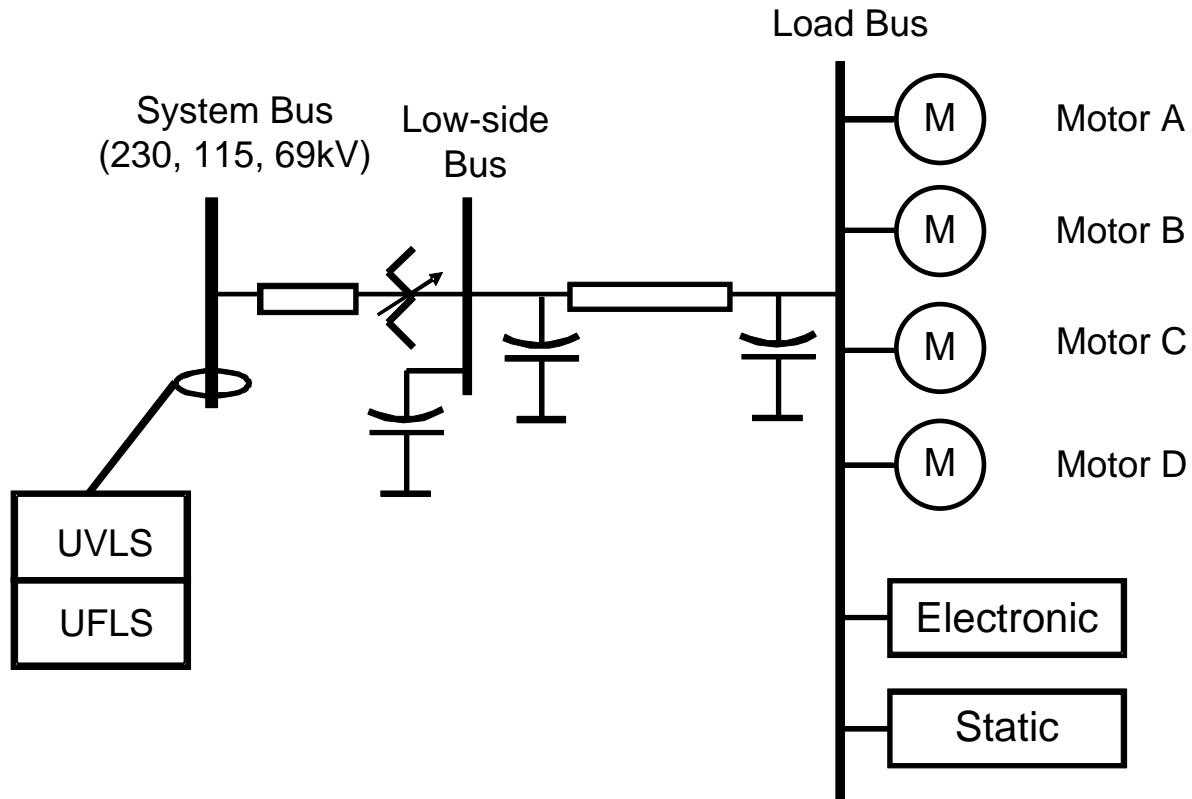
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Background

- **Objectives**
 - **Explore the sensitivity of WECC planning models to uncertainty in the composition and behavior of loads**
 - **Provide guidance for future planning studies and data collection**
- **Transmission Providers: PacifiCorp, PG&E, SCE, and SRP**
- **Tasks**
 - **Develop list of parametric simulations to be conducted**
 - **Investigate sensitivities of the 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**
 - **Detailed analysis for specific parameters and cases**
 - **High-sensitivity parameters**
 - **Stressed base case**

Composite Load Model in WECC



Study Work

- **Sensitivity analysis procedure:**
 - **Phase 1 Base Case: No stalling**
 - **Phase 2 Base Case: Set $T_{stall} = 0.033$ sec**
 - **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)**
- **Presentation of results:**
 - **Identify study thresholds and flag observations**
 - **Compute sensitivities with respect to Phase 2 Base Case**
 - **Results summarized by parameter**

Key Parameters (Motor D)

- **Vstall** – Stall voltage, p.u.
- **Tstall** – Stall time delay, sec.
- **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
- **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

Key Parameters (Motors A, B, C)

