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Xcel Energy

Missile Site Area
Reactive Power Study

Final Report

REP-0480
Revision #00

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Submitted By:
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Title:	**Missile Site Wind Integration Reactive Power Study: Final Report REP-0480, Revision #00**	
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EXECUTIVE SUMMARY

INTRODUCTION

In 2018, Xcel Energy received approval from the Colorado Public Utilities Commission (PUC) to proceed with its Colorado Energy Plan (CEP). The CEP includes the retirement of two coal-fired plants, adding more than 1100 MW of wind generation, more than 700 MW of solar generation, and 275 MW of battery storage. Of the 1100 MW of wind generation, an additional 800 MW will be added to the Rush Creek Gen-Tie (Gen-Tie), bringing the total wind generation connected to the radial line to 1400 MW. To accommodate the additional 800 MW, the Gen-Tie, which is an 83 mile radial 345 kV transmission circuit from Missile Site 345 kV Substation, will be extended by approximately 87 additional miles. The Gen-Tie currently interconnects the 600 MW Rush Creek Wind Project, which consists of the Rush Creek I 380 MW collector station at the Pronghorn 345 kV substation and terminates at the Rush Creek II 220 MW collector station. To accommodate the additional wind plants a new switching station will be built at the existing end of the line creating the Shortgrass switching station, near Rush Creek II. The Rush Creek II and three new wind collector stations (Bronco Plains, Cheyenne Ridge West, and Cheyenne Ridge East) will be connected to the Shortgrass switching station via a 73 mile and a 14 mile radial line.

The objective of the "Missile Site Area Reactive Power Study" is to examine the impact of CEP Portfolio (CEPP) of generation by evaluating the voltage performance of the planned system with the extended radial transmission line and additional wind generation, and provide a baseline for the minimum necessary reactive compensation requirements for the local (in and around Missile Site) system. Steady-state and transient stability analyses were performed to determine the minimum amount of steady-state and dynamic reactive compensation needed to interconnect the CEPP generation, focusing on the new wind generation connected to the Gen-Tie. The following tasks were performed to determine the impact of the new generation:

- Task 1: Ferranti Effect Overvoltage Analysis of the Gen-Tie
- Task 2: Steady-State Contingency Analysis
- Task 3: Time Domain Transient Stability Analysis
- Task 4: PV and QV Analysis
- Task 5: Sensitivity Analysis

Additional studies are recommended to evaluate the steady-state and dynamic performance of manufacturer-specific wind turbine generators (including their collector systems) and dynamic reactive power compensation devices.

OVERALL RECOMMENDATIONS

Study results were evaluated using Standards developed by the North American Electric Reliability Council (NERC) and criteria developed by WECC. The following are recommendations based on the analysis presented in this report:

(1) Shunt reactors are needed to control the high voltages along the Gen-Tie line under low/no generation conditions. The following is recommended:
   a. 2x30 Mvar of static shunt reactive compensation at Shortgrass 345 kV
(2) Capacitive compensation is needed to control low voltages on the Gen-Tie and the local system that ties the Gen-Tie to the Denver-metro area. Compensation should be added at the following locations: (Note all reactive compensation was sized to meet minimum WECC criterion.)
   a. Daniels Park 345 kV: 115 Mvar of steady-state capacitive compensation
   b. Harvest Mile 345 kV: 115 Mvar of steady-state capacitive compensation
   c. Missile Site 345 kV: 300 Mvar of steady-state capacitive compensation
   d. Pronghorn 345 kV: 130 Mvar of total capacitive compensation
      i. 80 Mvar of steady-state capacitive compensation
      ii. +/-50 Mvar dynamic reactive compensation (minimum)
(3) The dynamic stability analysis performed in this report assumed the wind plants along the Gen-Tie were capable of operating in the low short-circuit strength conditions observed during this study.
   a. It is recommended Xcel Energy provide the N-0, minimum N-1 (loss of the single branch with the highest short-circuit contribution), and minimum N-2 (loss of the two branches with the highest short-circuit contribution) fault current at the 345 kV terminals of the wind plants to the plant developer/wind turbine manufacturer for confirmation of the ability of the wind plants to operate at the identified system strengths and guidance in the tuning of their power plant and wind turbine controls.
(4) It is recommended Xcel Energy confirms the voltage and frequency ride through settings of the following generators to ensure accurate modeling representation:
   a. Cedar Point
   b. Peetz Logan 1
(5) It is recommended Xcel Energy review the steady-state and dynamic reactive power limits of the following generators:
   a. Titan Solar
   b. Cedar Point
   c. Comanche
   d. Pawnee

e. Peetz Logan 4

SUMMARY OF ANALYSES

Ferranti Effect Overvoltage Analysis

A Ferranti effect overvoltage analysis was performed to determine if the existing/planned shunt reactors along the Gen-Tie line are sufficient to control the voltage to within equipment Maximum Continuous Operating Voltage (MCOV). The objective of the "Ferranti Effect Overvoltage Analysis" was to examine the worst case operating scenario for steady-state overvoltages, where the Missile Site gen-tie line is energized without any of the wind plants on-line. The following are the findings:

- It was determined the charging associated with the Gen-Tie line could cause a maximum steady-state change in voltage at Missile Site 345 kV of 2.1% without shunt compensation along the gen-tie line.
- When considering the existing 3x23 Mvar reactors at Rush Creek I 34.5 kV and the 2x24 Mvar reactors at Rush Creek II 34.5 kV, the entire Gen-Tie line can be energized as long as the Missile Site 345 kV bus voltage can be regulated to less than or equal to 354.4 $kV_{L-L,RMS}$ (1.027 p.u.) before energizing the Gen-Tie line.
- Two 30 Mvar shunt reactors at Shortgrass 345 kV will provide Xcel with operational flexibility to operate the Gen-Tie line under no power flow scenarios without relying on the shunt reactors at the 34.5 kV terminals of Rush Creek I and II.

Steady-State Analysis

A steady-state analysis was performed to determine the amount of steady-state reactive power compensation needed to accommodate the CEPP generation, including the Gen-Tie line extension and interconnection of additional wind generation to the Gen-Tie while still meeting WECC planning criterion. N-0, N-1, and stuck breaker contingencies at and around Missile Site were examined. All contingencies that resulted in non-convergence, thermal overloads, or voltage criteria violations were flagged. The following are the findings:

- When considering heavy summer peak loading and maximum (1400 MW) wind generation, significant amounts of steady-state shunt capacitive compensation was needed to meet WECC voltage criteria for base case (N-0) conditions.
  - It was determined the steady-state reactive power compensation identified for base case conditions was sufficient for the N-1 and stuck breaker contingencies examined.

Table ES-1 shows a summary of the existing shunt compensation included in this analysis. Table ES-2 shows the recommended minimum reactive power compensation. Note this is the minimum needed to satisfy the WECC voltage criterion for the heavy summer and light spring case (0 MW and 1400 MW dispatch) for base case (N-0) and N-1/stuck breaker conditions.

Table ES-1
Existing Reactive Power Support Included for this Analysis

Case Name	Pre-Existing Static Support (Mvar)						
	Missile Tap 230 kV (70621)	Missile Cap 345 kV (88888)	Missile Site 345 kV (70624)	Limon I 345 kV (70625)	Daniels Park 345 kV (70601)	Rush Creek W1 34.5 kV (70629)	Rush Creek W2 34.5 kV (70631)
Light Spring – High wind – Gen-Tie 1400 MW	90	50	0	0	0	130.2	51
Light Spring – High wind – Gen-Tie 1600 MW	150	50	0	0	0	130.2	51
Light Spring – High wind – Gen-Tie 0 MW	0	0	0	0	-40	-69	-48
Heavy Summer – High wind – Gen-Tie 1400 MW	150	50	0	40	0	130.2	51
Heavy Summer – High wind – Gen-Tie 1600 MW	150	50	0	40	0	130.2	51
Heavy Summer – High wind – Gen-Tie 0 MW	50	0	-60	0	0	-69	-48

Table ES-2
Additional Reactive Power Support Needed for Base Case (N-0), N-1, and Stuck Breaker Conditions

Additional Static Support (Mvar)			
Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
115	115	130	300

Transient Stability Analysis

A transient stability analysis was performed to determine the need for dynamic reactive compensation to accommodate the increase in wind generation along the Gen-Tie, or if the fixed/mechanically switched reactive compensation identified as necessary in the steady-state analysis is able to adequately provide the reactive support required by the system during dynamic events. Limiting contingencies identified in the steady-state analysis were examined, and all contingencies that resulted in non-convergence, delayed voltage recovery, voltage criteria violations, or system instability were reported. The following are the findings:

- Without any dynamic reactive support, the system remained stable, no delayed voltage recovery was observed, and all bus voltages recovered between 0.90 p.u. and 1.10 p.u. However, oscillations of concern were observed for several contingencies. It is anticipated these oscillations are caused by the weak interconnection point and controllability of the power plant controllers of the inverter-based wind generation plants of interest.
- With the addition of a +/- 50 Mvar Static Var Compensator (SVC) at the Pronghorn 345 kV bus oscillations of concern were significantly improved.
    - Note the steady-state analysis (Section 3) determined that a minimum of 130 Mvars of reactive power support was required at the Pronghorn 345 kV bus. The reactive compensation can be installed as a combination of static and dynamic support. This

study examined a +/- 50 Mvar SVC as minimum dynamic compensation, but other combinations of the reactive compensation can be used as a form of mitigation. For example, the size of the dynamic compensation can be increased and the static compensation can be decreased as long as the net compensation is at least 130 Mvar.

- The notable improvement in oscillation damping represents the significant contribution of the SVC to voltage regulation on the Gen-tie line. Actual performance of the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants under weak grid conditions may be worse than idealized stability models indicate, therefore additional dynamic reactive compensation beyond the +/- 50 Mvar SVC would be highly beneficial to regulate voltage along the tie line.
- The stability models used in this study represent idealized wind plant performance and do not capture the potential reduced controllability and possible degraded performance under weak grid conditions as experienced by the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants. Tuning the wind plants for weak grid conditions will typically result in slower performance, reducing the contribution of the wind plants to voltage regulation, especially during the critical post fault recovery period. Before the wind plants are finalized and the necessary system compensation is finalized by Xcel Energy, it is recommended Xcel Energy work closely with the wind turbine manufacturers to evaluate wind plant dynamic performance using detailed OEM "user-models" of the wind turbine generators adequate for the low short-circuit ratio observed along the Missile Site Gen-Tie line under actual conditions. It is recommended that key cases from this analysis are re-examined with specific user-models to evaluate impacts on the required system compensation.

Sensitivity analyses were performed in the time domain to provide insight to the dynamic analysis results. The following sensitives were examined and provided the following insight:

- Wind Plant Controller AVR (REPCA) Gain Sensitivity
    - As a sensitivity, several different integral and proportional gains were examined to determine if the instability observed for the limiting N-1 contingency (loss of the Missile Site – Smoky Hill 345 kV line) was caused by poorly tuned gains or another underlying issue.
    - It was observed the plant controller gains had a significant impact on stability of the system. The low short-circuit strength at the plants under evaluation in this study should be considered during the control tuning studies performed by the plant developers/wind turbine manufacturer.
- Steady-State versus Dynamic Discrepancies
    - It was observed less shunt compensation was required to maintain WECC post contingency steady-state voltage limits in the dynamic analysis than in the steady-state analysis.

  - It was observed several nearby generators were able to provide reactive support in the time domain in excess of their steady-state limits, this increased short-term reactive support allowed the network solution to converge with less additional dynamic support required.
  - It is recommended Xcel Energy confirms the following units have the expected reactive power capability to ensure the needed reactive power support is available:
    - Titan Solar
    - Cedar Point
    - Comanche
    - Pawnee
    - Peetz Logan 4
- Most Severe Single Contingency: Frequency Excursion Study
  - This analysis evaluated transient stability as measured by frequency excursions for the N-1 condition when the full 1400 MW of generation drops offline (the loss of the Pronghorn – Missile Site 345 kV line).
  - No frequency excursions of concern or transient stability issues were observed for PSCo's Balancing Authority Area 70.

PV/QV Analysis

A PV and QV analysis was performed to determine the transfer capability and reactive power margin of load serving buses in the Missile Site area. The PV analysis was used to determine the transfer capability and determine if active power margins exist in the study area. The QV analysis was used to determine the reactive power margins and determine if sufficient reactive power exists for the buses with the criteria outlined by Xcel and WECC for the Missile Site area.

- The PV analysis shows there is minimal acceptable active power margin with the recommended reactive power devices.
  - From the PV analysis it was determined for base case conditions there is less than a 100 MW margin until base case voltage criteria is not met (bus voltages are below 0.95 p.u.).
  - From the PV analysis it was determined for the limiting contingency there is a 20 MW margin until case divergence issues were observed.
- The QV analysis at the Pronghorn 345 kV bus shows there is minimal acceptable reactive power margin with the recommended reactive power devices.
  - The QV analysis shows for base case conditions, there is a minimal amount of reactive power support at Pronghorn 345 kV for the minimum voltage requirement (0.95 p.u.), but there is less than 38 Mvar of reactive power margin.
  - The QV analysis shows for the limiting contingency, there is a minimal amount of reactive power support at Pronghorn 345 kV for the minimum voltage requirement (0.90 p.u.), but there is less than 27 Mvar of reactive power margin.

Sensitivity Analyses

Sensitivity analyses were performed in the time domain to provide insight to the dynamic analysis results. The following sensitivities were examined and provided the following insight:

- N-2 Outage Sensitivity
  - The limiting N-2 contingency, the loss of the Missile Site – Smoky Hill and Missile Site – Daniels Park 345 kV sharing a common structure resulted in thermally overloaded lines/transformers and potential voltage collapse. It was determined shunt compensation was not a feasible mitigation option for the limiting N-2 case because of the thermal overloads in Xcel Energy's 230 kV system.
  - It is recommended Xcel further investigate mitigation techniques for the limiting N-2 contingency by a transmission solution or transfer trip scheme.
- Reduced Dispatch Sensitivity
  - The steady-state analysis and the dynamic analysis determined static compensation is needed to meet WECC voltage criteria for base case and contingency conditions with the wind generation along the Gen-Tie line at 1400 MW. The objective of the reduced dispatch analysis was to analyze the impact of reduced generation levels along the Gen-Tie to determine the effect of power transfer on the need for reactive power compensation.
    - It was determined if the generation is reduced to 1200 MW, an additional 70 Mvar of static compensation is needed at Daniels Park to meet WECC Criterion for base case (N-0), N-1, and stuck breaker conditions.
    - It was determined if the generation is reduced to 1000 MW, no additional static compensation is needed to meet WECC Criterion for base case (N-0), N-1, and stuck breaker conditions.

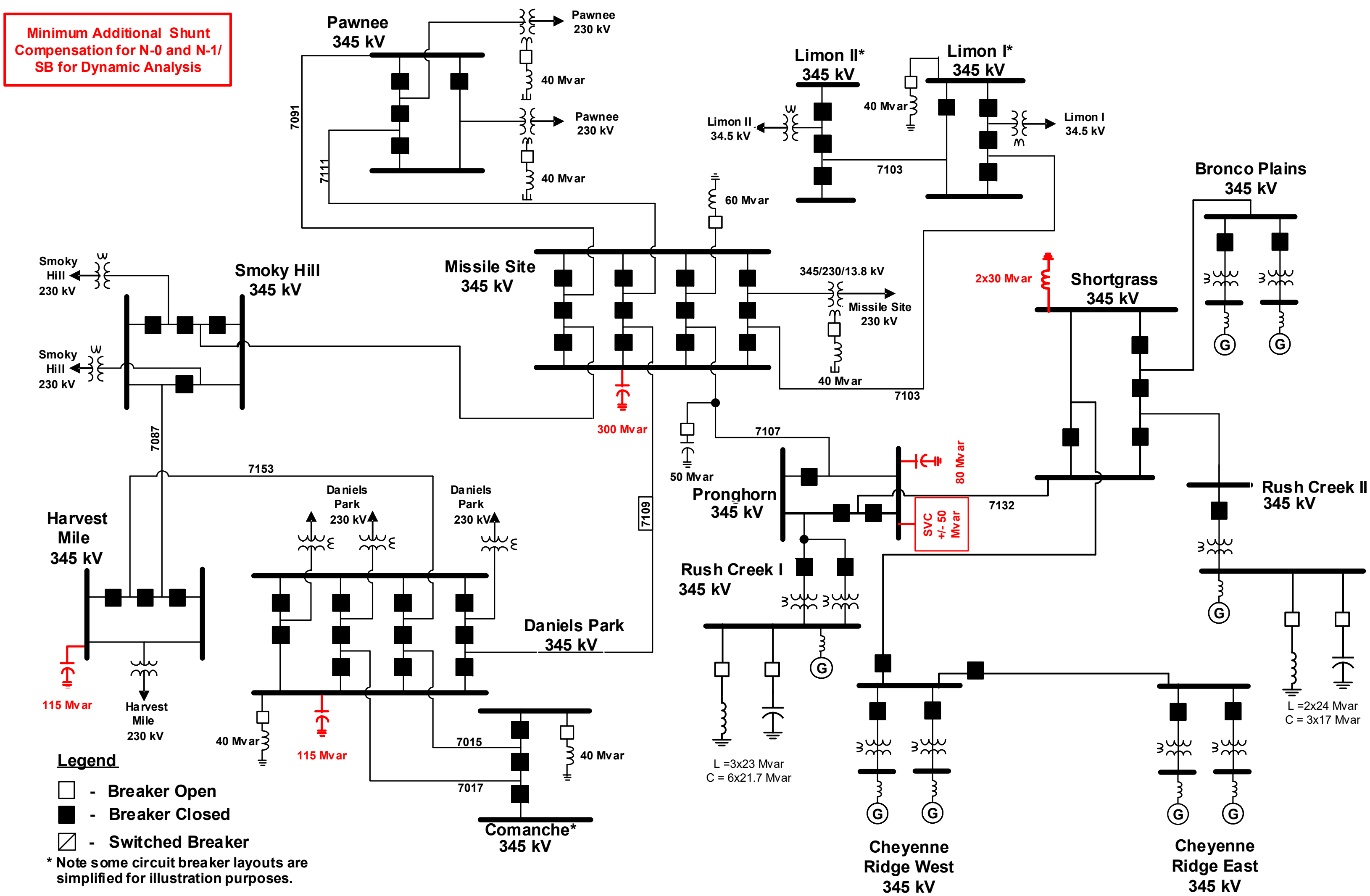

Figure ES-1. One-line diagram of the wind generation and immediate study area with recommended static and dynamic reactive power compensation.

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SECTION 1
MODEL DEVELOPMENT

1.1 Background and Introduction

The purpose of this study is to evaluate the voltage performance of the planned system with the longer radial transmission line and additional wind generation, and provide a baseline for the minimum necessary reactive compensation requirements for the local system. Standard power system engineering software programs were used for the analysis, including steady-state (powerflow), and dynamic (transient stability), and electromagnetic transient (EMT) programs. These analyses were used to develop recommendations for steady-state and dynamic reactive compensation needed to interconnect the new wind generation to the longer transmission line.

1.2 Electromagnetic Transient Program Model

MEPPI previously performed an electromagnetic transients (EMT) study for the Pronghorn and Rush Creek II 345 kV substations in April 2017. Xcel Energy confirmed that the power system has not changed significantly since then, as such, MEPPI used the EMT model of the Xcel Energy power system that was developed for that analysis as a starting point and added the new equipment associated with the Shortgrass 345 kV substation and the Bronco Plains, Cheyenne Ridge West, and Cheyenne Ridge East wind power plants. This updated EMT model was utilized for the Ferranti Effect Overvoltage analysis portion of the study.

1.3 Steady State Models

The primary objective of the steady-state analysis is to identify potential voltage concerns per WECC Criterion. MEPPI monitored the study area (Area 70) for thermal overloads and voltage violations. Several steady state models were used to determine the impact of increased generation on the contingency events, voltage profiles, and reactive power requirements. The steady-state analysis was performed with the objective of identifying the minimum amount of reactive compensation required to mitigate voltage and thermal violations to accommodate the additional CEPP generation, focusing on the new wind generation along the Gen-Tie line.

The study area of interest was defined as powerflow Area 70. Figure 1.3-1 shows a one-line diagram of the immediate study area. The generation of interest is the wind generation connected to the radial line off the Missile Site 345 kV substation (Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains).

Ten-year heavy summer and light spring loading conditions were modeled. The models originated from WECC approved cases, and were reviewed and modified by Xcel Energy. Both cases modeled maximum and minimum wind generation on the Gen-Tie, as well as in the northern region of the PSCo system. Tables 1.3-1 and 1.3-2 show a profile of the significant generation dispatch that was modeled for the heavy summer and light spring cases.

The intent of the heavy summer demand, high renewable and low conventional dispatch was to create heavily stressed, worst-case system conditions for the development of recommendations, as is common practice for Transmission Planning studies. The intent of the light spring demand, high renewable and low conventional dispatch was to create a scenario with renewable generation serving a significant portion of the load. A similar light spring case was created with no generation on the radial Gen-Tie to simulate high voltage along the line. These cases along with the Heavy Summer Case provide an appropriate bookend analysis of stressed, worst-case high voltage or low voltage conditions, as is common practice for Transmission Planning studies.

During the course of the studies completed, MEPPI worked with Xcel Energy to update modeling data, including the Cheyenne Ridge East and Cheyenne Ridge West collector systems.

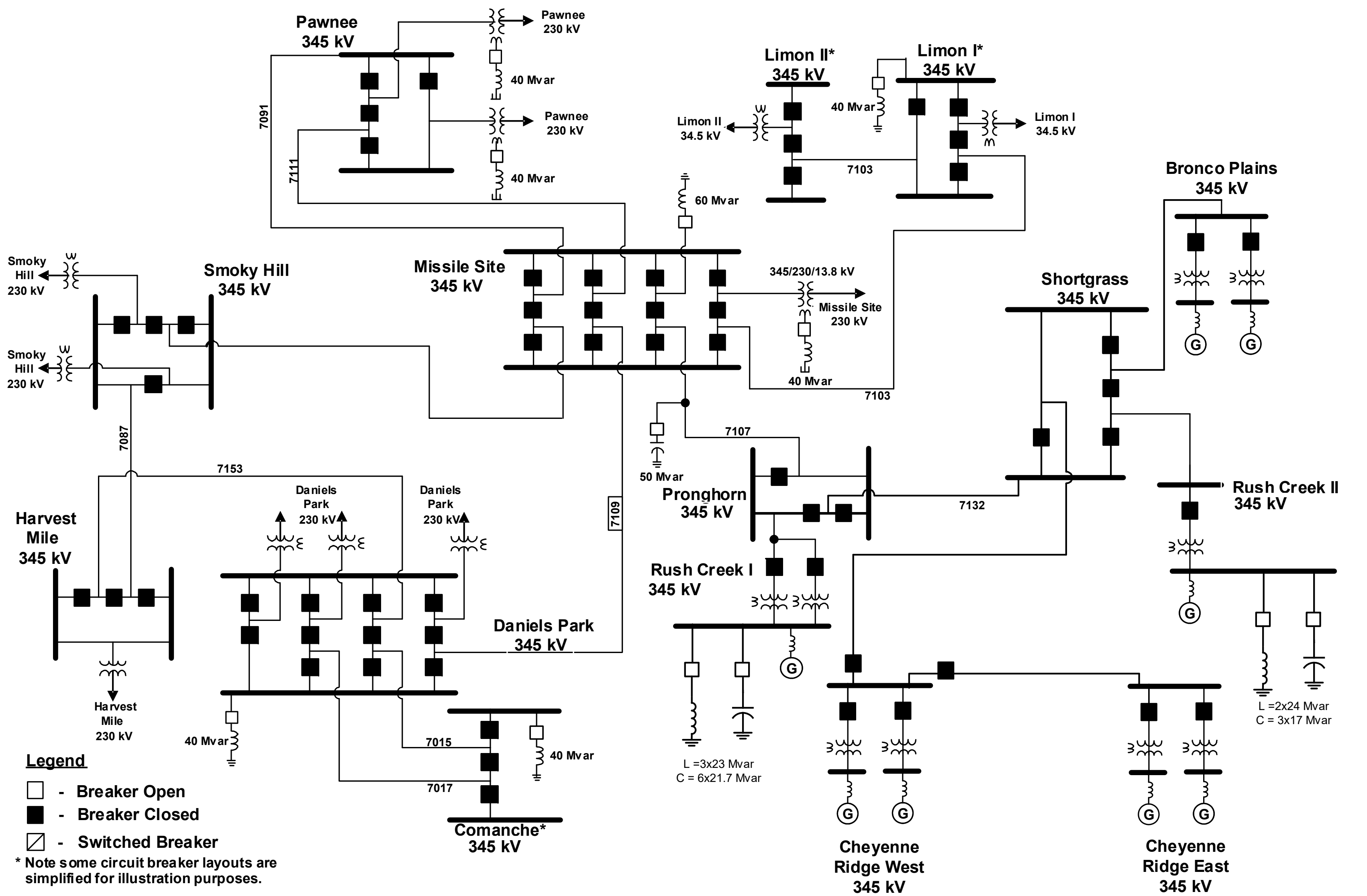


Figure 1.3-1. One-line diagram of the wind generation and immediate study area.

Table 1.3-1
Dispatch Assumptions in the Heavy Summer Case
(Missile Site & Pawnee area wind generation shown in bold)

Online Generation	Offline Generation
Wind: • **Bronco Plains 300 MW (100%)** • **Cheyenne Ridge 500 MW (100%)** • Cedar Creek 440 MW (80%) • **Cedar Point 250 MW (100%)** • Colorado Green 34 MW (21%) • Jackson Fuller 200 MW (80%) • **Limon 600 MW (100%)** • CEP W090 135/169 MW (80%) • **Peetz Logan 575 MW (100%)** • **Rush Creek 600 MW (100%)** • Spring Canyon 96 MW (80%) • Twin Butte 33 MW (21%) Solar: • Comanche: 102 MW (80%) • CEP S430 Solar: 61/72 MW (85%) • CEP X647: 212/250 MW (85%) • CEP S085: 60/75 MW (80%) • CEP X427: 94/110 MW (85%) • CEP X645: 170/200 MW (85%) • Titan: 43 MW (85%) Conventional: • Arapahoe 5, 6, 7 • Cherokee 5, 6, 7 • Comanche 3 • Fountain Valley 1, 2, 3 • Fort St Vrain 1, 2 • Pawnee • Plains End • Valmont 6	• Cherokee 4 • Comanche 1, 2 • Fort Lupton 1, 2 • Fort St Vrain 3, 4, 5, 6 • Fountain Valley 4, 5, 6 • Lamar DC • Manchief 1, 2 • RMEC 1, 2, 3 • Spindle 1, 2 • Spruce 1, 2 • Valmont 7, 8

Table 1.3-2
Dispatch Modeling in the Light Spring Case
(Missile Site & Pawnee area wind generation shown in bold)

Online Generation	Offline Generation
Wind: • **Bronco Plains 300 MW (100%)** • **Cheyenne Ridge 500 MW (100%)** • Cedar Creek 116 MW (21%) • **Cedar Point 125 MW (50%)** • Colorado Green 34 MW (21%) • Jackson Fuller 52 MW (21%) • **Limon 300 MW (50%)** • CEP W090: 33/169 MW (21%) • **Peetz Logan 287 MW (50%)** • **Rush Creek 600 MW (100%)** • Spring Canyon 42 MW (70%) • Twin Butte 41 MW (27%) Solar: • Comanche: 78 MW (65%) • CEP S430: 0 MW (0%) • CEP X647: 0 MW (0%) • CEP S085: 0 MW (0%) • CEP X427: 0 MW (0%) • CEP X645: 0 MW (0%) • Titan: 20 MW (40%) Conventional: • Cherokee 5 • Comanche 3 • Fort St Vrain 2	• Arapahoe 5, 6, 7 • Cherokee 4, 6, 7 • Comanche 1, 2 • Fort Lupton 1, 2 • Fort St Vrain 1, 3, 4, 5, 6 • Fountain Valley 1, 2, 3, 4, 5, 6 • Lamar DC • Manchief 1, 2 • Pawnee • Plains End • RMEC 1, 2, 3 • Spindle 1, 2 • Spruce 1, 2 • Valmont 6, 7, 8

Power Flow Model Data

The generation of interest is the wind generation connected to the radial line off the Missile Site 345 kV substation (Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains). The wind plants were represented by modeling the main plant transformers, the equivalent collector system, aggregate wind turbine transformer, and an aggregate wind turbine generator, which was provided by Xcel Energy. Refer to Tables 1.3-3 through 1.3-5 for the interconnection data used to represent the wind plants of interest.

- Table 1.3-3 shows the transformer data for the wind plants of interest
- Table 1.3-4 shows the line data for the wind plants of interest
- Table 1.3-5 shows the wind turbine data for the wind plants of interest

Based on steady-state power flow calculations, additional compensation is needed for the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants to meet power factor requirements. Note the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants will be expected to maintain a 0.95 power factor (leading and lagging) at the high side of their respective 345/34.5 kV transformers and were adjusted to meet the power factor requirements. Refer to Table 1.3-5 for the adjusted reactive power ranges.

Table 1.3-3
Transformer Data for the Wind Plants of Interest

Ref. No.	From Bus			To Bus			Ckt ID	MVA Base	R (p.u.)	X (p.u.)
	No.	Name	Voltage (kV)	No.	Name	Voltage (kV)				
1	70628	PRONGHORN	345	70629	RUSHCK_W1	34.5	T1	138.0	0.0024	0.1000
2	70628	PRONGHORN	345	70629	RUSHCK_W1	34.5	T2	138.0	0.0024	0.1000
3	70629	RUSHCK_W1	34.5	88886	RUSHCK_W1	0.69	T1	430.0	0.0063	0.0758
4	70630	SHORTGRASS	345	70631	RUSHCK_W2	34.5	T1	138.0	0.0024	0.1000
5	70631	RUSHCK_W2	34.5	88887	RUSHCK_W2	0.69	T1	248.0	0.0063	0.0758
6	70633	BRONCOPLNS	345	88882	BRONCO_PL	34.5	1	102.0	0.0022	0.0867
7	70633	BRONCOPLNS	345	88882	BRONCO_PL	34.5	2	102.0	0.0022	0.0867
8	88864	BRONCO_PL1	34.5	88863	BRONCO_PL1	0.69	1	336.0	0.0266	0.1999
9	2967	BUS34	345	2695	BUS4	34.5	1	90.0	0.0032	0.1100
10	2950	BUS31	345	2707	BUS5	34.5	1	90.0	0.0026	0.1100
11	2964	BUS32	345	2820	BUS22	34.5	1	90.0	0.0026	0.1100
12	2965	BUS33	345	2819	BUS21	34.5	1	90.0	0.0026	0.1100
13	2785	BUS17	34.5	2789	BUS18	0.69	1	132.3	0.0110	0.0994
14	2371	BUS8	34.5	2389	BUS9	0.69	1	130.2	0.0110	0.0994
15	2803	BUS19	34.5	2807	BUS20	0.69	1	132.3	0.0110	0.0994
16	2758	BUS15	34.5	2771	BUS16	0.69	1	130.2	0.0110	0.0994

Table 1.3-4
Line Data for the Wind Plants of Interest

Ref. No.	From Bus			To Bus			R (p.u.)	X (p.u.)	B (p.u.)
	No.	Name	Voltage (kV)	No.	Name	Voltage (kV)			
1	70628	PRONGHORN	345	70630	SHORTGRASS	345	0.00124	0.01928	0.33396
2	70633	BRONCOPLNS	345	70630	SHORTGRASS	345	0.00070	0.00666	0.12457
3	88882	BRONCO_PL	34.5	88864	BRONCO_PL1	34.5	0.00143	0.00068	0.02631
4	70630	SHORTGRASS	345	3029	BUS35	345	0.00000	0.00010	0.00000
5	70632	CHEYRDGE W	345	3029	BUS35	345	0.00197	0.03241	0.49282
6	70632	CHEYRDGE W	345	88884	CHEYRDGE E	345	0.00035	0.00582	0.08843
7	70632	CHEYRDGE W	345	2967	BUS34	345	0.00000	0.00010	0.00000
8	70632	CHEYRDGE W	345	2950	BUS31	345	0.00000	0.00010	0.00000
9	2707	BUS5	34.5	2785	BUS17	34.5	0.00182	0.00290	0.12100
10	2371	BUS8	34.5	2695	BUS4	34.5	0.00182	0.00290	0.12100
11	2803	BUS19	34.5	2820	BUS22	34.5	0.00182	0.00290	0.12100
12	2758	BUS15	34.5	2819	BUS21	34.5	0.00182	0.00290	0.12100
13	88884	CHEYRDGE E	345	2964	BUS32	345	0.00000	0.00010	0.00000
14	88884	CHEYRDGE E	345	2965	BUS33	345	0.00000	0.00010	0.00000

Table 1.3-5
Wind Turbine Data for the Wind Plants of Interest

Ref. No.	Bus No.	Bus Name	Scheduled Voltage (p.u.)(1)	Max P @ POI(2) (MW)	Required PF @ POI	Required Q @ POI (MVAr)	Plant Losses (Mvar)	Initial Generator Capability		Plant Shunt Compensation		Plant Capability @ POI		Adjusted Final Generator Capability		Description(4)
								Qmax (Mvar)	Qmin (Mvar)	Shunt Cap (Mvar)	Shunt L (Mvar)	Capacitive (Mvar)	Inductive (Mvar)	Qmax (Mvar)	Qmin(3) (Mvar)	
1	88886	RUSHCK_W1	1.00	376	0.95	123.59	-44.00	77.16	-77.16	130.20	-69.00	163.36	-190.16	77.16	-77.16	meets
2	88887	RUSHCK_W2	1.00	218	0.95	71.65	-2.67	41.00	-44.00	51.00	-48.00	89.33	-94.67	41.00	-44.00	meets
3	88863	BRONCO_PL1	1.02	290	0.95	95.32	-92.89	144.00	-144.00	0.00	0.00	51.11	-236.89	188.21	-30.00	adjusted
4	2789	BUS18	1.00	128.6	0.95	42.26	-32.00	25.2	-25.2	0.00	0.00	-6.80	-57.20	74.26	-7.00	adjusted
5	2389	BUS9	1.00	126.5	0.95	41.59	-32.00	25.2	-25.2	0.00	0.00	-6.80	-57.20	73.59	-7.00	adjusted
6	2807	BUS20	1.00	132.6	0.95	43.59	-32.00	41.4	-41.4	0.00	0.00	9.40	-73.40	75.59	-7.00	adjusted
7	2771	BUS16	1.00	126.5	0.95	41.59	-32.00	25.2	-25.2	0.00	0.00	-6.80	-57.20	73.59	-7.00	adjusted

(1) Generators were set to regulate their own bus voltage.

(2) The POI is considered at the high-side of the 345/34.5 kV transformers for power factor purposes

(3) For the new plants (Bronco Plains and Cheyenne Ridge West and East) Qmin was adjusted to result in a 0.95 p.u. at the POI o be conservative.

(4) Highlighted cells indicate plants that are not capable of meeting power factor requirements and were adjusted to maintain a 0.95 power factor (leading and lagging) at the high-side of their respective 345/34.5 kV transformers.

1.4 Dynamic Models

The dynamic datasets provided by Xcel Energy were reviewed with close attention to the study area and the wind generation of interest including the Rush Creek I, Rush Creek II, Bronco Plains, Cheyenne Ridge East, and Cheyenne Ridge West plants. The objective of this Section was to verify that all cases initialized without errors and resulted in flat lines. Note that Xcel Energy provided all data for the wind plants.

The following adjustments to the dynamic parameters were agreed upon with Xcel Energy and were made to the dynamic data files during the review of the cases:

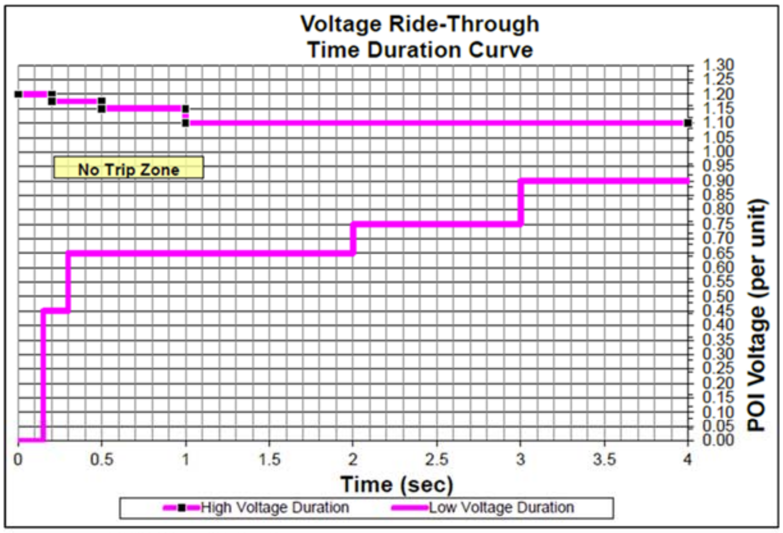
- Trip times were adjusted for the 250 MW Cedar Point 34.5 kV (bus 70622) plant to meet NERC PRC-024 ride-through requirements (shown in Figure 1.4-1). Table 1.4-1 shows default parameters, the original parameters provided in the dynamic data file provided to MEPPI, and the updated parameters that were adjusted to meet NERC PRC-024 for the General Electric wind turbine (GEWTG) model.
  - It was determined that quick tripping times resulted in the Missile Site 34.5 kV generator tripping offline 0.1 seconds after the fault was cleared. The generator will stay online if the trip time is extended. According to NERC PRC-024 extended trip times are required.
  - Note it was observed that the PTZLOGN1 34.5 kV generator also tripped during several contingencies due to short tripping times. These trip times were not extended.
  - It is recommended for Xcel Energy to review the above generator models and confirm the actual relay settings.
- Frequency protection was disabled for the Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants to avoid tripping during the fault.
  - Tripping due to high frequency was observed for several fault cases. It was observed that while the fault was applied and immediately after the fault was cleared the case diverged. The resulting numerical computation errors are partly caused by model limitations.
- Gains were adjusted for the Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plant controller (REPC_A) and were set to Kp = 1 and Ki = 1.
  - With the default gain settings oscillations were observed under contingency conditions that resulted in the need to tune the gains of the power plant controllers to help with system stability for base case and contingency conditions.
  - A sensitivity was completed to tune the gains. Note that detailed results can be found in Section 4.5 of this report.
- The reactive power ranges (Qmin and Qmax) were adjusted for the Cheyenne Ridge West and Cheyenne Ridge East plants to have a tight range (+/- 5 Mvar of the steady-state output of the plants).
  - The short-circuit ratio (SCR) at Cheyenne Ridge West and East is low (<4), the generic WECC renewable energy models may not be accurate representations of

the wind plants during dynamic events. To minimize the impact of using this model in "weak grid" scenarios where its accuracy is questionable, the reactive power capability of these two wind plants were locked so the generators could not provide dynamic var support during dynamic system events.

With the above adjustments to the dynamic cases, flat lines were achieved. Refer to Figures 1.4-2 through 1.4-5 for plots showing N-0 conditions for the heavy summer 1400 MW and light spring 1400 MW cases, respectively.

The following tables show the dynamic parameters used for each wind plant of interest:

- Table 1.4-2 shows parameter data for the dynamic representation of the generator/converter model (REGC_a) used for the wind plants of interest.
- Table 1.4-3 shows parameter data for the dynamic representation of the renewable energy electrical control model (REEC_a) used for the wind plants of interest.
- Table 1.4-4 shows parameter data for the dynamic representation of the WTG torque controller (WTGQ_a) used for the wind plants of interest.
- Table 1.4-5 shows parameter data for the dynamic representation of the simple aerodynamic model (WTGA_a) used for the wind plants of interest.
- Table 1.4-6 shows parameter data for the dynamic representation of the drive train model (WTGT_a) used for the wind plants of interest.
- Table 1.4-7 shows parameter data for the dynamic representation of the WTG pitch controller model (WTGP_a) used for the wind plants of interest.
- Table 1.4-8 shows parameter data for the dynamic representation of the power plant controller model (REPC_a) used for the wind plants of interest.



Ride Through Duration:

High Voltage Ride Through Duration		Low Voltage Ride Through Duration	
Voltage (pu)	Time (sec)	Voltage (pu)	Time (sec)
≥1.200	Instantaneous trip	<0.45	0.15
≥1.175	0.20	<0.65	0.30
≥1.15	0.50	<0.75	2.00
≥1.10	1.00	<0.90	3.00

Figure 1.4-1. Voltage Ride-Through Time Duration Curve from NERC PRC-024.

Table 1.4-1
GEWTG Model Adjustment for Extended Trip Times

EPCL Variable	*Default Data*	*Original MISSILE SITE 34.5 kV*	*Updated MISSILE SITE 34.5 kV*	*Description*
lpp	0.8	0.8	0.8	Generator effective reactance (X''), p.u.
dVtrp1	-0.25	-0.25	-0.25	Delta voltage trip level, p.u.
dVtrp2	-0.5	-0.3	-0.3	Delta voltage trip level, p.u.
dVtrp3	-0.7	-0.7	-0.7	Delta voltage trip level, p.u.
dVtrp4	-0.85	0.11	0.11	Delta voltage trip level, p.u.
dVtrp5	0.1	0.15	0.15	Delta voltage trip level, p.u.
dVtrp6	0.15	0.3	0.3	Delta voltage trip level, p.u.
dTtrp1	1.9	1	1.9	Voltage trip time, sec.
dTtrp2	1.2	**0.1**	1.2	Voltage trip time, sec.
dTtrp3	0.7	**0.01**	0.7	Voltage trip time, sec.
dTtrp4	0.2	1	0.2	Voltage trip time, sec.
dTtrp5	1	**0.1**	1	Voltage trip time, sec.
dTtrp6	0.1	**0.02**	0.1	Voltage trip time, sec.
fcflg	0	0	0	Flag 0 = DFAG; 1 = FC
rrpwr	10	5	5	LVPL ramp rate limit, p.u.
brkpt	0.9	0.9	0.9	LVPL characteristic breakpoint, p.u.
zerox	0.5	0.5	0.5	LVPL characteristic zero crossing, p.u.

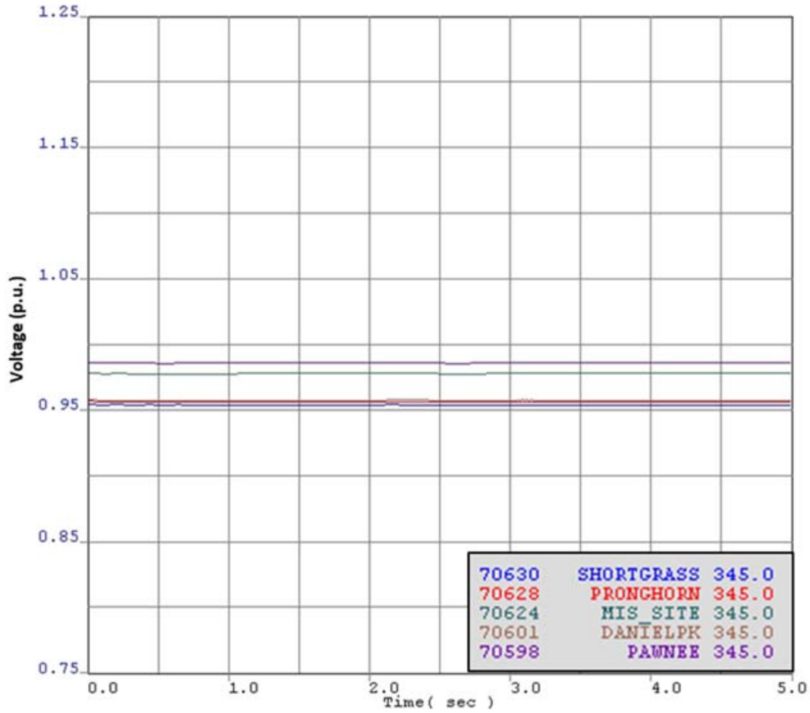


Figure 1.4-2. Voltage plots showing no-fault simulation for the heavy summer 1400 MW case.

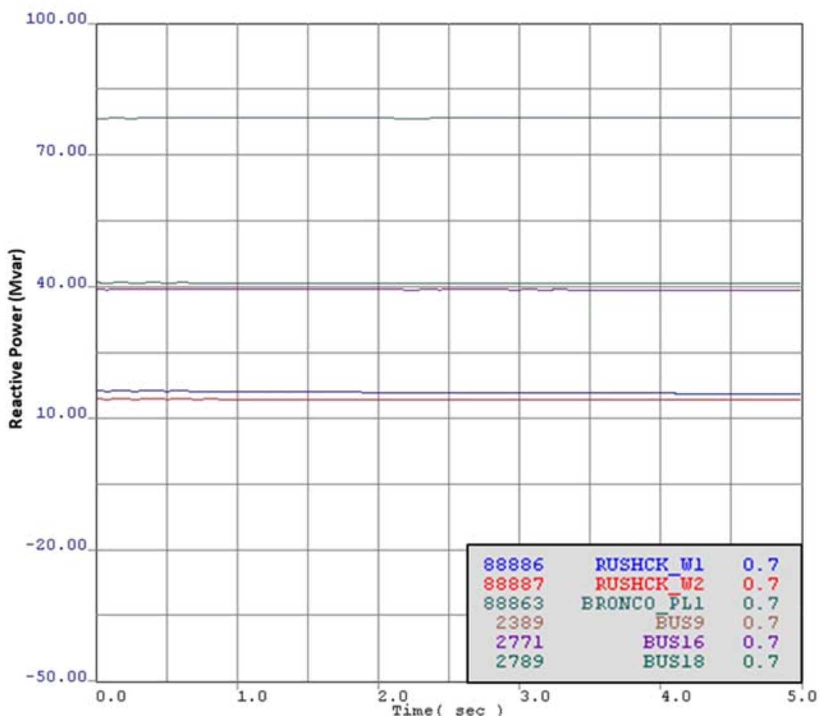


Figure 1.4-3. Reactive power plots showing no-fault simulation for the heavy summer 1400 MW case.