- **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

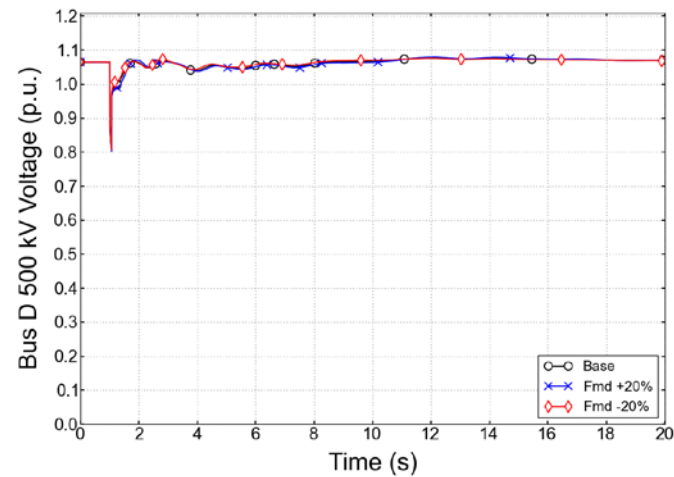
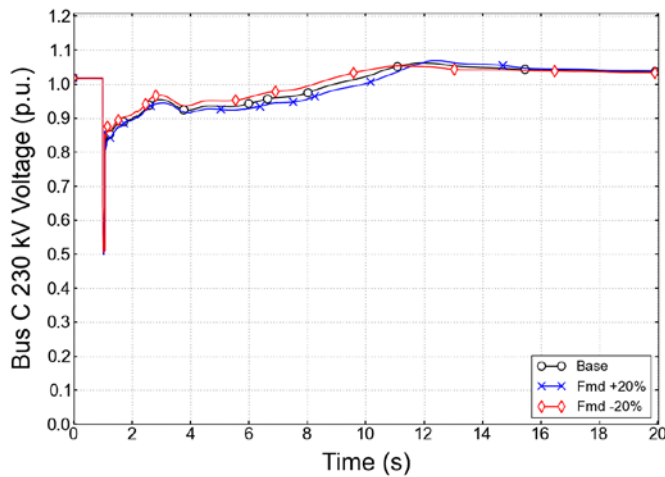
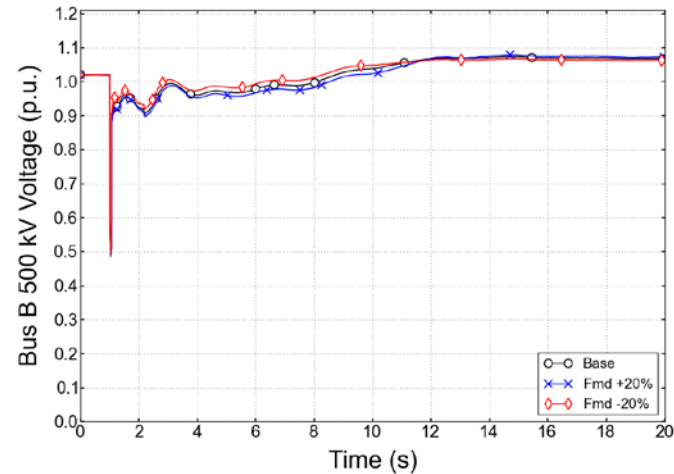
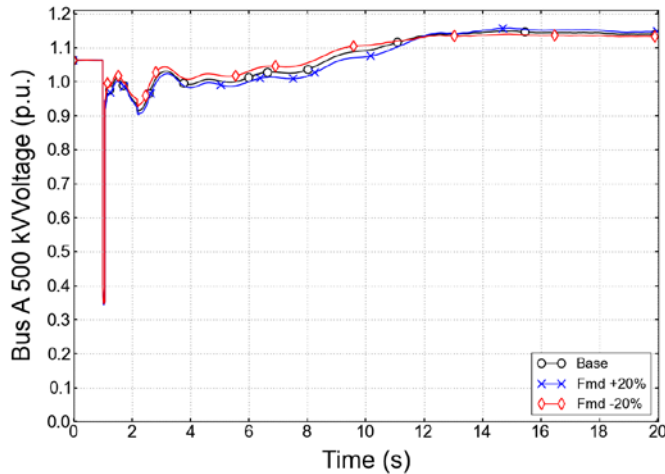
Ref. No.	Description of Parameter	Phase 1	Phase 2		
			Base Value as given in dyd/dyr	Minimum Value	Maximum Value
1	Vstall, Stall voltage, p.u.	0.5	0.5	0.3	0.8
2	Tstall, Stall time delay, sec.	9999	0.033	0.01667	0.25
3	Vc1off, Contactor voltage at which tripping starts, p.u.	0.5	0.5	0.3	0.7
4	Vc2off, 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, p.u.	0.6	0.6	0.4	0.8
6	Vc2on, Contactor voltage at which reconnection starts, p.u.	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

Notes:

1. Contactor settings (Vc1off, Vc2off, Vc1on, Vc2on) are changed simultaneously.
2. Motor fraction (FmA, FmB, FmC, FmD) base values are examples. Load fractions vary from load to load in the base case.