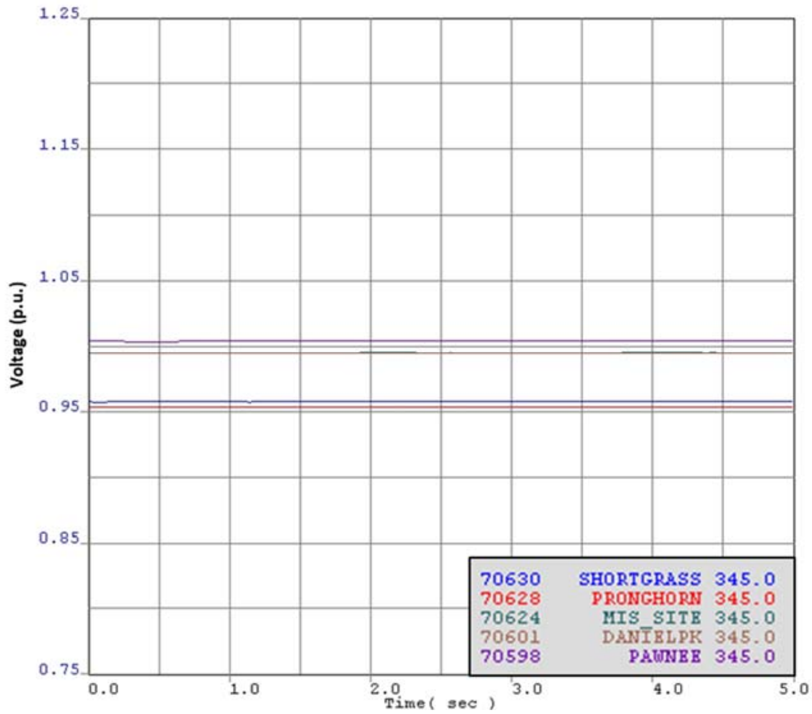


Figure 1.4-4. Voltage plots showing no-fault simulation for the light spring 1400 MW case.

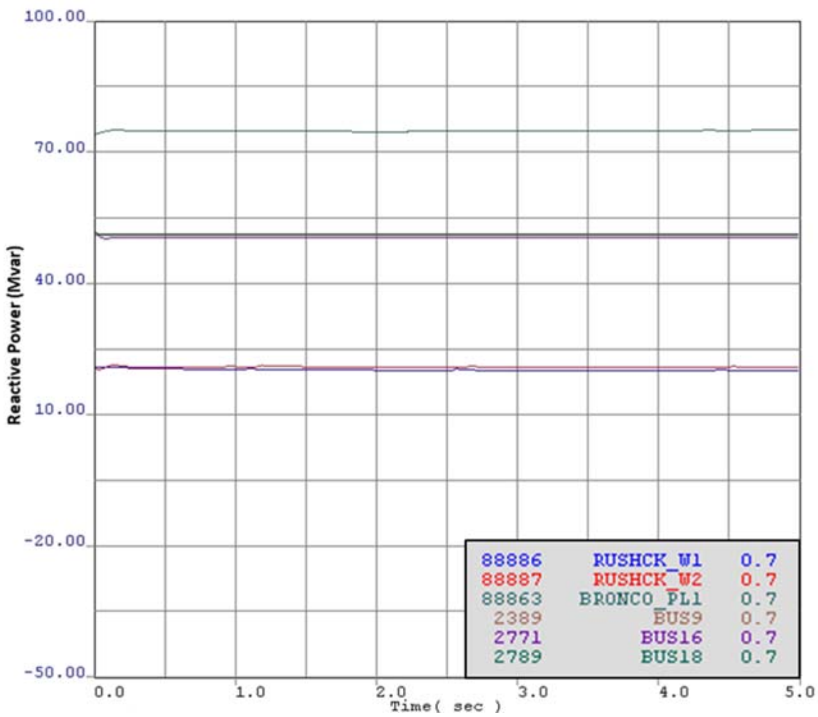


Figure 1.4-5. Reactive power plots showing no-fault simulation for the light spring 1400 MW case.

Table 1.4-2
Dynamic Data for the REGC_a Models used for the Wind Plants of Interest

Generator/Converter Model (REGC_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
MVA	403	230	126.53	128.57	132.63	126.53	336	MVA
lvplsw	1	1	1	1	1	1	1	Connect (1) / disconnect (0) Low Volt. Power Logic switch
rrpwr	0.45	0.45	0.45	0.45	0.45	0.45	10	LVPL ramp rate limit, p.u.
brkpt	0.5	0.5	0.5	0.5	0.5	0.5	0.9	LVPL characteristic breakpoint, p.u.
zerox	-9999	-9999	-9999	-9999	-9999	-9999	0.5	LVPL characteristic zero crossing, p.u.
lvpl1	1.22	1.22	1.22	1.22	1.22	1.22	1.22	LVPL breakpoint, p.u.
vtmax	1.2	1.2	1.2	1.2	1.2	1.2	1.2	Voltage limit used in the high voltage reactive power logic, p.u. See Instantaneous High Voltage Reactive Power Logic Flowchart.
lvpnt1	0.2	0.2	0.2	0.2	0.2	0.2	0.8	High voltage point for low voltage active power logic, p.u. See Instantaneous Low Voltage Active Power Logic Flowchart.
lvpnt0	-9999	-9999	-9999	-9999	-9999	-9999	0.4	Low voltage point for low voltage active power logic, p.u. See Instantaneous Low Voltage Active Power Logic Flowchart.
qmin	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	-1.3	Limit in the high voltage reactive power logic, p.u. See Instantaneous High Voltage Reactive Power Logic Flowchart.
accel	0.5	0.5	0.5	0.5	0.5	0.5	0.7	Acceleration factor used in the high voltage reactive power logic, p.u. See Instantaneous High Voltage Reactive Power Logic Flowchart.
tg	0.02	0.02	0.02	0.02	0.02	0.02	0.02	Time constant, sec.
tfltr	0.02	0.02	0.02	0.02	0.02	0.02	0.02	Voltage measurement time constant, sec.
iqrmax	77	77	77	77	77	77	99	Upward rate limit on reactive current command p.u./sec. See Note m.
iqrmin	-77	-77	-77	-77	-77	-77	-99	Downward rate limit on reactive current command p.u./sec. See Note m.
xe	0	0	0	0	0	0	0.8	Generator effective reactance, p.u. See Note n.

Table 1.4-3
Dynamic Data for the REEC_a Models used for the Wind Plants of Interest

Renewable Energy Electrical Control Model (REEC_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
mvab	0	0	0	0	0	0	0	MVA base (See Note a)
vdip	0.85	0.85	0.85	0.85	0.85	0.85	-99	Vterm < vdip activates the current injection logic, p.u. (see Note b)
vup	1.15	1.15	1.15	1.15	1.15	1.15	99	Vterm > vup activates the current injection logic, p.u. (see Note b)
trv	0.03	0.03	0.03	0.03	0.03	0.03	0	Transducer time constant, sec.
dbd1	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.05	Deadband in voltage error, p.u.
dbd2	0.04	0.04	0.04	0.04	0.04	0.04	0.05	Deadband in voltage error, p.u.
kqv	2	2	2	2	2	2	0	Reactive current injection gain during voltage dip (and overvoltage) conditions, p.u./p.u.
iqh1	1	1	1	1	1	1	1.05	Maximum limit of reactive current injection (**iqinj**), p.u.
iql1	-1	-1	-1	-1	-1	-1	-1.05	Maximum limit of reactive current injection (**iqinj**), p.u.
vref0	0	0	0	0	0	0	0	Reference voltage (See Note e)
iqfrz	-0.025	-0.025	-0.025	-0.025	-0.025	-0.025	0.15	Value at which Iqinj is held for **thld** seconds following a voltage dip if **thld** > 0, p.u.
thld	0.2	0.2	0.2	0.2	0.2	0.2	0	Time delay associated with the computation of **iqinj** and with the operation of switch SW (See block diagram and description of SW switch operation below block diagram), sec.
thld2	0.22	0.22	0.22	0.22	0.22	0.22	0	The active current command (**Ipcmd**) is held for **thld2** seconds after voltage_dip returns to zero.
tp	0.03	0.03	0.03	0.03	0.03	0.03	0.05	Electrical power transducer time constant, sec.
qmax	0.5	0.5	0.5	0.5	0.5	0.5	0.436	Reactive power maximum limit, p.u.
qmin	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.436	Reactive power minimum limit, p.u.
vmax	1.1	1.1	1.1	1.1	1.1	1.1	1.1	Voltage control maximum limit, p.u.
vmin	0.9	0.9	0.9	0.9	0.9	0.9	0.9	Voltage control minimum limit, p.u.
kqp	0	0	0	0	0	0	0	Proportional gain, p.u.
kqi	0.05	0.05	0.05	0.05	0.05	0.05	0.1	Integral gain, p.u.
kvp	0	0	0	0	0	0	0	Proportional gain, p.u.
kvi	40	40	40	40	40	40	40	Integral gain, p.u.
vref1	0	0	0	0	0	0	0	User-defined reference on the inner-loop voltage control (default value is zero), p.u.
tiq	0.01	0.01	0.01	0.01	0.01	0.01	0.02	Time constant, sec.
dpmax	0.02	0.02	0.02	0.02	0.02	0.02	99	Up ramp rate on power reference p.u./sec.
dpmin	-0.02	-0.02	-0.02	-0.02	-0.02	-0.02	-99	Down ramp rate on power reference p.u./sec.

Table 1.4-3 (Continued)
Dynamic Data for the REEC_a Models used for the Wind Plants of Interest

Renewable Energy Electrical Control Model (REEC_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
pmax	1.05	1.05	1.05	1.05	1.05	1.05	1	Maximum power reference, p.u.
pmin	0	0	0	0	0	0	0	Minimum power reference, p.u.
imax	1.12	1.12	1.12	1.12	1.12	1.12	1.82	Maximum allowable total current limit, p.u.
tpord	0.02	0.02	0.02	0.02	0.02	0.02	0.02	Time constant, sec.
pfflag	0	0	0	0	0	0	0	Power factor flag: 1 = Power factor control; 0 = Q control
vflag	0	0	0	0	0	0	1	Voltage control flag: 1: Q Control; 0 : Voltage control
qflag	0	0	0	0	0	0	1	Reactive power control flag 1 : Voltage/Q control; 0 : Constant power factor or Q Control
pflag	0	0	0	0	0	0	0	Power reference flag: 1 : reference is Pref*speed (Do not use with Type 3 WTG); 0 : reference is Pref
pqflag	0	0	0	0	0	0	0	Flag for P or Q priority selection on current limit: 1 : P priority; 0 : Q priority
vq1	0.02	0.02	0.02	0.02	0.02	0.02	-1	User defined voltage used to define VDL1 function, p.u.
iq1	0.2	0.2	0.2	0.2	0.2	0.2	1.45	User defined current used to define VDL1 function, p.u.
vq2	0.17	0.17	0.17	0.17	0.17	0.17	2	User defined voltage used to define VDL1 function, p.u.
iq2	0.97	0.97	0.97	0.97	0.97	0.97	1.45	User defined current used to define VDL1 function, p.u.
vq3	0.8	0.8	0.8	0.8	0.8	0.8	0	User defined voltage used to define VDL1 function, p.u.
iq3	1.1	1.1	1.1	1.1	1.1	1.1	0	User defined current used to define VDL1 function, p.u.
vq4	1	1	1	1	1	1	0	User defined voltage used to define VDL1 function, p.u.
iq4	1.17	1.17	1.17	1.17	1.17	1.17	0	User defined current used to define VDL1 function, p.u.
vp1	0.5	0.5	0.5	0.5	0.5	0.5	-1	User defined voltage used to define VDL2 function, p.u.
ip1	0.426	0.426	0.426	0.426	0.426	0.426	1.1	User defined current used to define VDL2 function, p.u.
vp2	0.85	0.85	0.85	0.85	0.85	0.85	2	User defined voltage used to define VDL2 function, p.u.
ip2	0.426	0.426	0.426	0.426	0.426	0.426	1.1	User defined current used to define VDL2 function, p.u.
vp3	0.851	0.851	0.851	0.851	0.851	0.851	0	User defined voltage used to define VDL2 function, p.u.
ip3	0.426	0.426	0.426	0.426	0.426	0.426	0	User defined current used to define VDL2 function, p.u.
vp4	0.9	0.9	0.9	0.9	0.9	0.9	0	User defined voltage used to define VDL2 function, p.u.
ip4	1.01	1.01	1.01	1.01	1.01	1.01	0	User defined current used to define VDL2 function, p.u

Table 1.4-4
Dynamic Data for the WTGQ_a Models used for the Wind Plants of Interest

WTG Torque Controller (WTGQ_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
mvab	0	0	0	0	0	0	0	MVA base (See Note a)
kip	0.4	0.4	0.4	0.4	0.4	0.4	1.5	Integral gain, pu/pu/sec
kpp	2	2	2	2	2	2	2.5	Proportional gain, pu/pu
tp	0.08	0.08	0.08	0.08	0.08	0.08	0.05	Power measurement lag time constant, sec
twref	60	60	60	60	60	60	60	Speed reference time constant, sec
temax	1.12	1.12	1.12	1.12	1.12	1.12	1.1	Maximum torque, pu (see Note b)
temin	0	0	0	0	0	0	0	Minimum torque, pu
p1	0.4	0.4	0.4	0.4	0.4	0.4	0.15	User defined point, pu
spd1	0.67	0.67	0.67	0.67	0.67	0.67	0.85	User defined point, pu
p2	0.49	0.49	0.49	0.49	0.49	0.49	0.23	User defined point, pu
spd2	0.82	0.82	0.82	0.82	0.82	0.82	0.95	User defined point, pu
p3	0.58	0.58	0.58	0.58	0.58	0.58	0.35	User defined point, pu
spd3	0.97	0.97	0.97	0.97	0.97	0.97	1.1	User defined point, pu
p4	0.67	0.67	0.67	0.67	0.67	0.67	0.46	User defined point, pu
spd4	1.12	1.12	1.12	1.12	1.12	1.12	1.2	User defined point, pu
tflag	1	1	1	1	1	1	0	Flag to specify PI controller input

Table 1.4-5
Dynamic Data for the WTGA_a Models used for the Wind Plants of Interest

Simple Aerodynamic Model (WTGA_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
mvab	0	0	0	0	0	0	0	MVA base (See Note a)
Ka	0.007	0.007	0.007	0.007	0.007	0.007	0.007	Aerodynamic gain factor
Theta0	0	0	0	0	0	0	0	Initial blade pitch angle, deg. (θ_o)

Table 1.4-6
Dynamic Data for the WTGT_a Models used for the Wind Plants of Interest

Drive Train Model (WTGT_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
mvab	0	0	0	0	0	0	0	MVA base (See Note a)
ht	3.32	3.32	3.32	3.32	3.32	3.32	4.94	Turbine inertia, MW-sec/MVA
hg	0.66	0.66	0.66	0.66	0.66	0.66	0	Generator inertia, MW-sec/MVA
dshaft	1.5	1.5	1.5	1.5	1.5	1.5	1.5	Damping coefficient p.u.
kshaft	73.4509	73.4509	73.4509	73.4509	73.4509	73.4509	-0.077	Stiffness constant, p.u.
wo	1	1	1	1	1	1	1.2	Initial “speed”, p.u.

Table 1.4-7
Dynamic Data for the WTGP_a Models used for the Wind Plants of Interest

WTG Pitch Controller (WTGP_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
mvab	0	0	0	0	0	0	0	MVA base (See Note a)
kiw	25	25	25	25	25	25	25	Pitch controller integral gain, pu/pu/sec
kpw	150	150	150	150	150	150	150	Pitch controller proportional gain, pu/pu
kic	30	30	30	30	30	30	30	Pitch compensation integral gain, pu/pu/sec
kpc	3	3	3	3	3	3	3	Pitch compensation proportional gain, pu/pu
kcc	0.3	0.3	0.3	0.3	0.3	0.3	1	Proportional gain, pu/pu
tpi	0.3	0.3	0.3	0.3	0.3	0.3	0.3	Pitch time, sec
pimax	27	27	27	27	27	27	27	Maximum pitch angle limit, deg
pimin	0	0	0	0	0	0	0	Minimum pitch angle limit, deg
piratmx	10	10	10	10	10	10	10	Maximum pitch angle rate, deg/sec
piratmn	-10	-10	-10	-10	-10	-10	-10	Minimum pitch angle rate, deg/sec

Table 1.4-8
Dynamic Data for the REPC_a Models used for the Wind Plants of Interest

Power Plant Controller (REPC_a)								
EPCL Variable	**Rush Creek I**	**Rush Creek 2**	**Cheynne Ridge W1**	**Cheynne Ridge W2**	**Cheyenne Ridge E1**	**Cheyenne Ridge E2**	**Bronco Plains**	**Description**
mvab	0	0	0	0	0	0	0	Base MVA
tfltr	0.03	0.03	0.03	0.03	0.03	0.03	0.03	Voltage or reactive power transducer time constant, sec.
kp	1	1	1	1	1	1	1	Proportional gain, p.u.
ki	1	1	1	1	1	1	1	Integral gain, p.u.
tft	0	0	0	0	0	0	0	Lead time constant, sec.
tfv	0	0	0	0	0	0	0	Lag time constant, sec.
refflg	1	1	1	1	1	1	1	= 1 : Voltage control; = 0: Reactive control
vfrz	0.85	0.85	0.85	0.85	0.85	0.85	0.85	If Vreg < vfrz, then state s2 is frozen
rc	0	0	0	0	0	0	0	Line drop compensation resistance, p.u.
xc	0	0	0	0	0	0	0	Line drop compensation reactance, p.u.
kc	0.05	0.05	0.05	0.05	0.05	0.05	0.05	Droop gain, p.u.
vcmpflg	1	1	1	1	1	1	1	Flag for selection of droop (=0), or line drop compensation (=1)
emax	5	5	5	5	5	5	5	Maximum error limit, p.u.
emin	-5	-5	-5	-5	-5	-5	-5	Minimum error limit, p.u.
dbd	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	Deadband
qmax	0.5	0.5	0.4	0.4	0.4	0.4	0.4	Maximum Q control output, p.u.
qmin	-0.5	-0.5	0.2	0.2	0.2	0.2	0.2	Minimum Q control output, p.u.
kpg	0.4	0.4	0.4	0.4	0.4	0.4	0.4	Proportional gain for power control, p.u.
kig	2.6667	2.6667	2.6667	2.6667	2.6667	2.6667	2.6667	Integral gain for power control, p.u.
tp	0.25	0.25	0.25	0.25	0.25	0.25	0.25	Lag time constant on Pgen measurement, sec.
fdbd1	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	-0.0005	Deadband downside, p.u.
fdbd2	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	Deadband upside, p.u.
femax	0.008	0.008	0.008	0.008	0.008	0.008	0.008	Maximum error limit, p.u.
femin	-0.008	-0.008	-0.008	-0.008	-0.008	-0.008	-0.008	Minimum error limit, p.u.
pmax	1.1	1.1	1.1	1.1	1.1	1.1	1.1	Maximum power, p.u.
pmin	0	0	0	0	0	0	0	Minimum power, p.u.
tlag	0.1	0.1	0.1	0.1	0.1	0.1	0.1	Lag time constant on Pref feedback, sec.
ddn	20	20	20	20	20	20	20	Downside droop, p.u.
dup	0	0	0	0	0	0	0	Upside droop, p.u.
frqflg	0	0	0	0	0	0	0	Pref output flag
outflag	0	0	0	0	0	0	0	Not used.
puflag	0	0	0	0	0	0	0	Per unit flag (See Note k)

SECTION 2
FERRANTI EFFECT OVERVOTLAGE ANALYSIS

2.1 Background and Introduction

The objective of the analysis presented in this section is to determine the equipment needed to control potential high voltages on the Gen-Tie during low/no generation conditions. When the wind plants along the Gen-Tie line are off-line, equipment such as shunt reactors may be needed to limit overvoltages along the circuit.

MEPPI previously performed an electromagnetic transients (EMT) study for the Pronghorn and Rush Creek II 345 kV substations in April 2017 ("REP0065_Xcel_MissileSite_Transients_R1.pdf"). Xcel Energy has confirmed that the power system has not changed significantly since then, as such, MEPPI used the EMT model of Xcel Energy's power system that was developed for that analysis as a starting point and added the new equipment associated with the Shortgrass 345 kV substation and the Bronco Plains, Cheyenne Ridge West, and Cheyenne Ridge East wind power plants. This updated EMT model was utilized for the analysis presented in this report section.

2.2 Steady-State Voltage Change Analysis

<u>Limits for Steady-State Voltage Change at the Bus</u>

When a shunt capacitor or reactor is energized, the inherent reactive power of the shunt device will cause the voltage at the bus where the shunt device is connected to increase (for a capacitor) or decrease (for a reactor).The following limits were used for the maximum voltage deviation at a bus:

- Under system intact conditions (N-0) – 3%
- With the largest fault current contributing element out of service (N-1) – 5%

Equation 1.2-1 can be used to estimate the anticipated voltage deviation resulting from capacitor bank switching:

$$\Delta V = \left(\frac{Mvar}{MVA_{SC}}\right) \times 100\% \qquad (1.2\text{-}1)$$

where

Mvar = shunt device rating
MVA_{SC} = the available 3-phase short-circuit current MVA at the bus under study

For example, the short-circuit capacity at the Pronghorn 345 kV substation under base system conditions and with an outage of the largest short-circuit contributing element (the Missile Site – Smoky Hill 345 kV line) is approximately 3078 MVA and 2785 MVA, respectively. Therefore, the anticipated voltage change at the Missile Site 345 kV bus when energizing a 60 Mvar shunt capacitor can be calculated as follows:

- Base conditions (N-0):

$$\Delta V = \left(\frac{Mvar}{MVA_{SC}}\right) \times 100\% = \left(\frac{60}{3078}\right) \times 100\% = 1.9\%$$

- Outage conditions:

$$\Delta V = \left(\frac{Mvar}{MVA_{SC}}\right) \times 100\% = \left(\frac{60}{2785}\right) \times 100\% = 2.2\%$$

Approach for the Steady-State Voltage Change Analysis

The following is the approach used for the steady-state voltage change analysis:

(1) Using the EMT model described in Section 1.1 of this report calculate the bus strength (three-phase grounded fault current) at key buses along the Gen-Tie line under minimum N-1 system strength conditions (outage of the Missile Site – Smoky Hill 345 kV line).
(2) Calculate the steady-state change in voltage at key buses within the Gen-Tie line with various size shunt reactors.
(3) Tabulate the results and compare them to the limits specified above.

Results for the Steady-State Voltage Change Analysis

The results of the steady-state voltage change analysis are provided in Table 2.2-1. The results of this analysis provide guidance with regards to maximum step size of shunt capacitor and reactors at various buses along the Gen-Tie line. The following maximum sizes can be used at the buses under evaluation in this analysis:

- Pronghorn 345 kV = 91 Mvar (at 345 kV)
- Shortgrass 345 kV = 60 Mvar (at 345 kV)
- Cheyenne Ridge W 345 kV = 36 Mvar (at 345 kV)

Table 2.2-1

Summary Results for the Steady-State Voltage Change Analysis

Ref. No.	Bus Number	Bus Name	Bus Strength (MVA)	ΔV from Shunt Reactor Energizing[2]				
				30 Mvar	36 Mvar	50 Mvar	60 Mvar	91 Mvar
Base Case (N-0) System Conditions								
1	70624	Missile Site	8782	0.3%	0.4%	0.6%	0.7%	1.0%
2	70628	Pronghorn	3078	1.0%	1.2%	1.6%	1.9%	3.0%
3	70630	Shortgrass	1982	1.5%	1.8%	2.5%	3.0%	4.6%
5	70632	Cheyenne Ridge W	1219	2.5%	3.0%	4.1%	4.9%	7.5%
Minimum Single Outage (N-1) System Conditions[1]								
1	70624	Missile Site	6729	0.4%	0.5%	0.7%	0.9%	1.4%
2	70628	Pronghorn	2785	1.1%	1.3%	1.8%	2.2%	3.3%
3	70630	Shortgrass	1847	1.6%	1.9%	2.7%	3.2%	4.9%
5	70632	Cheyenne Ridge W	1165	2.6%	3.1%	4.3%	5.1%	7.8%

(1) Bus strength assuming an N-1 outage of Missile Site - Smoky Hill 345 kV line

(2) $\Delta V = Mvar_{shunt}/MVA_{sys} * 100$

2.3 Ferranti Effect Overvoltage Analysis

Approach for the Ferranti Effect Overvoltage Analysis

The objective of the "Ferranti Effect Overvoltage Analysis" is to examine the worst case operating scenario for steady-state overvoltages, where the Gen-Tie line is energized without any of the wind plants on-line. The following approach was used for the analysis:

1) Using the developed system transients model of Xcel Energy's system, energize a specific section of the Gen-Tie line from Missile Site 345 kV under the minimum N-1 system strength condition (an outage of the Missile Site – Smoky Hill 345 kV line). Figures 2.3-1 through 2.3-4 illustrate the system configurations examined below for the Ferranti Effect overvoltage analysis:
    a) Energize the entire Gen-Tie with all wind plants off-line
    b) Energize the Gen-Tie through Shortgrass with all wind plants off-line as shown in Figure 2.3-2
    c) Energize the Gen-Tie through Bronco Plains with all wind plants off-line as shown in Figure 2.3-3
    d) Energize the Gen-Tie through Cheyenne Ridge East with all wind plants off-line as shown in Figure 2.3-4
2) Key cases from Step (1) were re-examined considering various dispatches of the following shunt reactors along the Gen-Tie line:
    a) 3x23 Mvar at Rush Creek I 34.5 kV
    b) 2x24 Mvar at Rush Creek II 34.5 kV

c) 2x30 Mvar at Shortgrass 345 kV

3) The steady-state bus voltages along the Gen-Tie line were quantified for Steps (1) and (2) and the maximum operating voltage at Missile Site 345 kV, before energizing the Gen-Tie line, was quantified.

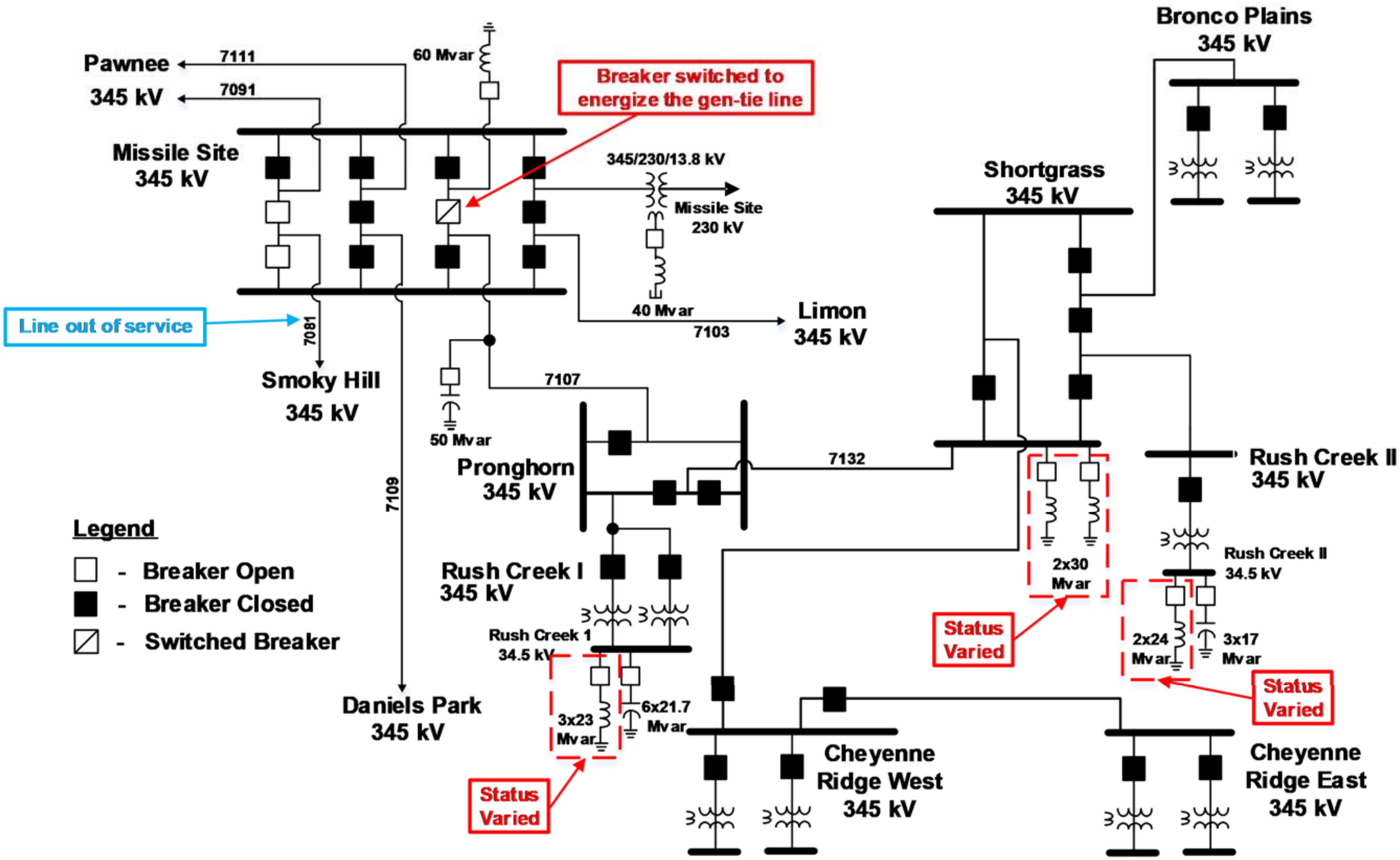


Figure 2.3-1. Base One-Line Diagram Highlighting the System Conditions under Evaluation.

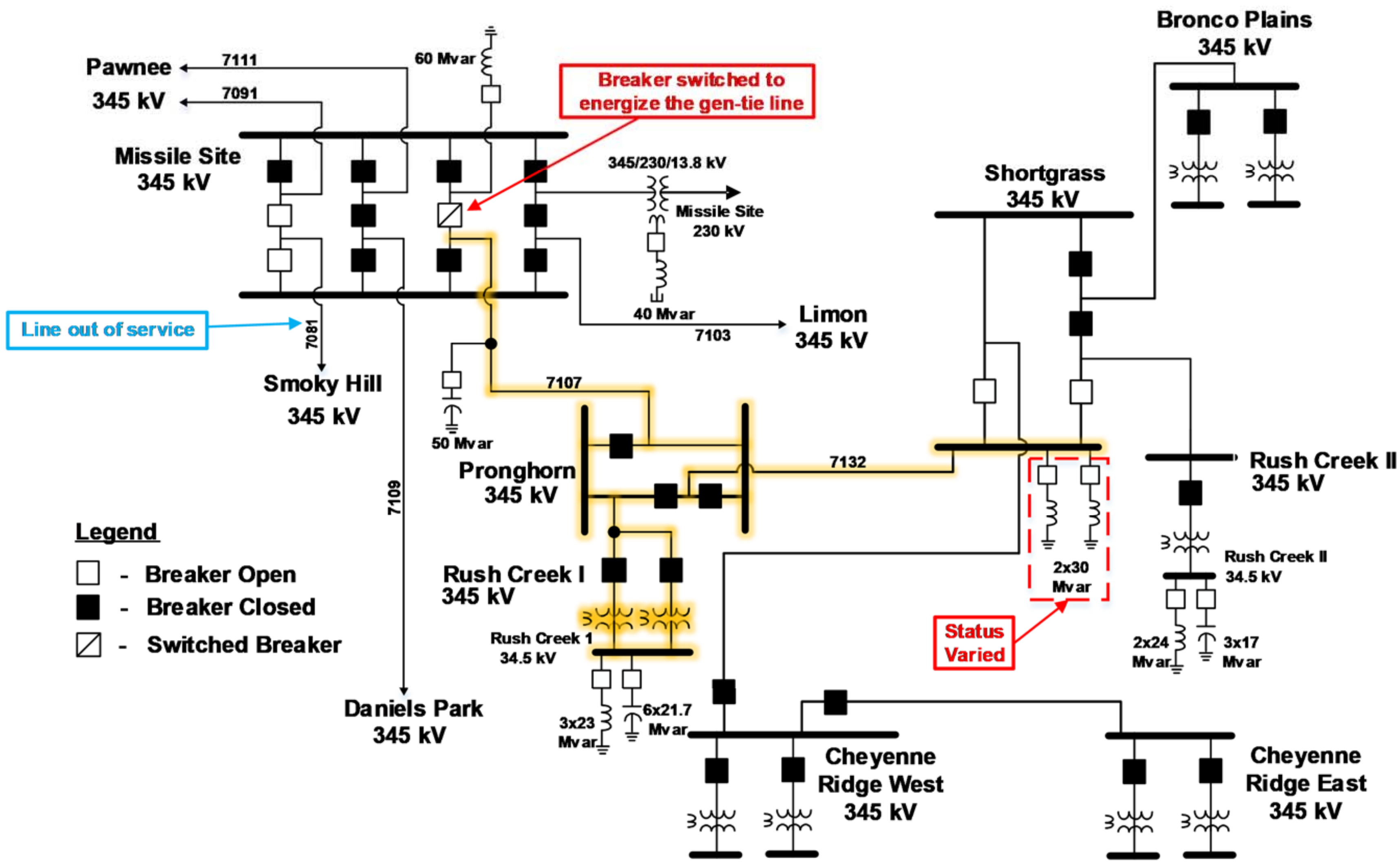


Figure 2.3-2. One-Line Diagram of the Case where the Missile Site Gen-Tie line is Energized through Shortgrass 345 kV with All Wind Plants Off-Line.

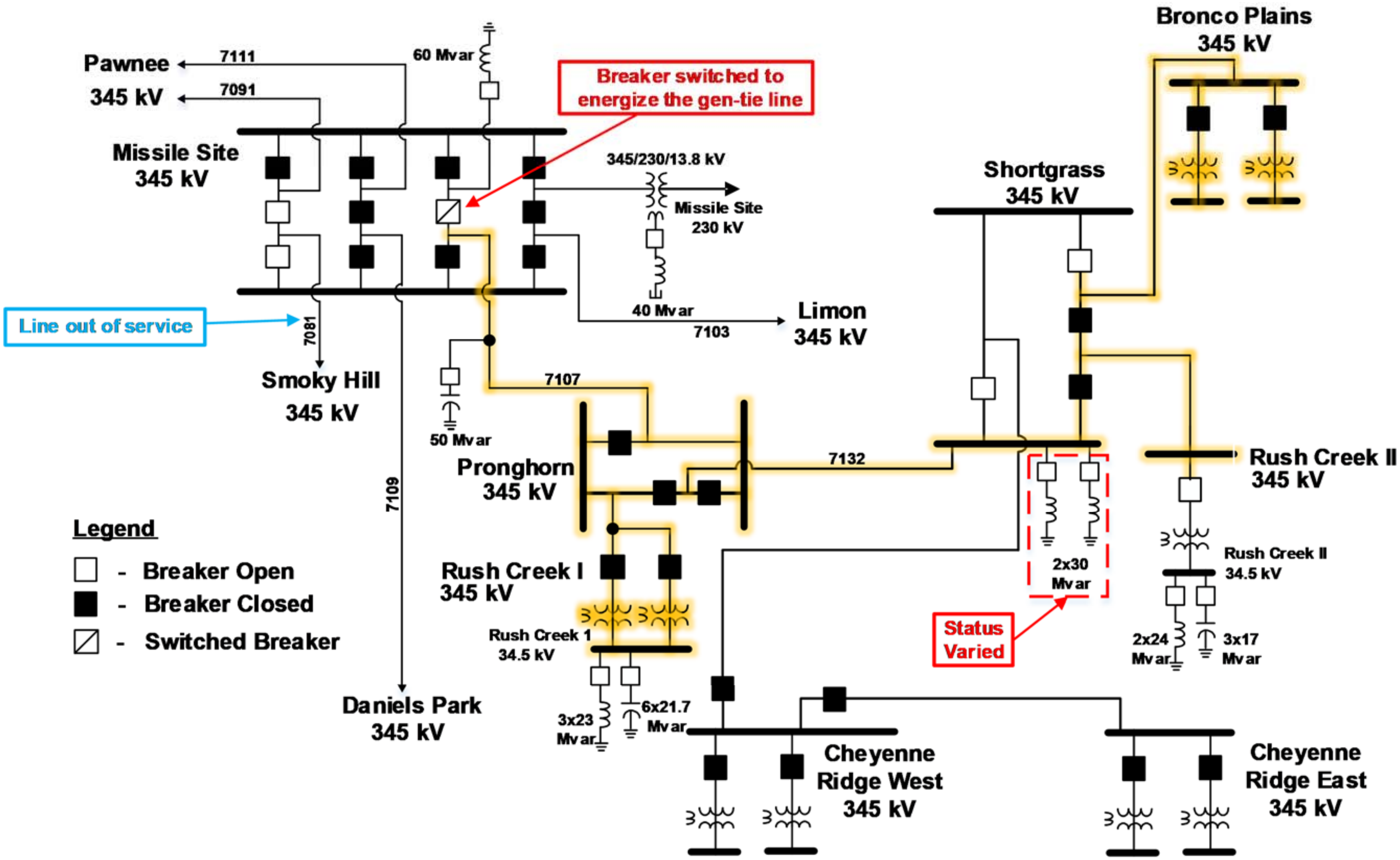


Figure 2.3-3. One-Line Diagram of the Case where the Missile Site Gen-Tie line is Energized through Bronco Plains 345 kV with All Wind Plants Off-Line.

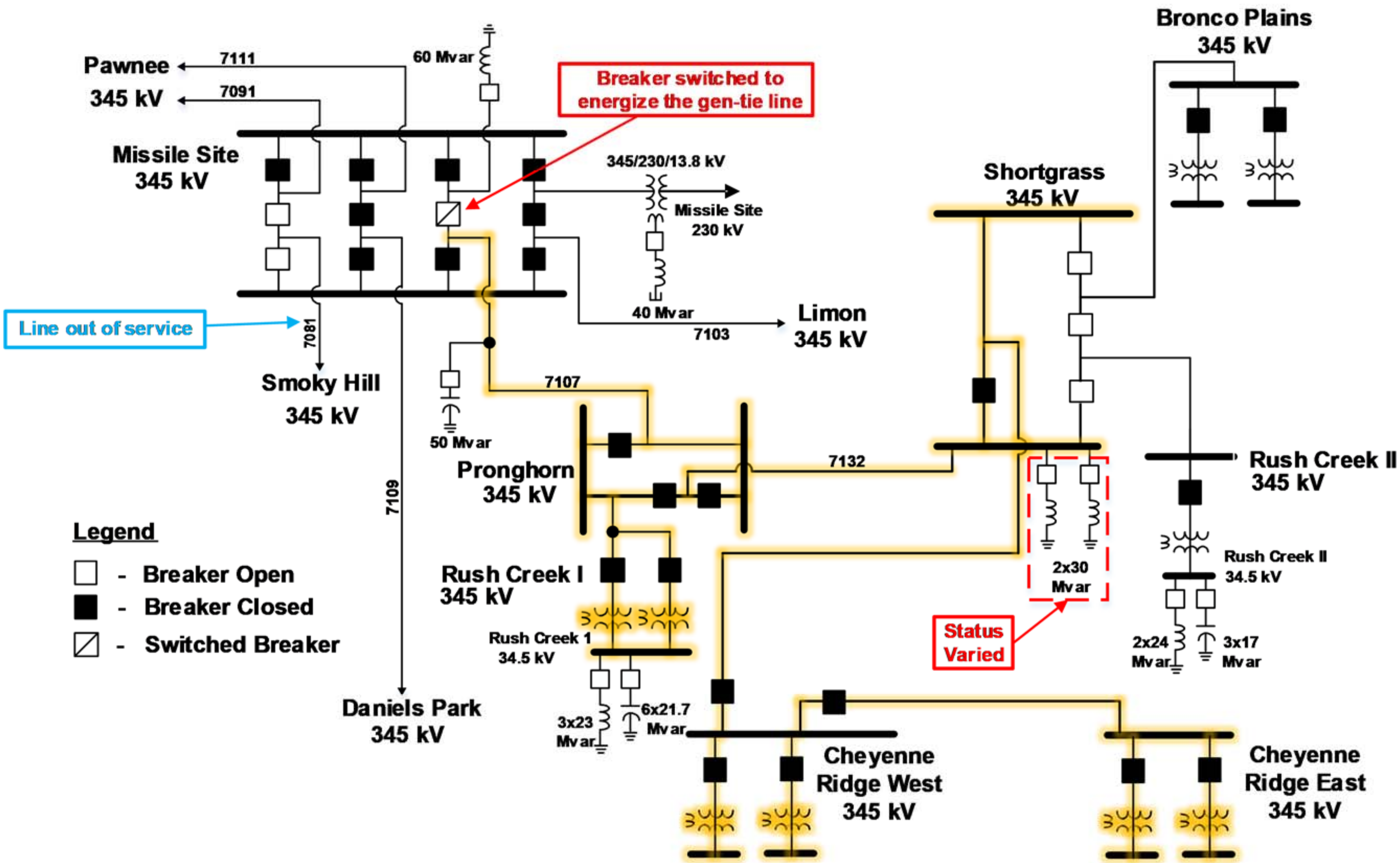


Figure 2.3-4. One-Line Diagram of the Case where the Missile Site Gen-Tie line is Energized through Cheyenne Ridge East 345 kV with All Wind Plants Off-Line.

Results for the Ferranti Effect Overvoltage Analysis

The objective of the "Ferranti Effect Overvoltage Analysis" is to examine the worst case operating scenario for steady-state overvoltages, where the Gen-Tie line is energized without any of the wind plants on-line. When a transmission line is left open-ended the charging current associated with the line will flow from the line to the system. The current flowing along the line will result in a voltage rise (Ferranti Effect) across the open-ended line from the sending-end to the remote-end.

The results of the Ferranti Effect overvoltage analysis are included in Table 2.3-1. For the various system operating conditions examined a maximum sending end voltage at Missile Site 345 kV before operating the Gen-Tie line open-ended was quantified such that the voltage along the gen-tie line is less than or equal to 1.05 p.u. (on a 345 kV bus) after the line is operated open-ended. In the case of the Gen-Tie line, open-ended operation can occur in one of the following ways:

- During energization of the circuit as the only source of synchronization power for the line is from Missile Site.
  - This will occur on initial system energization and following a trip of the gen-tie line.
- Loss of generation along the line such that all plants are outputting near 0 MW and do not have the ability to regulate the voltage at their terminals.

The following summarizes the results of the Ferranti Effect Overvoltage Analysis:

- The charging associated with the Gen-Tie line can cause a maximum steady-state change in voltage at Missile Site 345 kV of 2.1% without shunt compensation along the Gen-Tie (Ref. No. 1).
- When considering the existing 3x23 Mvar reactors at Rush Creek I 34.5 kV and the 2x24 Mvar reactors at Rush Creek II 34.5 kV then the entire Gen-Tie can be energized as long as Xcel Energy can regulate the Missile Site 345 kV bus voltage to less than or equal to 354.4 $kV_{L-L,RMS}$ (1.027 p.u.) before energizing the Gen-Tie.
- If Xcel Energy would like to be able to energize the Gen-Tie line through Shortgrass without relying on the shunt compensation at Rush Creek I and II then they need to control the steady-state bus voltage at Missile Site 345 kV to less than or equal to:
  - 353.5 $kV_{L-L,RMS}$ (1.025 p.u.) with 0x30 Mvar shunt reactors on-line at Shortgrass 345 kV (Ref. No. 11).
  - 358.5 $kV_{L-L,RMS}$ (1.039 p.u.) with 1x30 Mvars shunt reactors on-line at Shortgrass 345 kV (Ref. No. 12).
  - 361.6 $kV_{L-L,RMS}$ (1.048 p.u.) with 2x30 Mvars shunt reactors on-line at Shortgrass 345 kV (Ref. No. 13).
- If Xcel Energy would like to be able to energize the Gen-Tie through Cheyenne Ridge East without relying on the shunt compensation at Rush Creek I and II then they need to control the steady-state bus voltage at Missile Site 345 kV to less than or equal to:
  - 339.1 $kV_{L-L,RMS}$ (0.983 p.u.) with 0x30 Mvar shunt reactors on-line at Shortgrass 345 kV (Ref. No. 11).

- 344.7 $kV_{L-L,RMS}$ (0.999 p.u.) with 1x30 Mvars shunt reactors on-line at Shortgrass 345 kV (Ref. No. 12).
- 350.5 $kV_{L-L,RMS}$ (1.016 p.u.) with 2x30 Mvars shunt reactors on-line at Shortgrass 345 kV (Ref. No. 13).