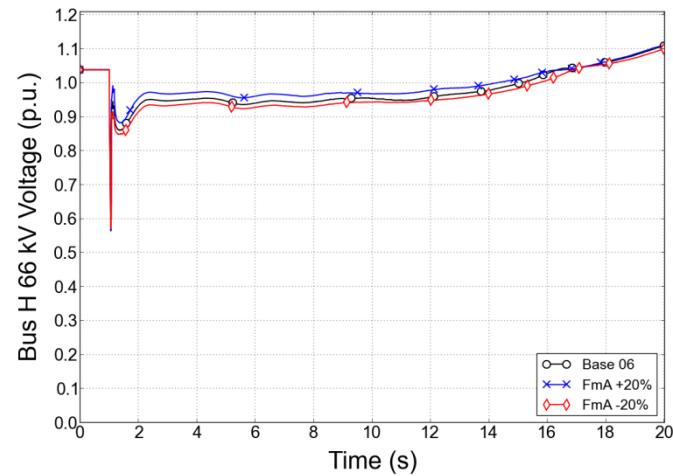
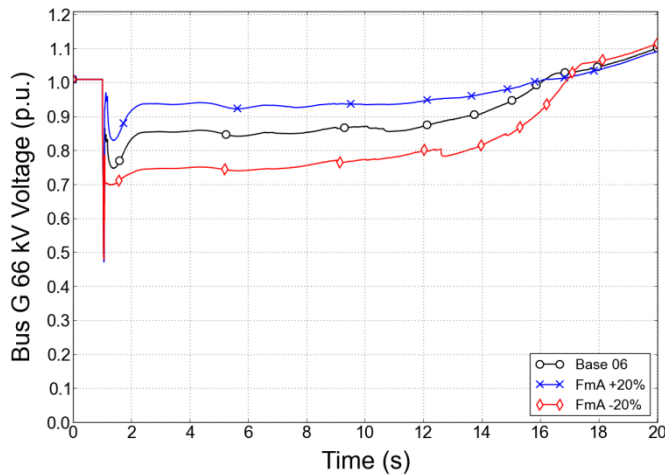
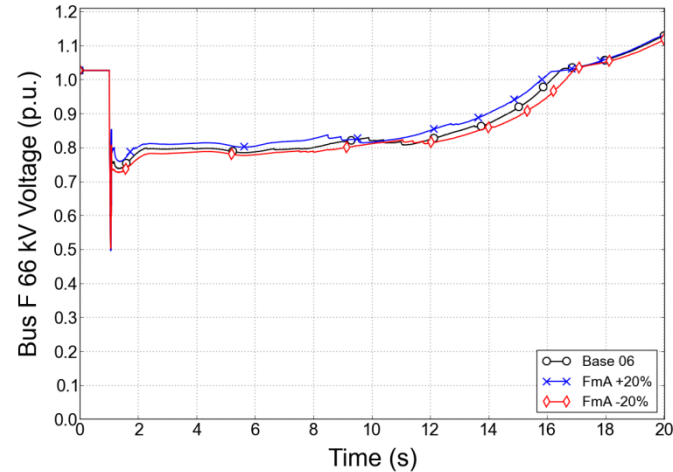
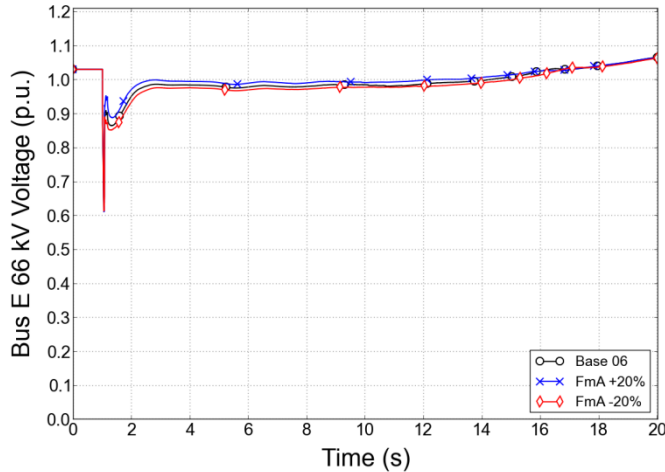
FmD (Voltages)

Contingency 14: Fmd



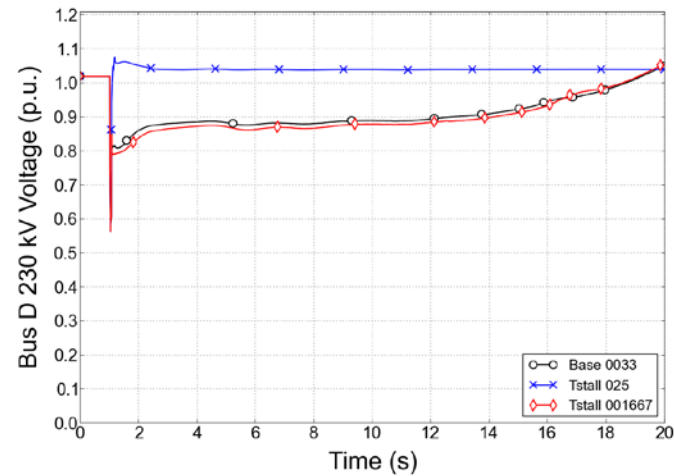
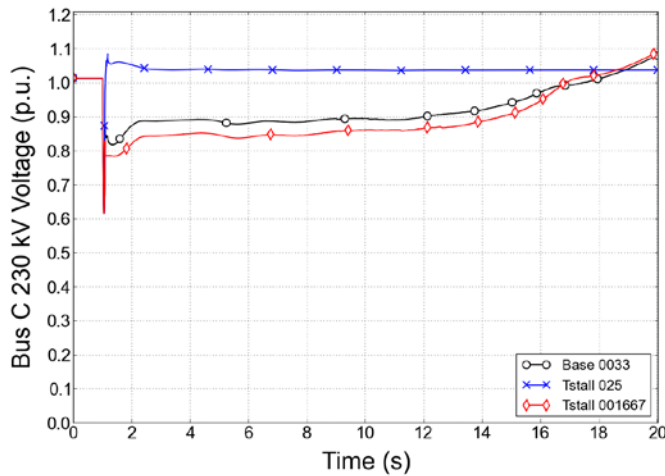
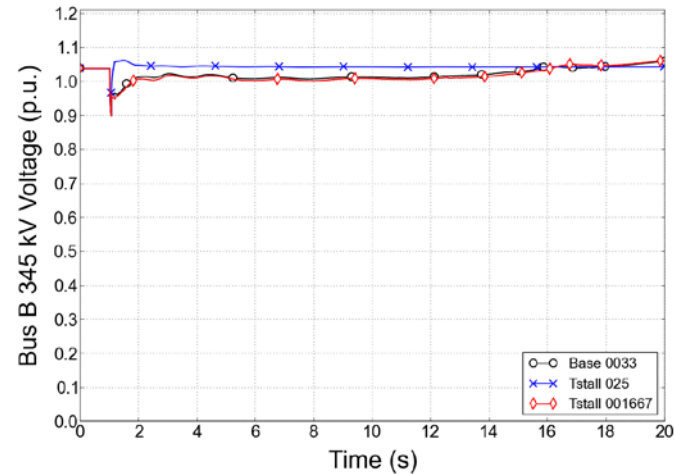
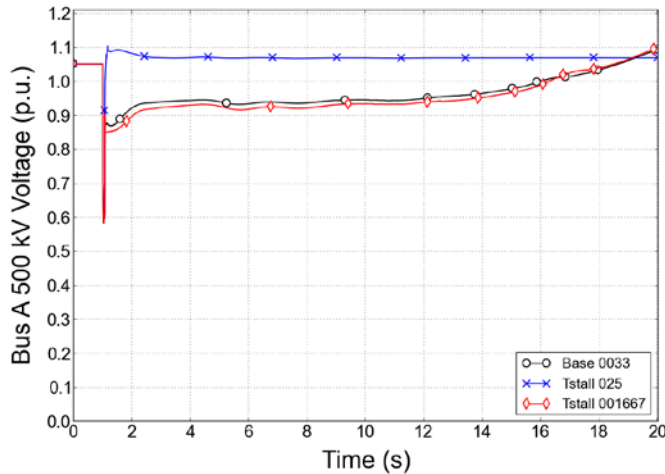
FmA (Voltages)