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Table 2.3-1
Summary Results for the Ferranti Effect Steady-State Overvoltage Analysis

Ref. No.	Total Shunt Compensation (Mvar)			Final Steady-State Voltage														Maximum Voltage at Missile Site Before Line Switching[1]	
				Missile Site 345 kV		Pronghorn 345 kV		Shortgrass 345 kV		Rush Creek 2 345 kV		Bronco Plains 345 kV		Cheynne Ridge W 345 kV		Cheynne Ridge E 345 kV			
	RC1 3x23 Mvar (34.5 kV)	RC2 2x24 Mvar (34.5 kV)	Shortgrass 2x30 Mvar (345 kV)	($kV_{L-L,RMS}$)	(pu)	($kV_{L-L,RMS}$)	(pu)	($kV_{L-L,RMS}$)	(pu)	($kV_{L-L,RMS}$)	(pu)	($kV_{L-L,RMS}$)	(pu)	($kV_{L-L,RMS}$)	(pu)	($kV_{L-L,RMS}$)	(pu)	($kV_{L-L,RMS}$)	(pu)
Full Missile Site Gen-Tie Line Energized with all Wind Plants Off																			
1	0	0	0	344.2	0.998	353.0	1.023	358.6	1.039	358.6	1.039	358.7	1.040	362.2	1.050	362.2	1.050	336.9	0.977
2	0	0	30	348.2	1.009	354.9	1.029	358.5	1.039	358.5	1.039	358.6	1.040	362.1	1.050	362.2	1.050	342.6	0.993
3	0	0	60	352.3	1.021	356.8	1.034	358.4	1.039	358.4	1.039	358.5	1.039	362.1	1.049	362.2	1.050	348.2	1.009
4	69	48	0	355.7	1.031	356.1	1.032	358.6	1.039	358.6	1.039	358.7	1.040	362.2	1.050	362.2	1.050	354.4	1.027
5	69	48	30	359.9	1.043	358.0	1.038	358.6	1.039	358.6	1.039	358.7	1.040	362.2	1.050	362.2	1.050	360.3	1.044
6	69	48	60	360.3	1.044	356.1	1.032	354.7	1.028	354.7	1.028	354.8	1.028	358.2	1.038	358.3	1.038	>362.25	>1.05
7	69	0	60	357.6	1.036	357.0	1.035	358.6	1.039	358.6	1.039	358.7	1.040	362.2	1.050	362.2	1.050	357.1	1.035
8	69	0	30	352.8	1.023	354.6	1.028	358.2	1.038	358.2	1.038	358.4	1.039	361.9	1.049	362.2	1.050	350.5	1.016
9	0	48	30	354.5	1.027	357.7	1.037	358.3	1.039	358.3	1.039	358.4	1.039	361.9	1.049	362.1	1.050	351.2	1.018
10	0	48	60	359.1	1.041	360.0	1.044	358.6	1.039	358.6	1.039	358.7	1.040	362.2	1.050	362.2	1.050	357.5	1.036
Missile Site Gen-Tie Through Shortgrass Energized with all Wind Plants Off																			
11	0	0	0	357.2	1.035	361.0	1.046	362.2	1.050	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	353.5	1.025
12	0	0	30	360.6	1.045	362.2	1.050	361.4	1.048	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	358.5	1.039
13	0	0	60	362.1	1.050	361.5	1.048	358.7	1.040	0.0	0.000	0.0	0.000	0.0	0.000	0.0	0.000	361.6	1.048
Missile Site Gen-Tie Through Bronco Plains Energized with all Wind Plants Off																			
14	0	0	0	355.5	1.031	360.2	1.044	362.1	1.050	0.0	0.000	362.2	1.050	0.0	0.000	0.0	0.000	351.2	1.018
15	0	0	30	359.7	1.043	362.2	1.050	362.1	1.050	0.0	0.000	362.2	1.050	0.0	0.000	0.0	0.000	357.0	1.035
16	0	0	60	362.0	1.049	362.3	1.050	360.2	1.044	0.0	0.000	360.3	1.044	0.0	0.000	0.0	0.000	360.9	1.046
Missile Site Gen-Tie Through Cheyenne Ridge East Energized with all Wind Plants Off																			
17	0	0	0	345.6	1.002	353.7	1.025	358.6	1.039	0.0	0.000	0.0	0.000	362.2	1.050	362.2	1.050	339.0	0.983
18	0	0	30	349.8	1.014	355.6	1.031	358.6	1.039	0.0	0.000	0.0	0.000	362.1	1.050	362.2	1.050	344.7	0.999
19	0	0	60	354.0	1.026	357.6	1.037	358.6	1.039	0.0	0.000	0.0	0.000	362.2	1.050	362.2	1.050	350.5	1.016

(1) The maximum voltage that Missile Site 345 kV can be at before energizing/operating open-ended the representatvie section of the Missile Site Gen-Tie line while still maintaining all energized bus allong the circuit at or below 1.05 p.u.

2.4 Summary for the Ferranti Effect Overvoltage Analysis

Two 30 Mvar shunt reactors at Shortgrass 345 kV will provide Xcel Energy with operational flexibility to operate the Gen-Tie line under no power flow scenarios without relying on the shunt reactors at the 34.5 kV terminals of Rush Creek I and II.

It is recommended that Xcel Energy review the results of this analysis and determine a realistic maximum voltage that they can regulate Missile Site to without the new Gen-Tie line and compare the results to the steady-state limits provided in the summary table column labeled “Maximum Voltage at Missile Site Before Line Switching”.

SECTION 3
STEADY-STATE ANALYSIS

3.1 Background and Introduction

A steady-state contingency analysis was performed to determine the amount of steady-state reactive power compensation needed for the interconnection of the CEPP generation, focusing on the additional wind generation to the Gen-Tie to meet planning criteria. Contingencies specified by Xcel Energy were examined, and all contingencies that resulted in non-convergence, thermal overloads, or voltage criteria violations were flagged.

After the steady-state analysis was completed, Xcel Energy provided an update to the Cheyenne Ridge East and Cheyenne Ridge West collector systems. The full steady-state analysis was completed using the “initial power flow cases”, the cases, approach, and results are included in Appendix A of this report. Key cases were then re-examined with the updated case, which are described in the following sections.

3.2 Review and Construction of the Steady-State Models

The study area of interest was defined as PSCo Balancing Area 70. Figure 3.2-1 shows a one-line diagram of the immediate study area. The generation of interest is the wind generation connected to the radial line off the Missile Site 345 kV substation (Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains).

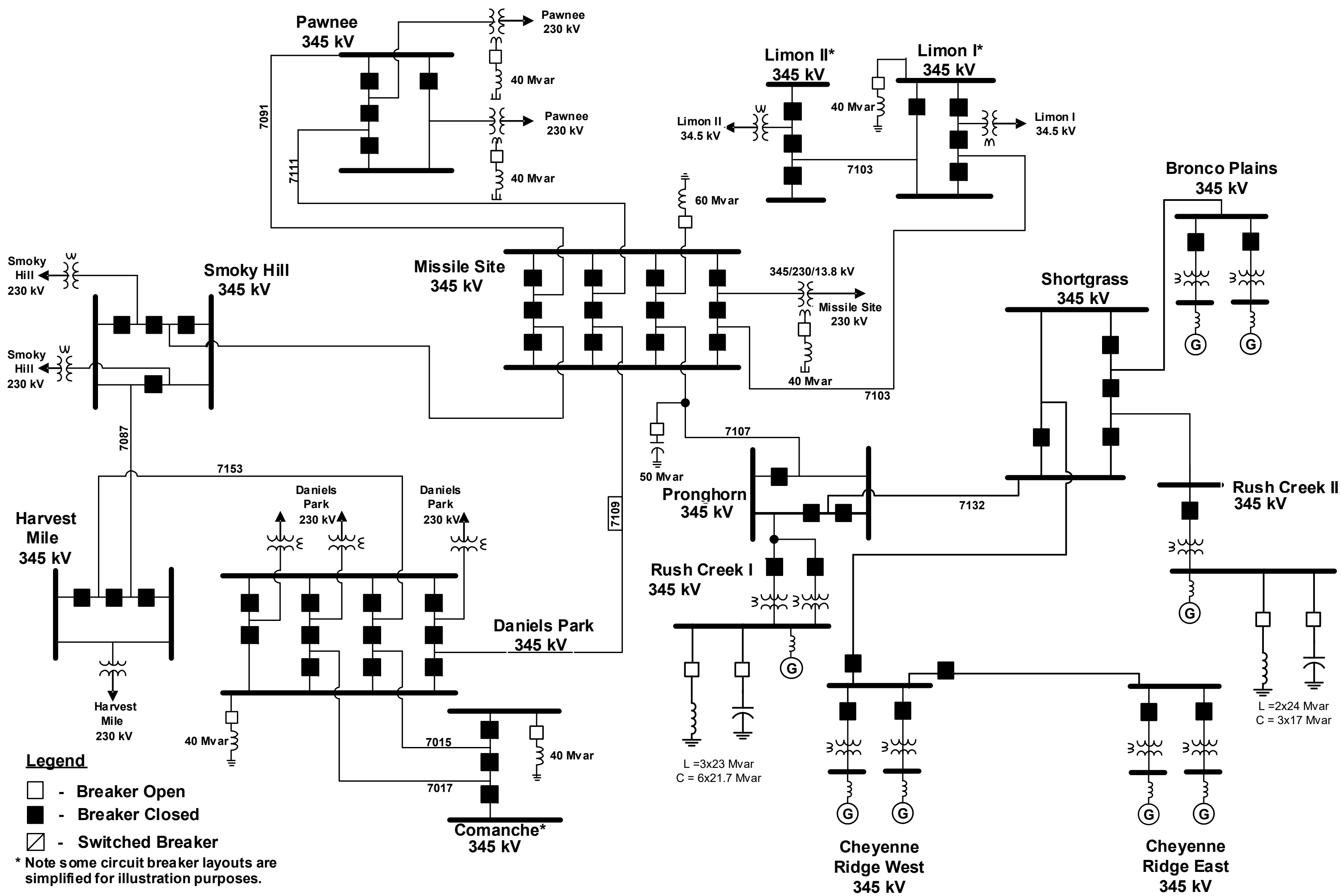

Figure 3.2-1. One-line diagram of the wind generation and immediate study area.

After the initial steady-state analysis was completed (results presented in Appendix A), Xcel Energy provided updates to some of the models, including the Cheyenne Ridge East and Cheyenne Ridge West collector systems. The data in Tables 3.2-1 through 3.2-3 include the updated information for the wind plants. This updated data was used for the dynamic stability analysis (Section 3), PV/QV (Section 4), and reduced dispatch analysis (Section 5). Key steady-state cases were re-examined using the updated data and it was confirmed that the change in representation had a minimal impact on the steady-state results.

Refer to Tables 3.2-1 through 3.2-3 for the interconnection data used to represent the wind plants of interest.

- Table 3.2-1 shows the transformer data for the wind plants of interest
- Table 3.2-2 shows the line data for the wind plants of interest
- Table 3.2-3 shows the wind turbine data for the wind plants of interest

Based on steady-state power flow calculations, additional compensation was needed for the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants to meet power factor requirements. Note the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants will be expected to maintain a 0.95 power factor (leading and lagging) at the high side of their respective 345/34.5 kV transformers and were adjusted to meet the power factor requirements. Refer to Table 3.2-3 for the adjusted reactive power ranges.

Table 3.2-1
Transformer Data for the Wind Plants of Interest

Ref. No.	From Bus			To Bus			Ckt ID	MVA Base	R (p.u.)	X (p.u.)
	No.	Name	Voltage (kV)	No.	Name	Voltage (kV)				
1	70628	PRONGHORN	345	70629	RUSHCK_W1	34.5	T1	138.0	0.0024	0.1000
2	70628	PRONGHORN	345	70629	RUSHCK_W1	34.5	T2	138.0	0.0024	0.1000
3	70629	RUSHCK_W1	34.5	88886	RUSHCK_W1	0.69	T1	430.0	0.0063	0.0758
4	70630	SHORTGRASS	345	70631	RUSHCK_W2	34.5	T1	138.0	0.0024	0.1000
5	70631	RUSHCK_W2	34.5	88887	RUSHCK_W2	0.69	T1	248.0	0.0063	0.0758
6	70633	BRONCOPLNS	345	88882	BRONCO_PL	34.5	1	102.0	0.0022	0.0867
7	70633	BRONCOPLNS	345	88882	BRONCO_PL	34.5	2	102.0	0.0022	0.0867
8	88864	BRONCO_PL1	34.5	88863	BRONCO_PL1	0.69	1	336.0	0.0266	0.1999
9	2967	BUS34	345	2695	BUS4	34.5	1	90.0	0.0032	0.1100
10	2950	BUS31	345	2707	BUS5	34.5	1	90.0	0.0026	0.1100
11	2964	BUS32	345	2820	BUS22	34.5	1	90.0	0.0026	0.1100
12	2965	BUS33	345	2819	BUS21	34.5	1	90.0	0.0026	0.1100
13	2785	BUS17	34.5	2789	BUS18	0.69	1	132.3	0.0110	0.0994
14	2371	BUS8	34.5	2389	BUS9	0.69	1	130.2	0.0110	0.0994
15	2803	BUS19	34.5	2807	BUS20	0.69	1	132.3	0.0110	0.0994
16	2758	BUS15	34.5	2771	BUS16	0.69	1	130.2	0.0110	0.0994

Table 3.2-2
Line Data for the Wind Plants of Interest

Ref. No.	From Bus			To Bus			R (p.u.)	X (p.u.)	B (p.u.)
	No.	Name	Voltage (kV)	No.	Name	Voltage (kV)			
1	70628	PRONGHORN	345	70630	SHORTGRASS	345	0.00124	0.01928	0.33396
2	70633	BRONCOPLNS	345	70630	SHORTGRASS	345	0.00070	0.00666	0.12457
3	88882	BRONCO_PL	34.5	88864	BRONCO_PL1	34.5	0.00143	0.00068	0.02631
4	70630	SHORTGRASS	345	3029	BUS35	345	0.00000	0.00010	0.00000
5	70632	CHEYRDGE W	345	3029	BUS35	345	0.00197	0.03241	0.49282
6	70632	CHEYRDGE W	345	88884	CHEYRDGE E	345	0.00035	0.00582	0.08843
7	70632	CHEYRDGE W	345	2967	BUS34	345	0.00000	0.00010	0.00000
8	70632	CHEYRDGE W	345	2950	BUS31	345	0.00000	0.00010	0.00000
9	2707	BUS5	34.5	2785	BUS17	34.5	0.00182	0.00290	0.12100
10	2371	BUS8	34.5	2695	BUS4	34.5	0.00182	0.00290	0.12100
11	2803	BUS19	34.5	2820	BUS22	34.5	0.00182	0.00290	0.12100
12	2758	BUS15	34.5	2819	BUS21	34.5	0.00182	0.00290	0.12100
13	88884	CHEYRDGE E	345	2964	BUS32	345	0.00000	0.00010	0.00000
14	88884	CHEYRDGE E	345	2965	BUS33	345	0.00000	0.00010	0.00000

Table 3.2-3
Wind Turbine Data for the Wind Plants of Interest

Ref. No.	Bus No.	Bus Name	Scheduled Voltage (p.u.)(1)	Max P @ POI(2) (MW)	Required PF @ POI	Required Q @ POI (MVAr)	Plant Losses (Mvar)	Initial Generator Capability		Plant Shunt Compensation		Plant Capability @ POI		Adjusted Final Generator Capability		Description(4)
								Qmax (Mvar)	Qmin (Mvar)	Shunt Cap (Mvar)	Shunt L (Mvar)	Capacitive (Mvar)	Inductive (Mvar)	Qmax (Mvar)	Qmin(3) (Mvar)	
1	88886	RUSHCK_W1	1.00	376	0.95	123.59	-44.00	77.16	-77.16	130.20	-69.00	163.36	-190.16	77.16	-77.16	meets
2	88887	RUSHCK_W2	1.00	218	0.95	71.65	-2.67	41.00	-44.00	51.00	-48.00	89.33	-94.67	41.00	-44.00	meets
3	88863	BRONCO_PL1	1.02	290	0.95	95.32	-92.89	144.00	-144.00	0.00	0.00	51.11	-236.89	188.21	-30.00	adjusted
4	2789	BUS18	1.00	128.6	0.95	42.26	-32.00	25.2	-25.2	0.00	0.00	-6.80	-57.20	74.26	-7.00	adjusted
5	2389	BUS9	1.00	126.5	0.95	41.59	-32.00	25.2	-25.2	0.00	0.00	-6.80	-57.20	73.59	-7.00	adjusted
6	2807	BUS20	1.00	132.6	0.95	43.59	-32.00	41.4	-41.4	0.00	0.00	9.40	-73.40	75.59	-7.00	adjusted
7	2771	BUS16	1.00	126.5	0.95	41.59	-32.00	25.2	-25.2	0.00	0.00	-6.80	-57.20	73.59	-7.00	adjusted

(1) Generators were set to regulate their own bus voltage.
(2) The POI is considered at the high-side of the 345/34.5 kV transformers for power factor purposes
(3) For the new plants (Bronco Plains and Cheyenne Ridge West and East) Qmin was adjusted to result in a 0.95 p.u. at the POI o be conservative.
(4) Highlighted cells indicate plants that are not capable of meeting power factor requirements and were adjusted to maintain a 0.95 power factor (leading and lagging) at the high-side of their respective 345/34.5 kV transformers.

3.3 Approach for the Steady-State Analysis

The primary objective of the steady-state analysis is to identify potential voltage concerns per WECC Criterion. The complete steady-state analysis presented in Appendix A was performed with the objective of identifying the minimum amount of reactive compensation required to mitigate voltage/thermal violations to accommodate the additional wind generation along the Gen-Tie line. The minimum reactive power needs identified in Appendix A were verified by examining key cases and contingencies with the updated power flow cases.

The following key power flow cases were used for the analysis:

- Heavy Summer – High wind – Gen-Tie 1400 MW
  - Constructed based on the 28HS1a_CEP_LowWind 0MW.sav and 28HS1a_CEP_HighWIND 1600MW.sav cases with Xcel Energy's guidance.
- Light Spring – High wind – Gen-Tie 1400 MW
  - 21LSP1a_CEP_HighWind 1400MW.sav

The minimum reactive compensation needed to mitigate voltage violations for base case (N-0) conditions (identified in Appendix A) were added to the updated power flow cases. Refer to Table 3.3-1 for the minimum reactive power compensation identified in the full steady-state analysis (presented in Appendix A) to satisfy the voltage criteria for the heavy summer and light spring base cases (N-0). Note this was the starting point for the updated power flow cases presented in this section.

Table 3.3-1
Reactive Power Support Needed for Base Case (N-0) Presented in Appendix A

Additional Static Support			
Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
115	115	130	300

Base case and limiting contingencies were examined to ensure no low voltages of concern were identified with the updated cases. The following key contingencies were examined for the updated power flow cases:

- The following N-1 contingencies were examined for the steady-state analysis:
  - Loss of the Missile Site – Smoky Hill 345 kV line
  - Loss of the Missile Site 345 kV Capacitor Bank
  - Loss of the Pronghorn 345 kV Capacitor Bank
- Stuck breaker contingencies were examined for the steady-state analysis at the following substations:
  - Loss of the Smoky Hill – Missile Site 345 kV line and the Missile Site – Pawnee 345 kV line
  - Loss of the Missile Site – Smoky Hill 345 kV line and the Harvest Mile – Smoky Hill 345 kV line

3.4 Steady-State Analysis Results

With the updated steady-state cases, it was determined that the steady-state reactive power compensation identified for base case conditions was sufficient for the N-1 and stuck breaker contingencies examined.

Note for the original steady-state analysis presented in Appendix A, it was determined that a post-contingency voltage of 0.94 p.u. was required at Harvest Mile 345 kV, a post-contingency voltage of 0.96 p.u. at Missile Site 345 kV, and a post-contingency voltage of 0.95 p.u. at Pronghorn 345 kV to avoid potential voltage collapse. With the updated heavy summer 1400 MW case, voltage collapse did not occur at these voltage levels and it was determined that no additional reactive power devices were needed beyond the devices required for base case (N-0) conditions. It is anticipated that minimum voltage levels above 0.90 p.u. exist for the post-contingency voltages at the Harvest Mile, Missile Site, and Pronghorn 345 kV buses, but these were not identified for this sensitivity since diverging issues were not identified.

- For reference purposes, Table 3.4-1 shows all existing reactive compensation and the status of the devices for the immediate study area.
- Refer to Table 3.4-2 for a summary of the additional reactive power compensation needed to meet base case (N-0) criteria for each examined case.
- Refer to Table 3.4-3 for result tables showing bus voltages with and without the additional reactive compensation for base case conditions.
- Refer to Table 3.4-4 and 3.4-5 for summary tables showing the bus voltages in the immediate study area for the limiting contingencies with only the planned compensation needed for base case (N-0) conditions for the heavy summer and light spring cases, respectively.

Table 3.4-1
Dispatch of Existing Reactive Power Support in the Immediate Study Area

Case Name	Pre-Existing Static Support (Mvar)						
	Missile Tap 230 kV (70621)	Missile Cap 345 kV (88888)	Missile Site 345 kV (70624)	Limon I 345 kV (70625)	Daniels Park 345 kV (70601)	Rush Creek W1 34.5 kV (70629)	Rush Creek W2 34.5 kV (70631)
Light Spring – High wind – Gen-Tie 1400 MW	90	50	0	0	0	130.2	51
Heavy Summer – High wind – Gen-Tie 1400 MW	150	50	0	40	0	130.2	51

Table 3.4-2
Dispatch of Additional Reactive Power Support Needed for the Immediate Study Area (In Addition to the Existing Devices)

Case Name	Additional Static Support				
	Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Cheyrdge W 345 kV (70632)	Missile Site 345 kV (70624)
Light Spring – High wind – Gen-Tie 1400 MW	0	0	0	0	0
Heavy Summer – High wind – Gen-Tie 1400 MW	115	115	130	0	300

Table 3.4-3
Summary Results for the Final Heavy Summer High Wind and Light Spring High Wind Cases Case with and without Reactive Power Compensation as Mitigation for Base Case Voltage Violations

Bus Number	Bus Name	kV	Contingency Description	No Mitigation		With Additional Reactive Power Compensation	
				Heavy Summer High wind 1400 MW	Light Spring High wind 1400 MW	Heavy Summer High wind 1400 MW	Light Spring High wind 1400 MW
70598	PAWNEE	345	Base Case (N-0)	0.966	1.005	0.991	1.005
70599	SMOKYHIL	345		0.932	1.001	0.967	1.001
70601	DANIELPK	345		0.930	0.995	0.962	0.995
70623	MIS_SITE	230		0.960	1.015	0.995	1.015
70624	MIS_SITE	345		0.946	0.995	0.986	0.995
70625	LIMON1	345		0.984	1.014	1.011	1.014
70626	LIMON2	345		0.987	1.016	1.013	1.016
70627	LIMON3	345		0.991	1.017	1.015	1.017
70597	HARVEST_MI	345		0.932	1.001	0.968	1.001
70628	PRONGHORN	345		0.929	0.954	0.967	0.954
70630	SHORTGRASS	345		0.945	0.959	0.968	0.959
70632	CHEYRDGE W	345		0.980	0.989	0.988	0.989
88884	CHEYRDGE E	345		0.983	0.993	0.991	0.993
70633	BRONCOPLNS	345		0.948	0.960	0.970	0.960

Table 3.4-4
Bus Voltages for Limiting Contingencies for the Final Power Flow Case with Only the Reactive Compensation Identified for Base Case (N-0) Conditions for the Heavy Summer Case

Ref. No.	Contingency Description	Contingency Type	Pawnee 345 kV	Smoky Hill 345 k	Daniels Park 345 kV	Missile Site 345 kV	Harvest Mile 345 kV	Pronghorn 345 kV	Shortgrass 345 kV	Cheyenne West 345 kV	Cheyenne East 345 kV	Bronco Plains 345 kV
1	Missile Site - Smoky Hill 345 kV	N-1	0.966	0.938	0.926	0.957	0.938	0.941	0.943	0.962	0.965	0.945
2	Smoky Hill - Missile Site 345 kV Missile Site - Pawnee 345 kV	SB	0.952	0.926	0.912	0.930	0.926	0.920	0.927	0.952	0.955	0.930
3	Missile Site - Smoky Hill 345 kV Harvest Mile - Smoky Hill 345 kV	SB	0.966	0.937	0.925	0.957	0.937	0.941	0.943	0.962	0.965	0.945
4	Missile Site 345 kV Capacitor Bank	N-1	0.975	0.951	0.949	0.959	0.952	0.942	0.944	0.963	0.965	0.946
5	Pronghorn 345 kV Capacitor Bank	N-1	0.983	0.960	0.956	0.974	0.960	0.934	0.938	0.960	0.962	0.941

Table 3.4-5
Bus Voltages for Limiting Contingencies for the Final Power Flow Case with Only the Reactive Compensation Identified for Base Case (N-0) Conditions for the Light Spring Case

Ref. No.	Contingency Description	Contingency Type	Pawnee 345 kV	Smoky Hill 345 k	Daniels Park 345 kV	Missile Site 345 kV	Harvest Mile 345 kV	Pronghorn 345 kV	Shortgrass 345 kV	Cheyenne West 345 kV	Cheyenne East 345 kV	Bronco Plains 345 kV
1	Missile Site - Smoky Hill 345 kV	N-1	0.983	0.994	0.982	0.975	0.994	0.940	0.949	0.983	0.987	0.951
2	Smoky Hill - Missile Site 345 kV Missile Site - Pawnee 345 kV	SB	0.979	0.990	0.977	0.964	0.990	0.933	0.944	0.980	0.983	0.946
3	Missile Site - Smoky Hill 345 kV Harvest Mile - Smoky Hill 345 kV	SB	0.983	0.998	0.981	0.974	0.990	0.940	0.949	0.983	0.986	0.951
4	Missile Site 345 kV Capacitor Bank	N-1	1.005	1.001	0.995	0.995	1.001	0.954	0.959	0.989	0.993	0.960
5	Pronghorn 345 kV Capacitor Bank	N-1	1.005	1.001	0.995	0.995	1.001	0.954	0.959	0.989	0.993	0.960

3.5 Summary for the Steady-State Analysis

The primary objective of the steady-state analysis was to identify potential voltage concerns per WECC Criterion.