Contingency 15: FmA



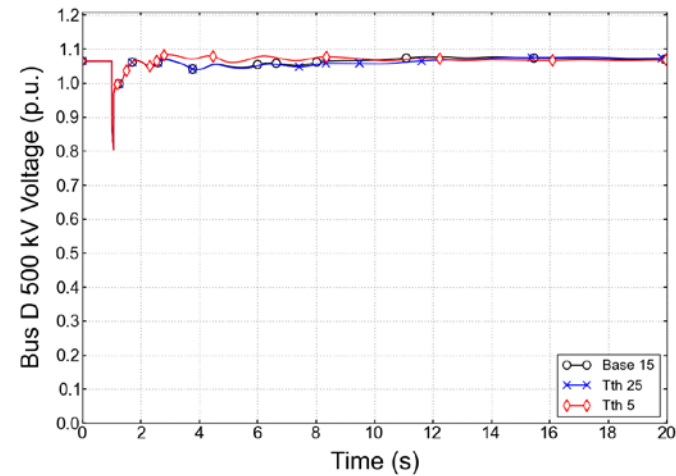
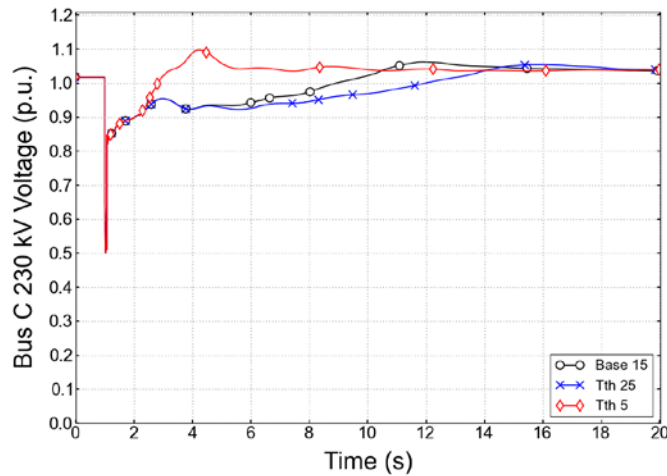
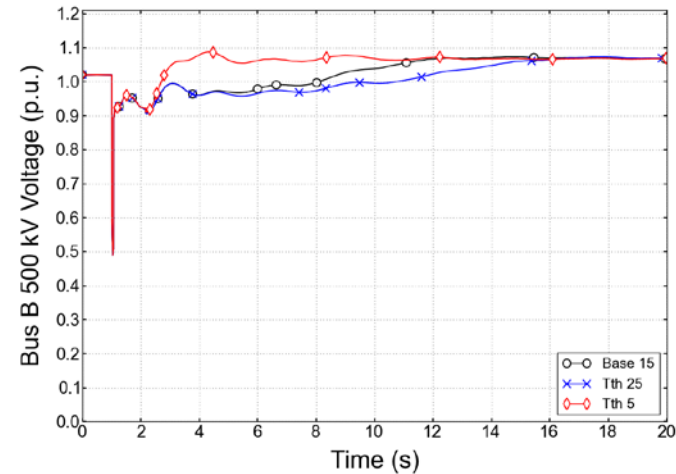
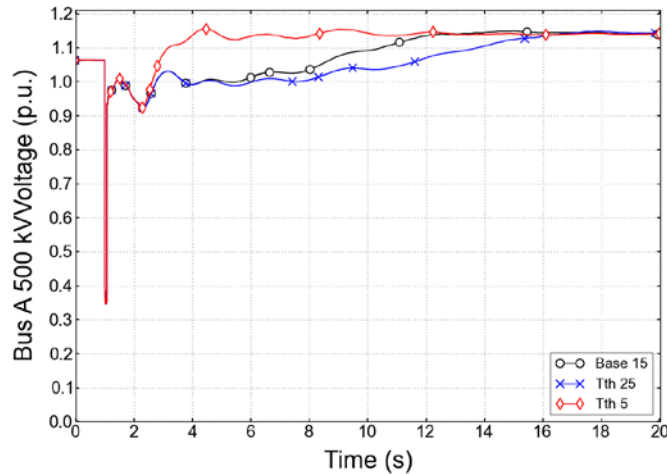
Tstall (Voltages)

Contingency 15: Tstall



Tth (Voltages)

Contingency 14: Tth



Sensitivity Metrics

- **Observations based on voltage recovery, generator stability**
 - **Flag bus voltages and generators based on study thresholds**
- **Compare the number of observations to the Phase 2 Base Case ($T_{stall} = 0.033$)**
- **Relative number and type of observations provides a sensitivity for each parameter**
 - **Voltage response (fast vs. slow)**
 - **Generator angles (transient stability, damping ratios)**
- **Compute overall sensitivities by aggregating all contingencies**

Study Criteria (Thresholds)

- **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**
 - **Voltage greater than 1.1 p.u, or greater than 1.05 p.u. for 5 seconds or longer.**
- **Any non-consequential load loss (total load loss to be calculated)**
- **Any generator that loses synchronism**
- **Damping ratio sensitivities (stressed cases)**

Sensitivity Results – Utility A (1)

Ref. No.	Variable	Setting	Voltage < 70% in 1 second		Voltage < 80% in 3 seconds		Voltage < 90% in 5 seconds		Voltage overshoot over 1.1 p.u.	
			# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)
1	Phase 2	-	78	-	1011	-	4506	-	3194	-
2	Fel	-20%	22	-72%	946	-6%	4450	-1%	2503	-22%
3		+20%	164	110%	1035	2%	4715	5%	3634	14%
4	FmA	-20%	19	-76%	1255	24%	5150	14%	2153	-33%
5		+20%	211	171%	882	-13%	4151	-8%	4582	43%
6	FmB	-20%	20	-74%	1043	3%	4631	3%	2523	-21%
7		+20%	151	94%	1049	4%	4392	-3%	3480	9%
8	FmC	-20%	22	-72%	1076	6%	4552	1%	2811	-12%
9		+20%	101	29%	1005	-1%	4558	1%	3466	9%
10	FmD	-20%	19	-76%	415	-59%	2928	-35%	2015	-37%
11		+20%	219	181%	1623	61%	5504	22%	3829	20%
12	Frst	0	78	0%	1011	0%	4518	0%	3302	3%
13	(0.2)	1	78	0%	1011	0%	4518	0%	2930	-8%
14	Fuvr	0	78	0%	1472	46%	5637	25%	2571	-20%
15	(0.1)	0.5	78	0%	27	-97%	66	-99%	6428	101%
16	Th1t	0.4	78	0%	1011	0%	4432	-2%	3199	0%
17	(0.7)	0.9	78	0%	1011	0%	4506	0%	3142	-2%
18	Th2t	1	78	0%	1011	0%	4505	0%	5196	63%
19	(1.2)	3	78	0%	1011	0%	4506	0%	1406	-56%

Notes:

1. Phase 2 base case values are shown in parentheses under each parameter.

Sensitivity Results – Utility A (2)

Ref. No.	Variable	Setting	Voltage < 70% in 1 second		Voltage < 80% in 3 seconds		Voltage < 90% in 5 seconds		Voltage overshoot over 1.1 p.u.	
			# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)
20	Trst (0.3)	0.1	78	0%	1011	0%	4518	0%	3176	-1%
21		1	78	0%	1011	0%	4518	0%	3265	2%
22	Tstall (0.033)	0.25	78	0%	27	-97%	62	-99%	8600	169%
23		0.01667	210	169%	5404	435%	13919	209%	8121	154%
24	Tth (15)	5	78	0%	1011	0%	4148	-8%	5948	86%
25		25	78	0%	1011	0%	4506	0%	2668	-16%
26	Ttr1 (0.02)	0.25	78	0%	1452	44%	5578	24%	2674	-16%
27		0.01667	78	0%	1020	1%	4501	0%	3292	3%
28	Vc1off (0.5)	0.7	18	-77%	133	-87%	3392	-25%	3599	13%
29		0.3	148	90%	2693	166%	7498	66%	3815	19%
30	Vrst (0.95)	1	78	0%	1011	0%	4518	0%	3276	3%
31		0.5	78	0%	340	-66%	3477	-23%	3049	-5%
32	Vstall (0.5)	0.3	78	0%	27	-97%	171	-96%	7688	141%
33		0.8	4822	6082%	32667	3131%	49106	990%	25291	692%
34	Vtr1 (0.6)	0.4	78	0%	1385	37%	5622	25%	2588	-19%
35		0.8	20	-74%	999	-1%	4763	6%	3179	0%

Notes:

1. Phase 2 base case values are shown in parentheses under each parameter.
2. Contactor settings (Vc1off, Vc2off, Vc1on, Vc2on) are changed simultaneously. (Ref. No. 28 and 29)

Sensitivity Results – Utility B (1)

Ref. No.	Variable	Setting	Voltage < 70% in 1 second		Voltage < 80% in 3 seconds		Voltage < 90% in 5 seconds		Voltage overshoot over 1.1 p.u.	
			# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)
1	Phase 2	-	10770	-	17866	-	23250	-	6717	-
2	Fel	-20%	10327	-4%	16271	-9%	21092	-9%	6160	-8%
3		+20%	10938	2%	19003	6%	24204	4%	7974	19%
4	FmA	-20%	11351	5%	16923	-5%	21160	-9%	4150	-38%
5		+20%	9818	-9%	18353	3%	24147	4%	9589	43%
6	FmB	-20%	9493	-12%	14016	-22%	17921	-23%	5018	-25%
7		+20%	11067	3%	19909	11%	25915	11%	8243	23%
8	FmC	-20%	10485	-3%	16572	-7%	21099	-9%	5838	-13%
9		+20%	10845	1%	18707	5%	23906	3%	7813	16%
10	FmD	-20%	8219	-24%	12982	-27%	17528	-25%	14550	117%
11		+20%	11259	5%	17608	-1%	23858	3%	1741	-74%
12	Frst	0	10770	0%	17910	0%	23220	0%	6478	-4%
13	(0.2)	1	10770	0%	17870	0%	23182	0%	7928	18%
14	Fuvr	0	12235	14%	22019	23%	26668	15%	2533	-62%
15	(0.1)	0.5	2899	-73%	3916	-78%	7354	-68%	15373	129%
16	Th1t	0.4	10770	0%	17884	0%	23243	0%	21466	220%
17	(0.7)	0.9	10770	0%	17851	0%	23183	0%	1062	-84%
18	Th2t	1	10770	0%	17880	0%	23254	0%	31083	363%
19	(1.2)	3	10770	0%	17862	0%	23252	0%	185	-97%

Notes:

1. Phase 2 base case values are shown in parentheses under each parameter.

Sensitivity Results – Utility B (2)