- It was determined that reactive power compensation was needed to meet WECC voltage criteria for base case (N-0) conditions.

With the updated steady-state case, it was determined that the steady-state reactive power compensation identified for base case conditions was sufficient for the N-1 and stuck breaker contingencies examined.

- Table 3.5-1 shows the minimum reactive power compensation needed to satisfy the voltage criteria for the heavy summer and light spring case (0 MW and 1400 MW dispatch) for base case and N-1/stuck breaker conditions for the final power flow case.
- Figure 3.5-1 shows a one-line diagram of the immediate study area and the reactive power devices needed to meet voltage criteria for base case conditions and for N-1 and stuck breaker contingency conditions.

Table 3.5-1
Additional Reactive Power Support Needed for Base Case (N-0), N-1, and Stuck Breaker Conditions

Additional Static Support			
Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
115	115	130	300

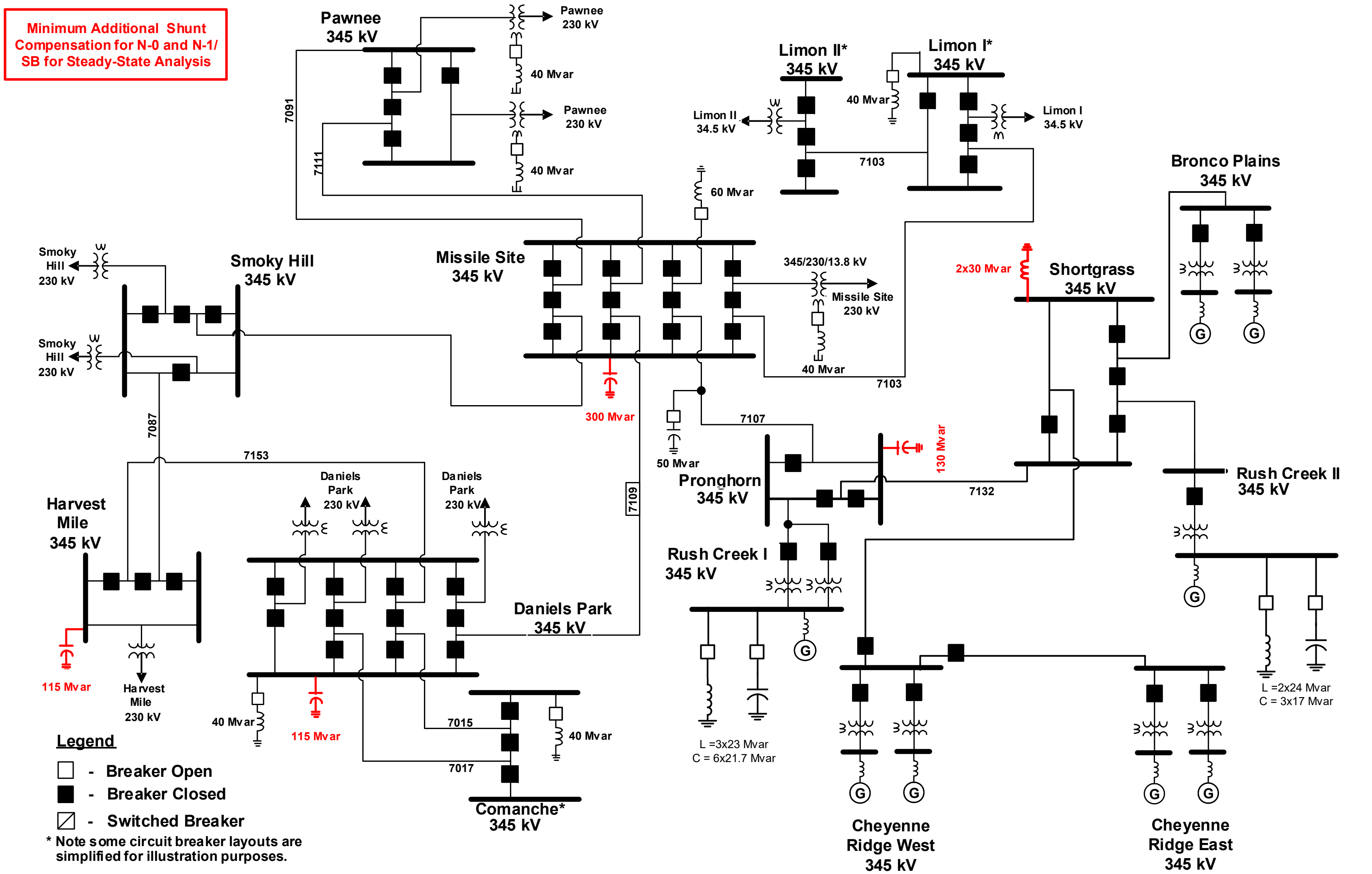

Figure 3.5-1. One-line diagram of the wind generation and immediate study area with static reactive power compensation.

SECTION 4
DYNAMIC ANALYSIS

4.1 Background and Introduction

A transient stability analysis was performed to determine if dynamic reactive compensation is required to accommodate the increase in wind generation along the Gen-Tie, or if the fixed/mechanically switched reactive compensation identified as necessary in the steady-state analysis is able to adequately provide the reactive support required by the system during dynamic events. Limiting contingencies identified in the steady-state analysis were examined, and all contingencies that resulted in non-convergence, delayed voltage recovery, voltage criteria violations, or system instability were reported.

After the completion of the steady-state analysis, focus was placed on the cases for 1400 MW dispatch of the new wind generation. After discussion with Xcel Energy it was determined that the same mitigation technique should be used for the heavy summer and light spring cases and for the different loading conditions and that the reactive compensation necessary to meet base case (N-0) voltage criteria found in the steady-state analysis should be used as the starting point for the dynamic analysis. To determine the impact of the new generation and to identify the potential need for dynamic reactive power compensation, the 1400 MW heavy summer and the 1400 MW light spring cases were examined.

4.2 Review and Construction of the Power Flow Cases

The shunt compensation illustrated in Table 4.2-1 was included in the cases as a starting point based on the results of the steady-state contingency analysis.

Table 4.2-1
Dispatch of Additional Reactive Power Support Needed for Base Case (N-0) and N-1 and Stuck Breaker Conditions

Additional Static Support (Mvar)			
Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
115	115	130	300

4.3 Approach for the Dynamic Analysis

The primary objective of the dynamic analysis is to identify potential control instabilities or delayed voltage recovery concerns to determine if dynamic reactive power compensation is necessary to accommodate the additional wind generation added to the Gen-Tie. MEPPI monitored the study Area 70 for voltage violations (delayed voltage recovery and low or high final voltages), system instability, and the response of the wind plants of interest.

The following cases and dynamic data files were used to identify any dynamic reactive power needs:

- Heavy Summer – High wind – Gen-Tie 1400 MW
  - Constructed based on the 28HS1a_CEP_LowWind 0MW.sav and 28HS1a_CEP_HighWIND 1600MW.sav cases with Xcel Energy's guidance.
  - 28HS1a1_CEP.dyd
- Light Spring – High wind – Gen-Tie 1400 MW
  - 21LSP1a_CEP_HighWind 1400MW.sav
  - 21LSP11_CEP.dyd

DYTOOLs (Dynamic Analysis Tools) in PSLF 21.0_05 was used to complete the dynamic analysis.

Table 4.3-1 shows all static shunt compensation required to meet base case (N-0) voltage criteria for the steady-state analysis in the study area, which was the starting point for the dynamic analysis.

Table 4.3-1
Additional Reactive Power Support Needed for Base Case (N-0) Conditions

Additional Static Support (Mvar)			
Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
115	115	130	300

Additional mitigation, if necessary was examined for the contingency analysis to mitigate any system stability or voltage recovery issues identified. Note all reactive power compensation was sized to meet the minimum requirements for contingency conditions by modeling a dynamic device (for this analysis a SVC) at the following key buses in the study area:

- Pronghorn 345 kV
- Missile Site 345 kV

Note these locations were chosen based on the contingency list and results from the steady-state analysis.

Reactive Device Modeling for the Dynamic Analysis

For this analysis, SVCs were used as the form of dynamic reactive power mitigation. A generic SVC model was used with typical parameters. Each SVC of similar size was modeled using the same parameters.

Each SVC was set to regulate the pre-fault steady-state bus voltage, so that the SVC would have minimal output for N-0 conditions. Note these voltages ranged based on the study year and loading condition. For example, for the heavy summer 1400 MW case the voltage set point for Missile Site 345 kV was 0.98 p.u. and the voltage set point for Pronghorn 345 kV was 0.96 p.u.

The SVSMO1 model was used to represent the SVCs for this analysis. The SVSMO1 model is designed to maintain a desired voltage at the regulated bus by adjusting the shunt susceptance (B) of the SVC. If the regulated bus voltage decreases below the voltage set point, the SVC increases its shunt susceptance (within controlled limits) to inject reactive power (Q) into the system, increasing the bus voltage back towards the desired set point. If the regulated bus voltage increases above the voltage set point, the SVC will absorb reactive power (within controlled limits), decreasing the bus voltage back towards the desired set point. The SVC injects/absorbs reactive power into the system based on the square of the terminal voltage ($Q=V^2xB$). Refer to Figure 4.3-1 for a block diagram of the SVSMO1 model and Table 4.3-2 for the list of parameters used for this analysis.

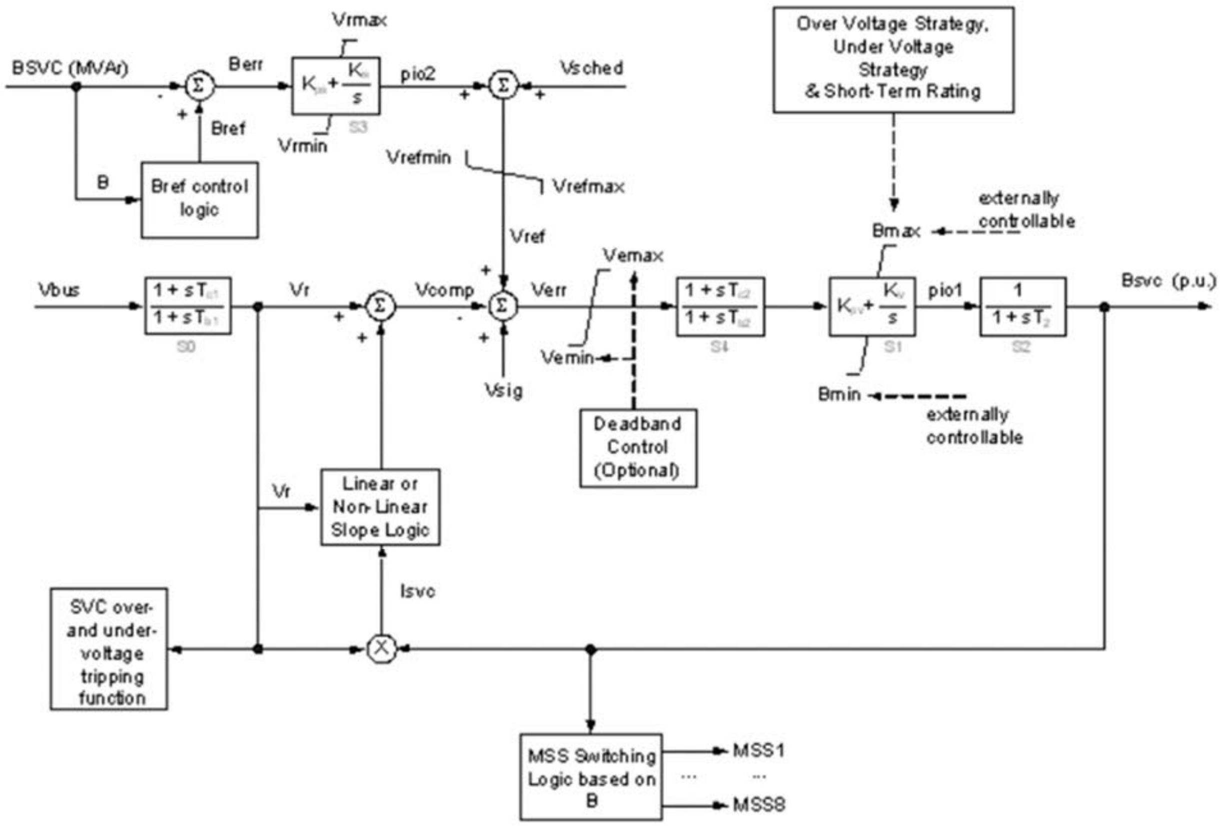

Figure. 4.3-1 Block diagram for the SVSMO1 model.

Table 4.3-2
Parameters used for the SVSMO1 Model

EPCL Variable	Modeled SVCs		Description
	70624	70628	
	Missile Site 345 kV	Pronghorn 345 kV	
UVSBmax	0	0	Max. capacitive limit during undervoltage strategy
UV1	0.4	0.4	Under voltage setpoint 1 (p.u.)
UV2	0	0	Under voltage setpoint 2 (p.u.)
UVT	0.005	0.005	Under voltage trip setpoint (p.u.)
OV1	1.25	1.25	Over voltage setpoint 1 (p.u.)
OV2	1.4	1.4	Over voltage setpoint 2 (p.u.)
UVtm1	0.005	0.005	Under voltage trip time 1 (sec.)
Uvtm2	30	30	Under voltage trip time 2 (sec.)
OVtm1	0.005	0.005	Over voltage trip time 1 (sec.)
Ovtm2	0.2	0.2	Over voltage trip time 2 (sec.)
flag1	0	0	0 - no MSS switching; 1 - MSS switching enabled
flag2	0	0	0 - linear slope; 1 - non-linear slope (piecewise)
Xc1	0.01	0.01	Slope (nominal linear slope or first section of piecewise linear slope) (p.u./p.u.)
Xc2	0	0	Slope of second section of piecewise linear slope (p.u./p.u.)
Xc3	0	0	Slope of third section of piecewise linear slope (p.u./p.u.)
Vup	1.4	1.4	Upper voltage break-point for non-linear slope (p.u.)
Vlow	0	0	Lower voltage break-point for non-linear slope (p.u.)
Tc1	0	0	Voltage measurement lead time constant (sec.)
Tb1	0.00867	0.00867	Voltage measurement lag time constant (sec.)
Tc2	0	0	Lead time constant for transient gain reduction (sec.)
Tb2	0	0	Lag time constant for transient gain reduction (sec.)
Kpv	2	2	Voltage regulator proportional gain (p.u./p.u.)
Kiv	1200	1200	Voltage regulator integral gain (p.u./p.u. sec.)
vemax	999	999	Max. allowed voltage error (p.u.)
vemin	-999	-999	Min. allowed voltage error (p.u.)
T2	0.00667	0.00667	Firing delay time constant (sec.)
Bshrt	0.5	0.5	Short-term max. capacitive rating of the SVC (p.u.)
Bmax	0.5	0.5	Continuous max. capacitive rating of SVC (p.u.) (Note n)
Bmin	-0.5	-0.5	Continuous min. inductive rating of SVC (p.u.) (Note n)
Tshrt	3	3	Short-term rating definite time delay (sec.)
Kps	0	0	Proportional gain of slow-suceptance regulator (p.u./p.u.)
Kis	0	0	Integral gain of slow-susceptance regulator (p.u./p.u. sec.)
Vrmax	0	0	Max. allowed PI controller output of slow-susceptance regulator (p.u.)
Vrmin	0	0	Min. allowed PI controller output of slow-susceptance regulator (p.u.)
Vdbd1	0	0	Steady-state voltage deadband; SVC is inactive between Vref+Vdbd1 to Vref-Vdbd1 (p.u.)
Vdbd2	0	0	Inner voltage deadband (p.u.). When Vdbd1 is exceeded SVC must come back within Vdbd2, for Tdbd seconds, in order to be locked again (p.u.)
Tdbd	0	0	Definite time deadband delay (sec.)
PLLdelay	0.015	0.015	PLL delay in recovering if voltage remains below UV1 for more than UVtm1 (sec.)
eps	0.5	0.5	Small delta added to the susceptance bandwidth of the slow-susceptance regulator in order to ensure its limits are not exactly identical to the MSS switching point (MVAr)

Table 4.3-2 (Continued)
Parameters used for the SVSMO1 Model

EPCL Variable	Modeled SVCs		Description
	70624	70628	
	Missile Site 345 kV	Pronghorn 345 kV	
Blcs	999	999	Large threshold for switching MSS on the capacitive side (MVAr)
Bscs	999	999	Small threshold for switching MSS on the capacitive side (MVAr)
Blis	-999	-999	Large threshold for switching MSS on the inductive side
Bsis	-999	-999	Small threshold for switching MSS on the inductive side (MVAr)
Tmssbrk	999	999	MSS breaker switch delay (for opening and closing; assumed the same value for all MSS) (sec.)
Tdelay1	999	999	Definite time delay for large switching threshold (sec.)
Tdelay2	999	999	Definite time delay for small switching threshold (sec.)
Tout	999	999	Discharge time for mechanically switched capacitors (sec.)

Metrics and Violations

The study area of interest was defined as Area 70. The following metrics were used to flag voltage violations for the dynamic analysis:

- Voltage Violations:
  - System stability was monitored for all buses
  - System stability was monitored for all nearby generation with focus placed on the Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains wind plants
    - Tripping of plants were flagged
    - Tripping of any generation in the study area was flagged
  - Buses were flagged if the final voltages were less than 0.95 p.u. or greater than 1.05 p.u. in Area 70 for base case conditions (N-0).
  - Buses were flagged if the final voltages were less than 0.90 p.u. or greater than 1.10 p.u. in Area 70 for contingency conditions.

Contingency List

The contingencies examined for this analysis were agreed upon with Xcel Energy and were based off the steady-state analysis results.

- The following N-1 contingencies were examined for the dynamic analysis:
  - Fault at Missile Site 345 kV resulting in the loss of the Missile Site – Smoky Hill 345 kV line
  - Fault at Missile Site 345 kV resulting in the loss of the Missile Site – Pronghorn 345 kV line

  - Fault at Missile Site 345 kV resulting in the loss of the Missile Site – Daniels Park 345 kV line
  - Fault at Daniels Park 345 kV resulting in the loss of the Daniels Park – Comanche 345 kV line
  - Fault at Pronghorn 345 kV resulting in the loss of the Pronghorn – Shortgrass 345 kV line
  - Fault at Cheyenne Ridge West 345 kV resulting in the loss of Cheyenne Ridge West – Cheyenne Ridge East 345 kV line
- The following stuck breaker contingencies were examined for the dynamic analysis:
  - Fault at Missile Site 345 kV with a stuck breaker resulting in the loss of both the Missile Site – Pawnee 345 kV lines
  - Fault at Missile Site 345 kV with a stuck breaker resulting in the loss of the Missile Site – Pawnee 345 kV and Missile Site – Smoky Hill 345 kV
  - Fault at Smoky Hill 345 kV with a stuck breaker resulting in the loss of the Smoky Hill – Missile Site 345 kV and Smoky Hill – Harvest Mile 345 kV line
  - Fault at Pronghorn 345 kV with a stuck breaker resulting in the loss of the Pronghorn – Shortgrass 345 kV and Pronghorn – Rush Creek W1 345 kV
  - Fault at Pronghorn 345 kV with a stuck breaker resulting in the loss of the Pronghorn – Shortgrass 345 kV and Shortgrass – Cheyenne Ridge W 345 kV
  - Fault at Daniels Park 345 kV with a stuck breaker resulting in the loss of the Missile Site – Daniels Park 345 kV and Daniels Park 345/230 kV transformer
  - Fault at Daniels Park 345 kV with a stuck breaker resulting in the loss of the Daniels Park – Comanche 345 kV and Daniels Park 345 kV Capacitor Bank

4.4 N-1 and Stuck Breaker Dynamic Analysis Results

The following cases were examined for the N-1 and stuck breaker contingencies for the heavy summer 1400 MW case to help identify reactive power compensation needs:

- No dynamic mitigation
- +/- 50 Mvar SVC at Missile Site 345 kV
- +/- 50 Mvar SVC at Pronghorn 345 kV

Refer to Figures 4.4-1 through 4.4-10 for comparison plots showing the impact of each mitigation solution. Below is a summary of the dynamic analysis results.

No Dynamic Mitigation

Refer to Table 4.4-1 for a summary of the results for the dynamic analysis for the limiting N-1 and stuck breaker contingencies examined.

- The system remained stable for all contingencies examined.

- Post fault oscillations of concern were observed for the following contingencies:
  - Fault at Missile Site 345 kV that results in the loss of the Missile Site – Smoky Hills 345 kV
  - Stuck break at Missile Site 345 kV that results in the loss of both Missile Site – Pawnee 345 kV lines
  - Stuck breaker at Missile Site 345 kV that results in the loss of the Missile Site – Pawnee 345 kV line and the Missile Site – Smoky Hill 345 kV line
  - Stuck breaker at Smoky Hill 345 kV that results in the loss of the Smoky Hill – Missile Site 345 kV line and Smoky Hill – Harvest Mile 345 kV line
- It was determined that there is a narrow range for the controller gains for a stable solution, indicating a potentially unstable condition. An SVC was explored as an option to help damp these oscillations by strengthening voltage regulation on the tie line.
- The stability models used in this study represent idealized wind plant performance and do not capture the reduced controllability and possible degraded performance under weak grid conditions as experienced by the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants. Tuning the wind plants for weak grid conditions will typically result in slower performance, reducing the contribution of the wind plants to voltage regulation, especially during the critical post fault recovery period. Before the wind plants are finalized, it is recommended that Xcel Energy work closely with the wind turbine manufacturers to evaluate wind plant dynamic performance using detailed OEM "user-models" of the wind turbine generators adequate for the low short-circuit ratio observed along the Missile Site gen-tie line under actual conditions.