Ref. No.	Variable	Setting	Voltage < 70% in 1 second		Voltage < 80% in 3 seconds		Voltage < 90% in 5 seconds		Voltage overshoot over 1.1 p.u.	
			# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)
20	Trst (0.3)	0.1	10770	0%	17851	0%	23234	0%	6961	4%
21		1	10550	-2%	17634	-1%	23148	0%	6818	2%
22	Tstall (0.033)	0.25	3439	-68%	24	-100%	30	-100%	9206	37%
23		0.01667	14448	34%	25039	40%	30774	32%	12215	82%
24	Tth (15)	5	10769	0%	17852	0%	23181	0%	29807	344%
25		25	10770	0%	17829	0%	23246	0%	185	-97%
26	Ttr1 (0.02)	0.25	12235	14%	21227	19%	26173	13%	9984	49%
27		0.01667	10896	1%	18238	2%	23555	1%	7056	5%
28	Vc1off (0.5)	0.7	2791	-74%	3248	-82%	9387	-60%	13917	107%
29		0.3	17262	60%	29810	67%	33771	45%	1764	-74%
30	Vrst (0.95)	1	10770	0%	17870	0%	23253	0%	6565	-2%
31		0.5	10770	0%	17939	0%	23667	2%	14915	122%
32	Vstall (0.5)	0.3	5474	-49%	2532	-86%	3466	-85%	2915	-57%
33		0.8	19832	84%	33328	87%	39705	71%	38333	471%
34	Vtr1 (0.6)	0.4	12042	12%	21813	22%	26404	14%	3602	-46%
35		0.8	10636	-1%	14462	-19%	19165	-18%	4893	-27%

Notes:

1. Phase 2 base case values are shown in parentheses under each parameter.
2. Contactor settings (Vc1off, Vc2off, Vc1on, Vc2on) are changed simultaneously. (Ref. No. 28 and 29)

Sensitivity Results – Utility C (1)

Ref. No.	Variable	Setting	Voltage < 70% in 1 second		Voltage < 80% in 3 seconds		Voltage < 90% in 5 seconds		Voltage overshoot over 1.1 p.u.	
			# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)
1	Phase 2	-	2127	-	2025	-	3092	-	2680	-
2	Fel	-20%	2097	-1%	2087	3%	3050	-1%	2370	-12%
3		+20%	2132	0%	2170	7%	3289	6%	2875	7%
4	FmA	-20%	2322	9%	2256	11%	3554	15%	2657	-1%
5		+20%	1925	-9%	1959	-3%	3021	-2%	2946	10%
6	FmB	-20%	2066	-3%	1990	-2%	2993	-3%	2373	-11%
7		+20%	2150	1%	2246	11%	3362	9%	2934	9%
8	FmC	-20%	2106	-1%	2016	0%	3059	-1%	2493	-7%
9		+20%	2096	-1%	2100	4%	3232	5%	2793	4%
10	FmD	-20%	1960	-8%	1524	-25%	2616	-15%	1846	-31%
11		+20%	2137	0%	2297	13%	3311	7%	2485	-7%
12	Frst (0.2)	0	2127	0%	2020	0%	3104	0%	2733	2%
13		1	2127	0%	2019	0%	3088	0%	2670	0%
14	Fuvr (0.1)	0	2433	14%	2738	35%	4075	32%	2655	-1%
15		0.5	1332	-37%	359	-82%	920	-70%	4248	59%
16	Th1t (0.7)	0.4	2128	0%	2018	0%	3058	-1%	2778	4%
17		0.9	2128	0%	2019	0%	3094	0%	1825	-32%
18	Th2t (1.2)	1	2127	0%	2019	0%	3096	0%	5426	102%
19		3	2128	0%	2019	0%	3094	0%	174	-94%

Notes:

1. Phase 2 base case values are shown in parentheses under each parameter.

Sensitivity Results – Utility C (2)

Ref. No.	Variable	Setting	Voltage < 70% in 1 second		Voltage < 80% in 3 seconds		Voltage < 90% in 5 seconds		Voltage overshoot over 1.1 p.u.	
			# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)	# of Buses	Delta (% change)
20	Trst (0.3)	0.1	2127	0%	2019	0%	3096	0%	2624	-2%
21		1	2127	0%	2019	0%	3096	0%	2736	2%
22	Tstall (0.033)	0.25	1264	-41%	106	-95%	59	-98%	5079	90%
23		0.01667	2882	35%	3104	53%	5100	65%	4877	82%
24	Tth (15)	5	2127	0%	2010	-1%	2905	-6%	5361	100%
25		25	2127	0%	2019	0%	3097	0%	204	-92%
26	Ttr1 (0.02)	0.25	2432	14%	2676	32%	3985	29%	3308	23%
27		0.01667	2158	1%	2065	2%	3097	0%	2679	0%
28	Vc1off (0.5)	0.7	1101	-48%	559	-72%	1291	-58%	2992	12%
29		0.3	3165	49%	3663	81%	5533	79%	3580	34%
30	Vrst (0.95)	1	2127	0%	2019	0%	3096	0%	2722	2%
31		0.5	2125	0%	1898	-6%	3042	-2%	2156	-20%
32	Vstall (0.5)	0.3	1748	-18%	264	-87%	418	-86%	3578	34%
33		0.8	4271	101%	6946	243%	10086	226%	8070	201%
34	Vtr1 (0.6)	0.4	2415	14%	2726	35%	4126	33%	2804	5%
35		0.8	2369	11%	2140	6%	3500	13%	3152	18%

Notes:

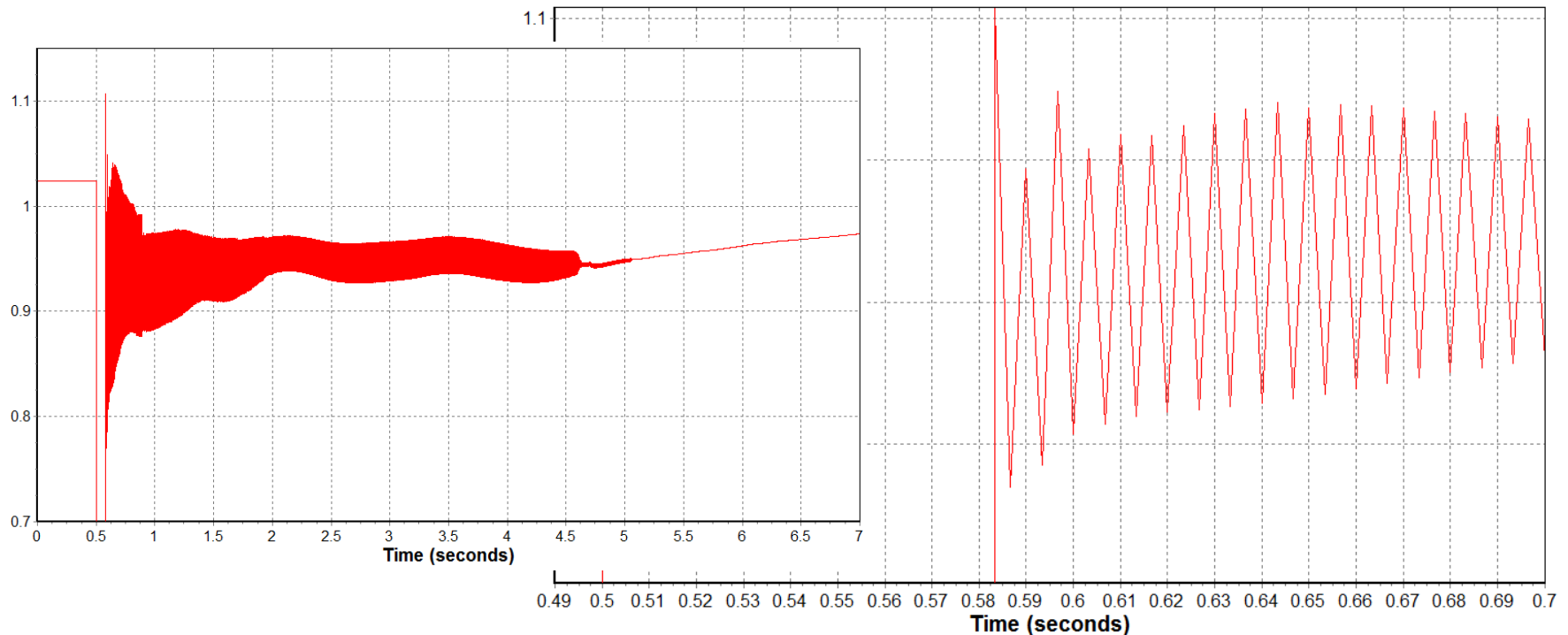
1. Phase 2 base case values are shown in parentheses under each parameter.
2. Contactor settings (Vc1off, Vc2off, Vc1on, Vc2on) are changed simultaneously. (Ref. No. 28 and 29)

Overall Summary

- **Observed similar results for all sets of data (SRP, SCE, PG&E, PacifiCorp)**
- **Important parameters across all four utilities studied:**
 - **Tstall and Vstall**
 - **Vc1on/Vc2on and Vc1off/Vc2off (Motor D contactor)**
 - **FmD**
 - **Tth**
 - **Th1t**
 - **Th2t**
 - **Fuvr**
 - **Vrst**

Other Observations

- Switching behavior can cause “hunting”
 - Example: Motor D contactors:



Next Steps

- **Discuss results with each Transmission Provider**
 - **Summary of results and sensitivity tables**
 - **Detailed results for each contingency can be provided**
 - **Select contingencies for more detailed analysis**
 - **Criteria for selecting contingencies to be documented**

- **Next stage of the study**
 - **Examine stressed case provided**
 - **Perform more in-depth sensitivity study on Motor D parameters**
 - **Sensitivity analysis on additional model parameters**
 - **Study results to be presented at November WECC LMTF meeting in Salt Lake City, UT**