- No delayed voltage recovery was observed.
- All bus voltages recovered above 0.90 p.u.
- All bus voltages recovered below 1.10 p.u.
- The following generator tripped for some contingencies examined due to short tripping times. These trip times do not meet NERC PRC-024 ride-through requirements.
  - PTZLOGN1 34.5 kV

+/- 50 Mvar SVC at Missile Site 345 kV

Refer to Table 4.4-2 for a summary of the results for the dynamic analysis for the limiting N-1 and stuck breaker contingencies examined with a +/- 50 Mvar SVC at Missile Site 345 kV. Note the scheduled voltage for the Missile Site 345 kV SVC is set to regulate the Missile Site 345 kV bus at 0.98 p.u.

- The system remained stable for all contingencies examined.
  - The oscillations previously observed (with no dynamic device) were better damped with the addition of the SVC.
  - The SVC at Missile Site provides some improvement in voltage regulation on the tie line, but significant impedance between Missile Site and Pronghorn reduces its impact, and the oscillations of concern are still prevalent.

- No delayed voltage recovery was observed.
- All bus voltages recovered above 0.90 p.u.
- All bus voltages recovered below 1.10 p.u.
- The following generator tripped for some contingencies examined due to short tripping times. These trip times do not meet NERC PRC-024 ride-through requirements.
    - PTZLOGN1 34.5 kV

+/- 50 Mvar SVC at Pronghorn 345 kV

Refer to Table 4.4-3 for a summary of the results for the dynamic analysis for the limiting N-1 and stuck breaker contingencies examined with a +/- 50 Mvar SVC at Pronghorn 345 kV for the heavy summer case. Note the scheduled voltage for the Pronghorn 345 kV SVC is set to regulate the Pronghorn 345 kV bus at 0.96 p.u.

- The system remained stable for all contingencies examined.
    - With the SVC at Pronghorn 345 kV (closer to the wind plants) the oscillations observed were well damped.
    - The notable improvement in oscillation damping represents the significant contribution of the SVC to voltage regulation on the tie line. Because actual performance of the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants under weak grid conditions may be worse than idealized stability models indicate, additional dynamic reactive compensation would be highly beneficial to regulate voltage along the tie line.
- No delayed voltage recovery was observed.
- All bus voltages recovered above 0.90 p.u.
- All bus voltages recovered below 1.10 p.u.
- The following generator tripped for some contingencies examined due to short tripping times. These trip times do not meet NERC PRC-024 ride-through requirements.
    - PTZLOGN1 34.5 kV

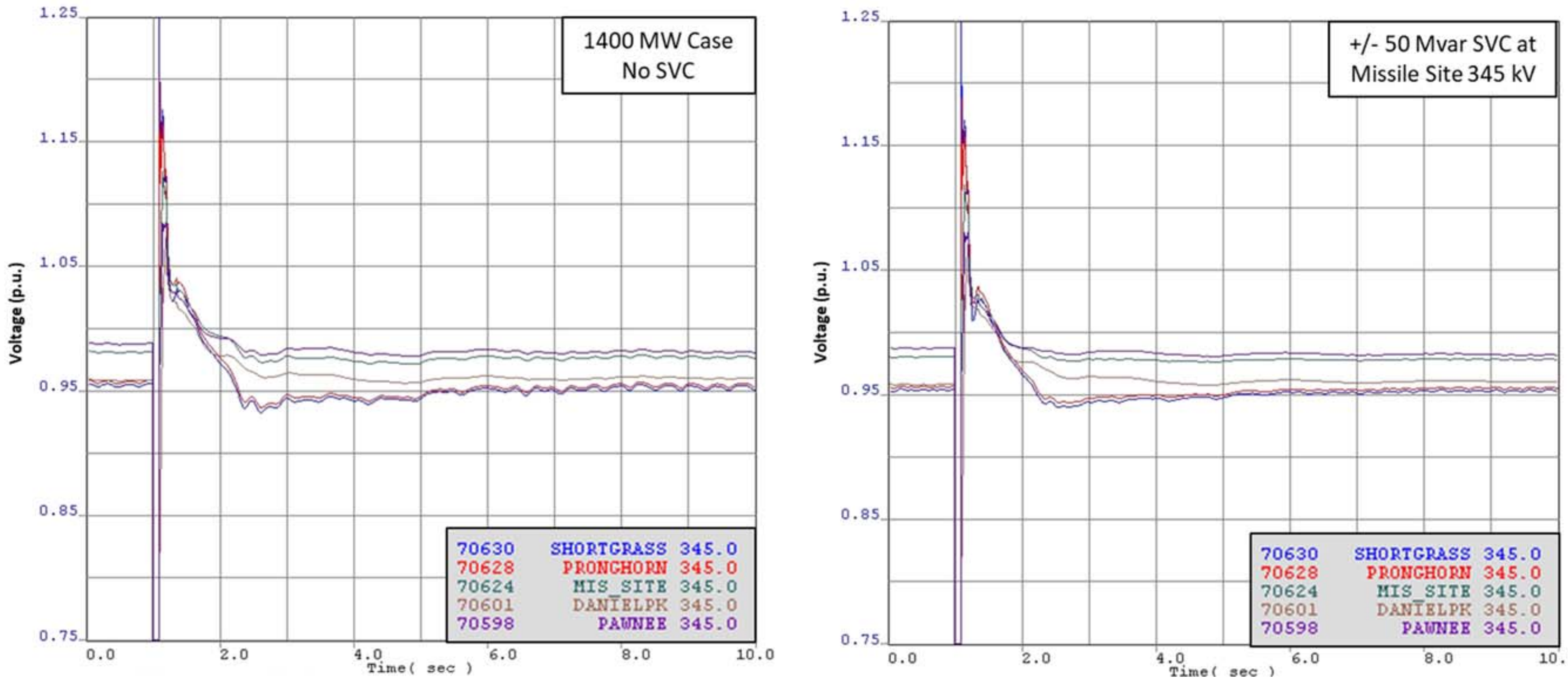

Figure 4.4-1. Voltage plots showing nearby bus voltage for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

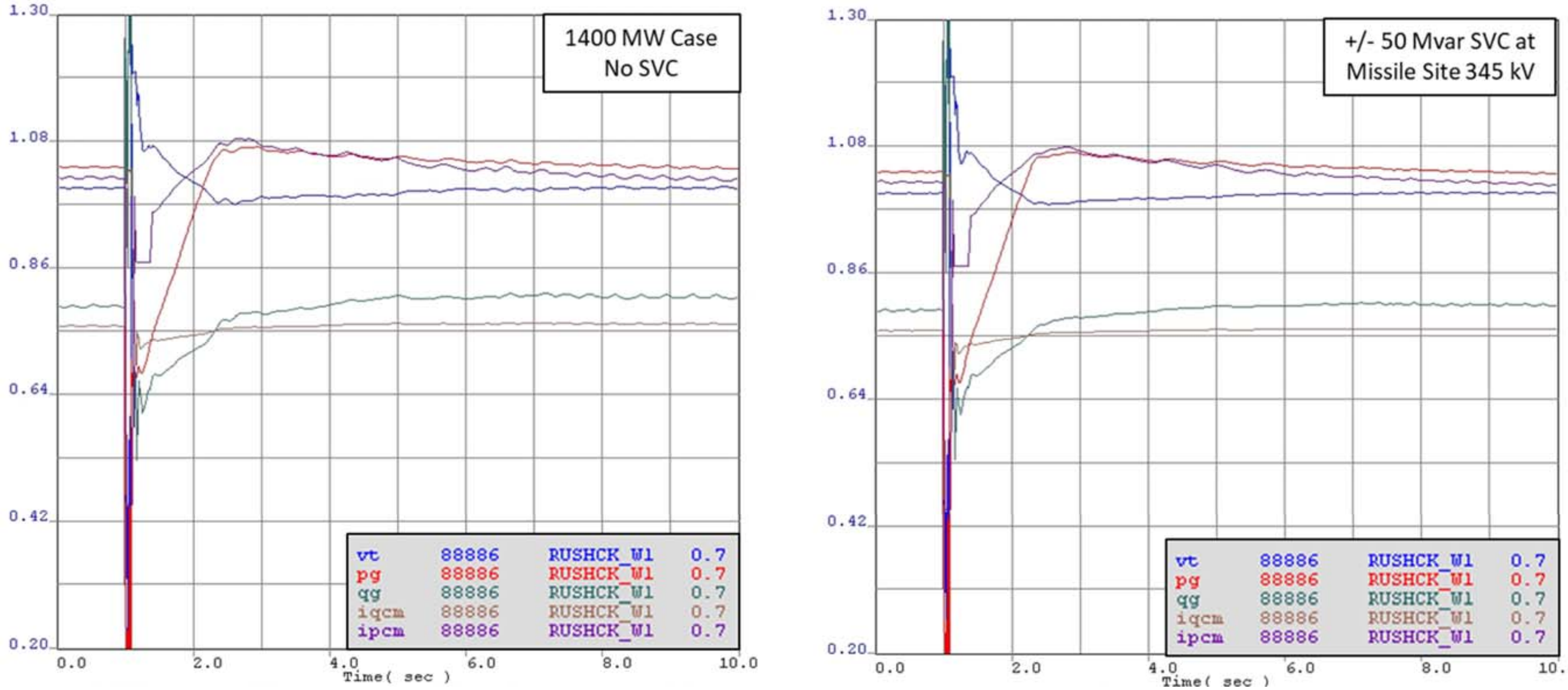

Figure 4.4-2. Response of the Rush Creek I unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

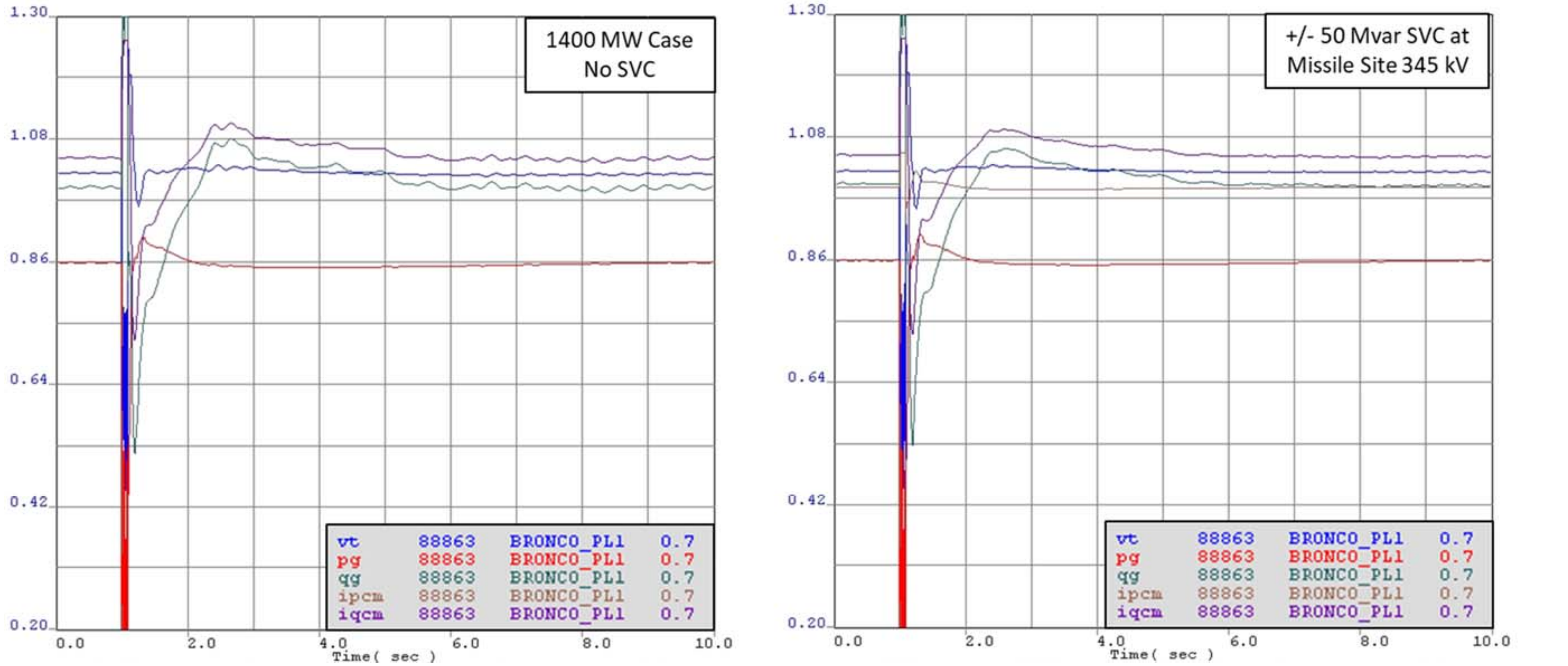

Figure 4.4-3. Response of the Bronco Plains unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

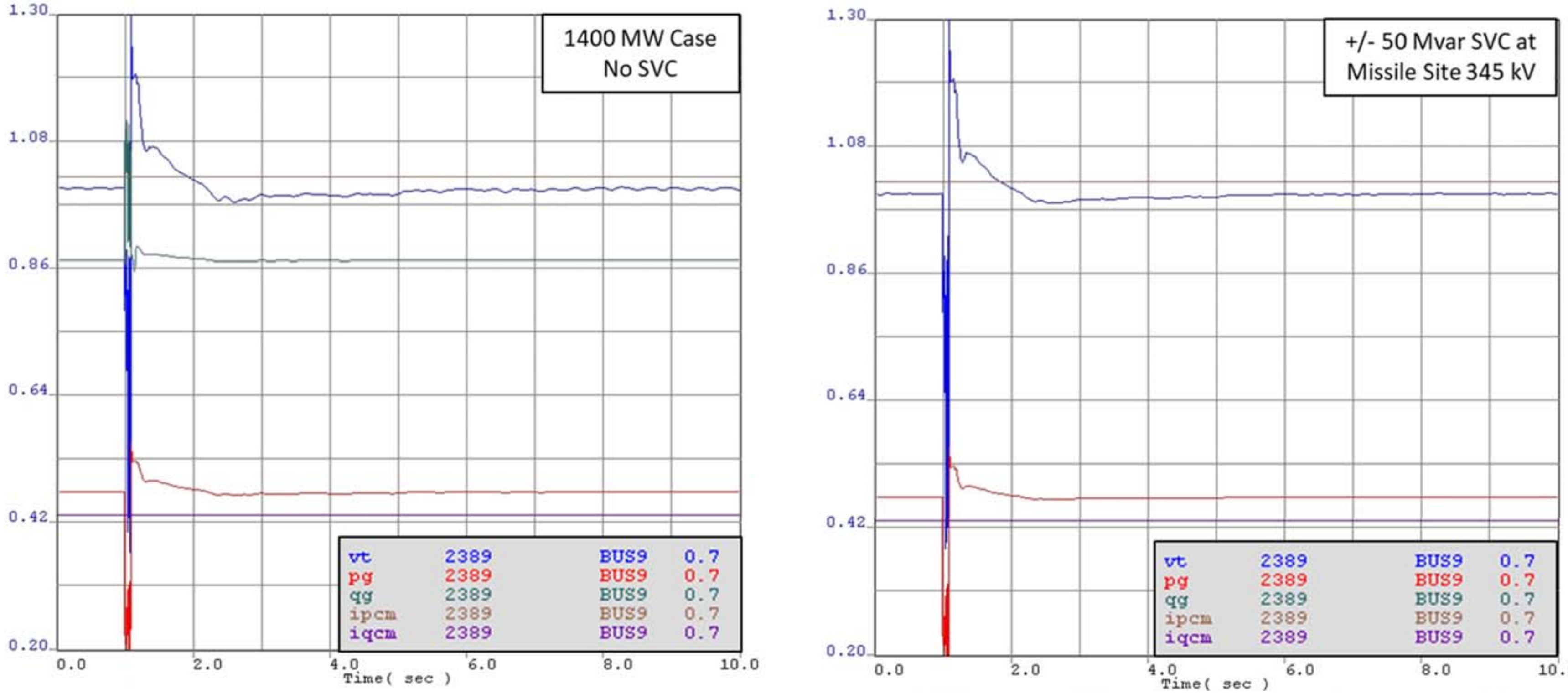

Figure 4.4-4. Response of the Cheyenne Ridge West unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

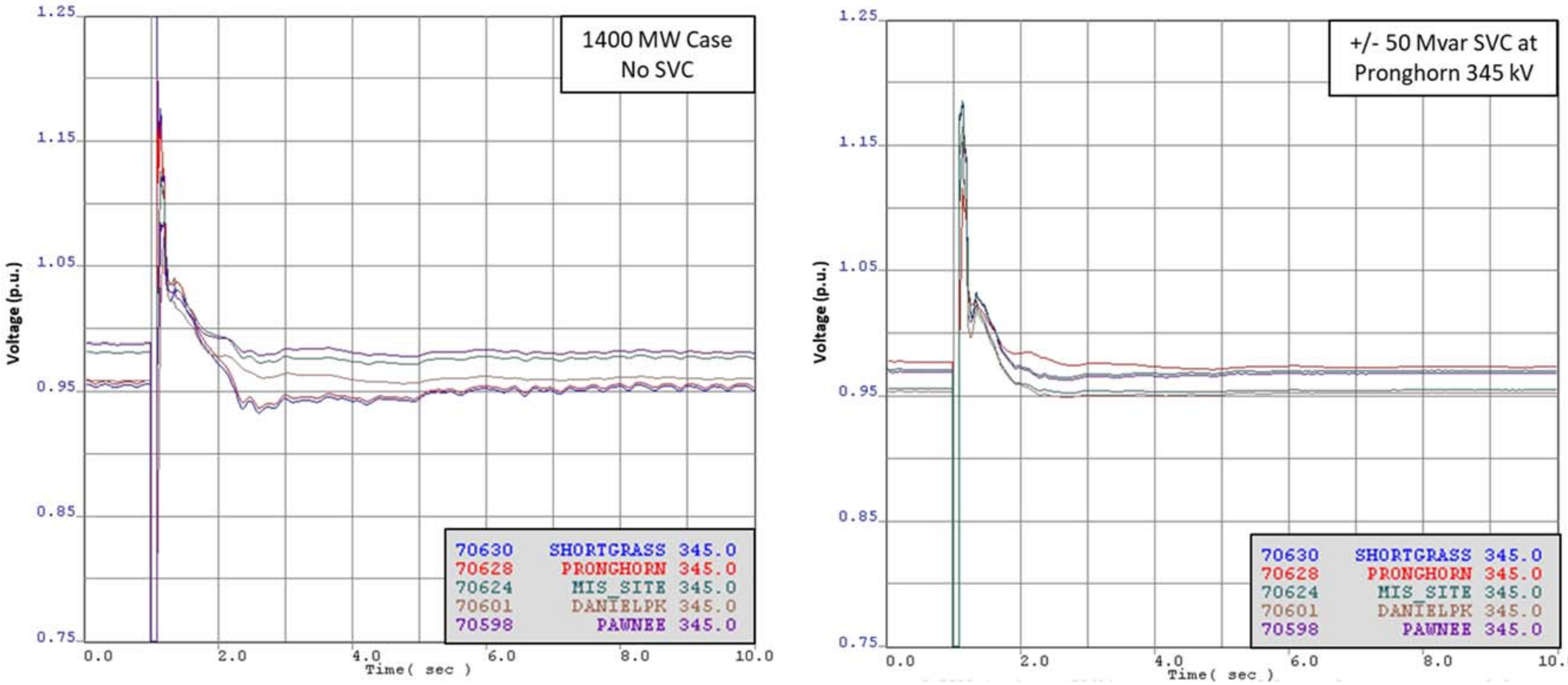

Figure 4.4-5. Voltage plots showing nearby bus voltage for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Pronghorn 345 kV bus.

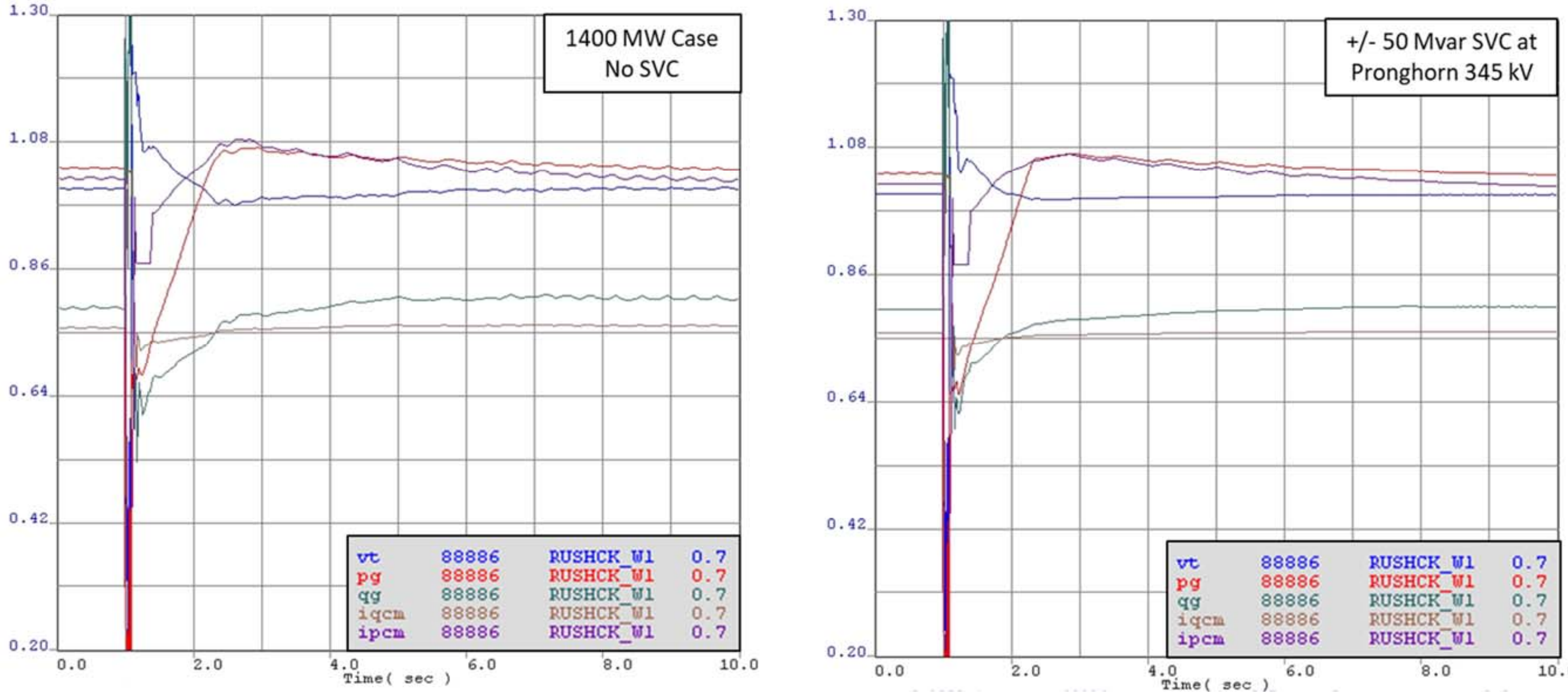

Figure 4.4-6. Response of the Rush Creek I unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Pronghorn 345 kV bus.

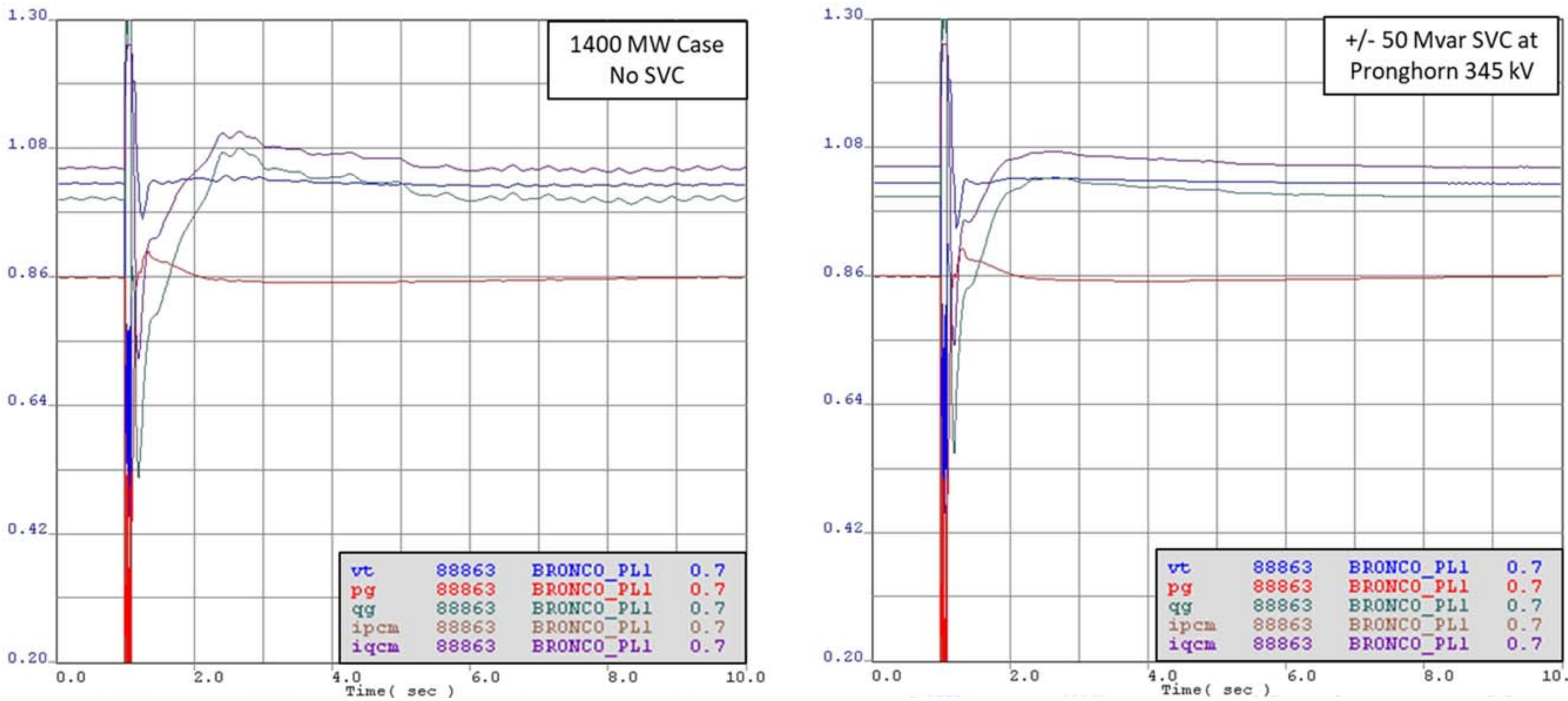

Figure 4.4-7. Response of the Bronco Plains unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Pronghorn 345 kV bus.

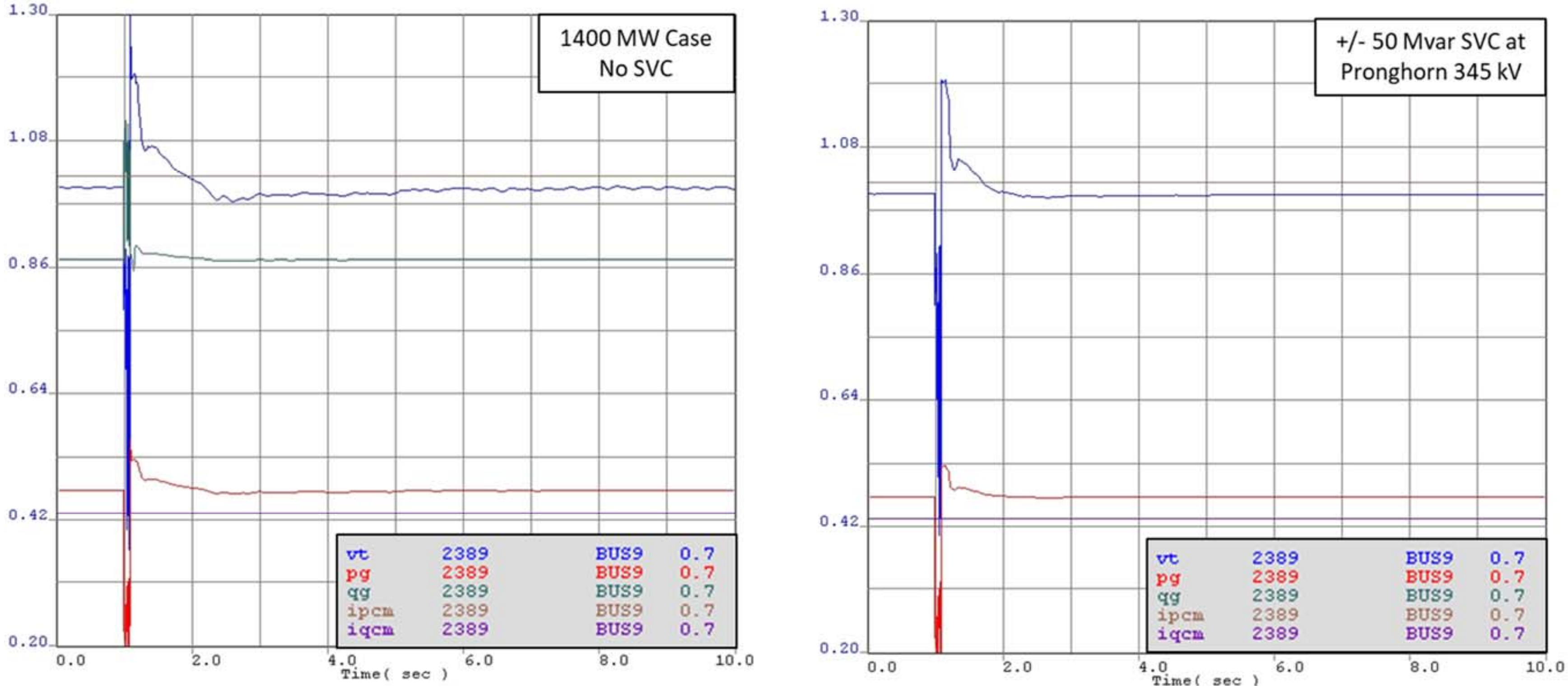

Figure 4.4-8. Response of the Cheyenne Ridge West unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with and without a dynamic device at the Pronghorn 345 kV bus.

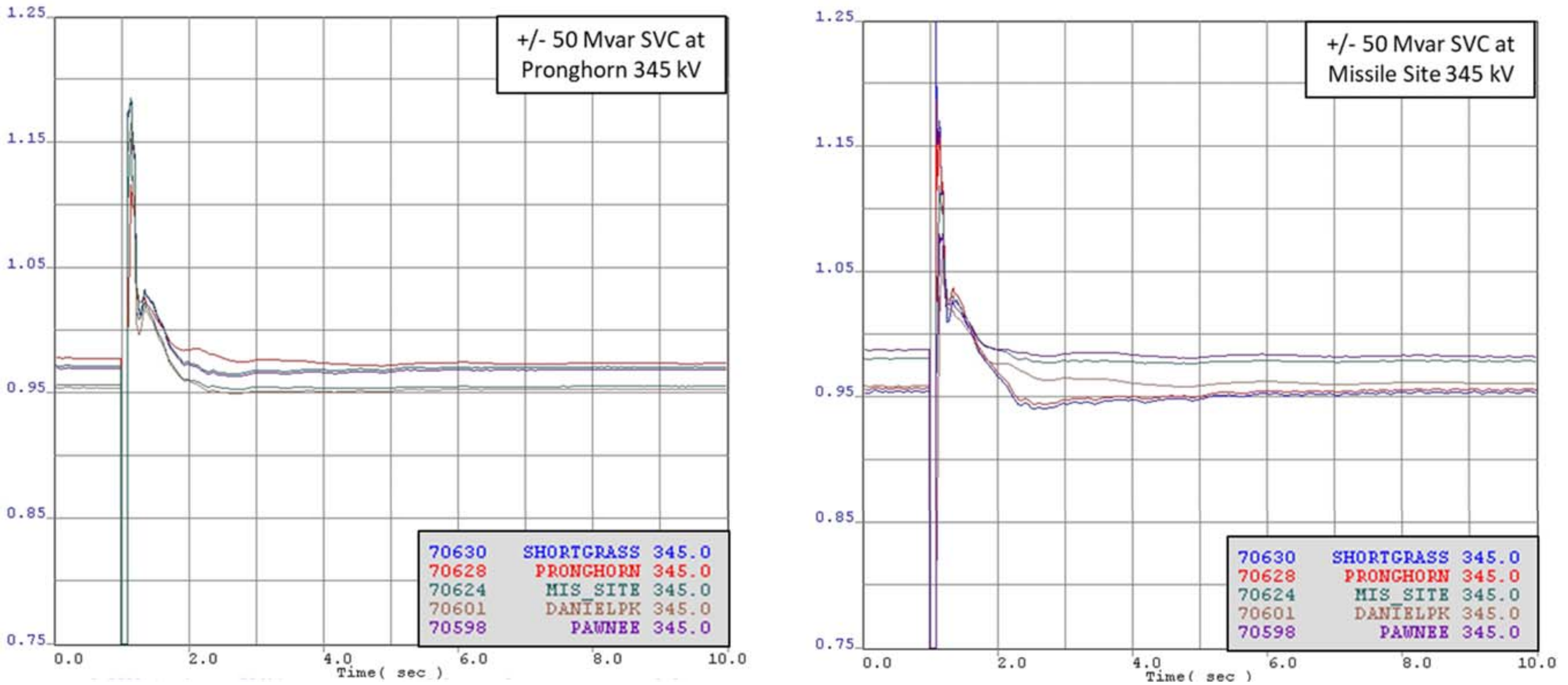

Figure 4.4-9. Voltage plots showing nearby bus voltage for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with a dynamic device at the Missile Site 345 kV bus and the Pronghorn 345 kV bus.

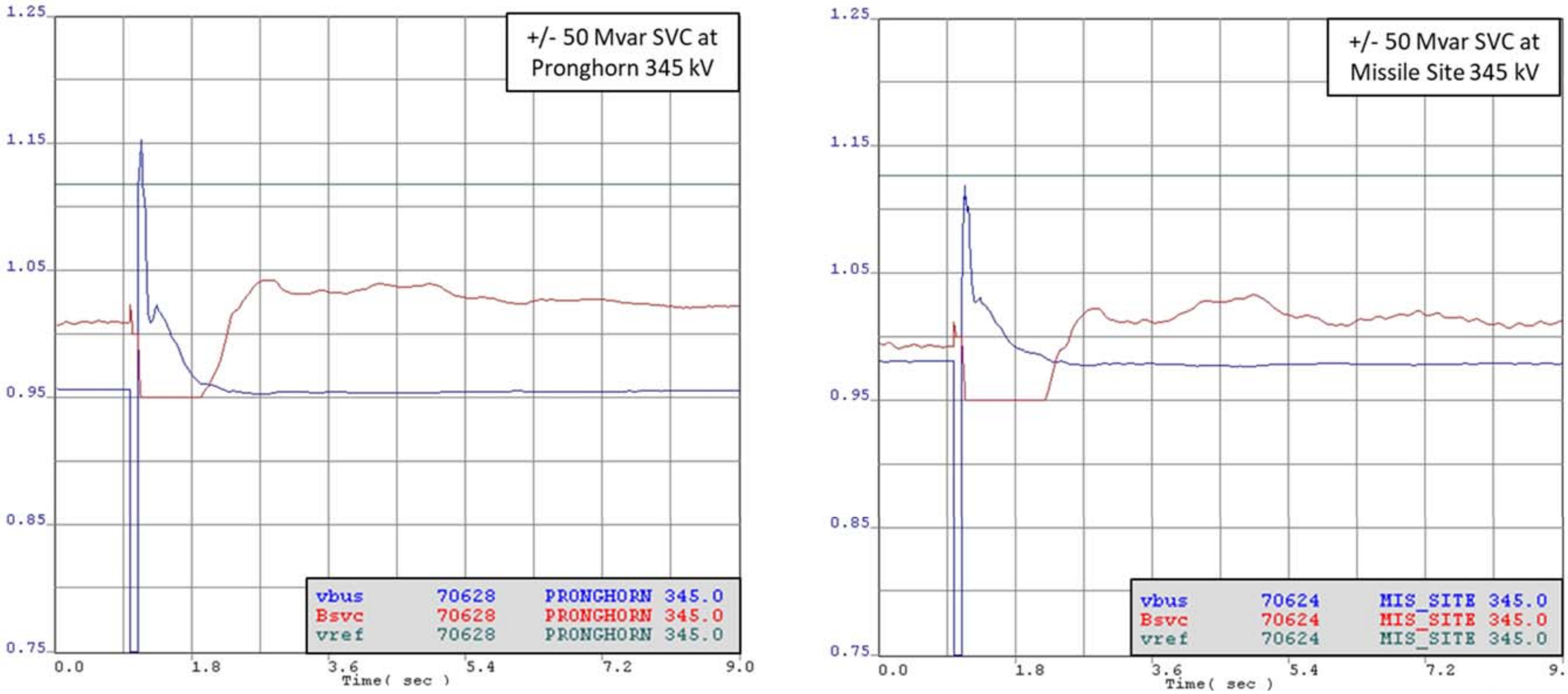

Figure 4.4-10. Response of the dynamic device for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the heavy summer 1400 MW case with a dynamic device at the Missile Site 345 kV bus and the Pronghorn 345 kV bus.

Table 4.4-1
Summary Results for the N-1 and Stuck Breaker Dynamic Analysis without Dynamic Mitigation (No Dynamic Devices)

Ref. No.	Contingecy Description	Fault Type	Is the System Stable?	Final Buses Below 90%		Final Buses above 1.10 p.u.		Tripped Generation	
				# of Buses	Bus List	# of Buses	Bus List	# of Gens	Bus List
1	Missile Site - Daniels Park 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
2	Pronghorn - Shortgrass 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
3	Missile Site - Pronghorn 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
4	Daniels Park - Comanche 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
5	Cheyenne Ridge West - Cheyenne Ridge East 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
6	Missile Site - Smoky Hill 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
7	Missile Site - Pawnee 345 kV line Missile Site - Pawnee 345 kV line	SB	Yes	0	N/A	0	N/A	0	N/A
8	Pronghorn - Shortgrass 345 kV line Pronghorn - Rush Creek W1 345 kV line	SB	Yes	0	N/A	0	N/A	0	N/A
9	Missile Site - Daniels Park 345 kV line Daniels Park 345/230 kV transformer	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
10	Missile Site - Pawnee 345 kV line Missile Site - Smoky Hill 345 kV line	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
11	Smoky Hill - Missile Site 345 kV Smoky Hill - Harvest Mile 345 kV	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
12	Pronghorn – Shortgrass 345 kV Shortgrass – Cheyenne Ridge W 345 kV	SB	Yes	0	N/A	0	N/A	0	N/A
13	Daniels Park – Comanche 345 kV Daniels Park 345 kV Capacitor Bank	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201

Table 4.4-2
Summary Results for the N-1 and Stuck Breaker Dynamic Analysis with a +/- 50 Mvar SVC at Missile Site 345 kV

Ref. No.	Contingecy Description	Fault Type	Is the System Stable? (Yes or No)	Missile Site 345 kV		Final Buses Below 90%		Final Buses above 1.10 p.u.		Tripped Generation	
				Final Bus Voltage (p.u.)	Final SVC Output B (p.u.)	# of Buses	Bus List	# of Buses	Bus List	# of Gens	Bus List
1	Missile Site - Daniels Park 345 kV line	N-1	Yes	0.98	-0.34	0	N/A	0	N/A	0	N/A
2	Pronghorn - Shortgrass 345 kV line	N-1	Yes	1.03	-0.50	0	N/A	0	N/A	0	N/A
3	Missile Site - Pronghorn 345 kV line	N-1	Yes	1.05	-0.50	0	N/A	0	N/A	0	N/A
4	Daniels Park - Comanche 345 kV line	N-1	Yes	0.99	-0.50	0	N/A	0	N/A	0	N/A
5	Cheyenne Ridge West - Cheyenne Ridge East 345 kV line	N-1	Yes	1.00	-0.50	0	N/A	0	N/A	0	N/A
6	Missile Site - Smoky Hill 345 kV line	N-1	Yes	0.98	0.11	0	N/A	0	N/A	0	N/A
7	Missile Site - Pawnee 345 kV line Missile Site - Pawnee 345 kV line	SB	Yes	0.98	-0.37	0	N/A	0	N/A	0	N/A
8	Pronghorn - Shortgrass 345 kV line Pronghorn - Rush Creek W1 345 kV line	SB	Yes	1.05	-0.50	0	N/A	0	N/A	0	N/A
9	Missile Site - Daniels Park 345 kV line Daniels Park 345/230 kV transformer	SB	Yes	0.99	-0.50	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
10	Missile Site - Pawnee 345 kV line Missile Site - Smoky Hill 345 kV line	SB	Yes	0.98	0.12	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
11	Smoky Hill - Missile Site 345 kV Smoky Hill - Harvest Mile 345 kV	SB	Yes	0.98	-0.50	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
12	Pronghorn – Shortgrass 345 kV Shortgrass – Cheyenne Ridge W 345 kV	SB	Yes	1.03	-0.50	0	N/A	0	N/A	0	N/A
13	Daniels Park – Comanche 345 kV Daniels Park 345 kV Capacitor Bank	SB	Yes	0.99	-0.50	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201

Table 4.4-3
Summary Results for the N-1 and Stuck Breaker Dynamic Analysis with a +/- 50 Mvar SVC at Pronghorn 345 kV

Ref. No.	Contingecy Description	Fault Type	Is the System Stable? (Yes or No)	Pronghorn 345 kV		Final Buses Below 90%		Final Buses above 1.10 p.u.		Tripped Generation	
				Final Bus Voltage (p.u.)	Final SVC Output B (p.u.)	# of Buses	Bus List	# of Buses	Bus List	# of Gens	Bus List
1	Missile Site - Daniels Park 345 kV line	N-1	Yes	0.96	-0.01	0	N/A	0	N/A	0	N/A
2	Pronghorn - Shortgrass 345 kV line	N-1	Yes	1.04	-0.50	0	N/A	0	N/A	0	N/A
3	Missile Site - Pronghorn 345 kV line	N-1	Yes	N/A	N/A	0	N/A	0	N/A	0	N/A
4	Daniels Park - Comanche 345 kV line	N-1	Yes	0.96	-0.22	0	N/A	0	N/A	0	N/A
5	Cheyenne Ridge West - Cheyenne Ridge East 345 kV line	N-1	Yes	0.99	-0.50	0	N/A	0	N/A	0	N/A
6	Missile Site - Smoky Hill 345 kV line	N-1	Yes	0.96	0.21	0	N/A	0	N/A	0	N/A
7	Missile Site - Pawnee 345 kV line Missile Site - Pawnee 345 kV line	SB	Yes	0.96	0.01	0	N/A	0	N/A	0	N/A
8	Pronghorn - Shortgrass 345 kV line Pronghorn - Rush Creek W1 345 kV line	SB	Yes	1.07	-0.50	0	N/A	0	N/A	0	N/A
9	Missile Site - Daniels Park 345 kV line Daniels Park 345/230 kV transformer	SB	Yes	0.96	-0.16	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
10	Missile Site - Pawnee 345 kV line Missile Site - Smoky Hill 345 kV line	SB	Yes	0.96	0.43	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
11	Smoky Hill - Missile Site 345 kV Smoky Hill - Harvest Mile 345 kV	SB	Yes	0.95	0.28	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
12	Pronghorn – Shortgrass 345 kV Shortgrass – Cheyenne Ridge W 345 kV	SB	Yes	1.04	-0.50	0	N/A	0	N/A	0	N/A
13	Daniels Park – Comanche 345 kV Daniels Park 345 kV Capacitor Bank	SB	Yes	0.96	-0.36	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201

Light Spring Sensitivity

After the results for the heavy summer 1400 MW case (limiting case) were discussed with Xcel Energy, it was determined that the location of the dynamic device should be the Pronghorn 345 kV bus due to the better voltage recovery. The light spring 1400 MW case was examined with a +/- 50 Mvar SVC at Pronghorn 345 kV to ensure that the SVC has sufficient inductive range (it is anticipate that light load conditions would result in overvoltages).

Refer to Figures 4.4-11 through 4.4-14 for comparison plots showing the impact of the recommended mitigation of a +/- 50 Mvar SVC at Pronghorn 345 kV.

+/- 50 Mvar SVC at Pronghorn 345 kV (Light Spring)

Refer to Table 4.4-4 and 4.4-5 for a summary of the results for the dynamic analysis for the limiting N-1 and stuck breaker contingencies examined with and without a +/- 50 Mvar SVC at Pronghorn 345 kV for the light spring case. Note the scheduled voltage for the Pronghorn 345 kV SVC is set to regulate the Pronghorn 345 kV bus at 0.95 p.u.

- The system remained stable for all contingencies examined.
  - With the SVC at Pronghorn 345 kV the oscillations observed were well damped.
  - The notable improvement in oscillation damping represents the significant contribution of the SVC to voltage regulation on the tie line. Because actual performance of the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants under weak grid conditions may be worse than idealized stability models indicate, additional dynamic reactive compensation would be highly beneficial to regulate voltage along the tie line.
- No delayed voltage recovery was observed.
- All bus voltages recovered above 0.90 p.u.
- All bus voltages recovered below 1.10 p.u.
- The following generator tripped for some contingencies examined due to short tripping times. These trip times do not meet NERC PRC-024 ride-through requirements.
  - PTZLOGN1 34.5 kV

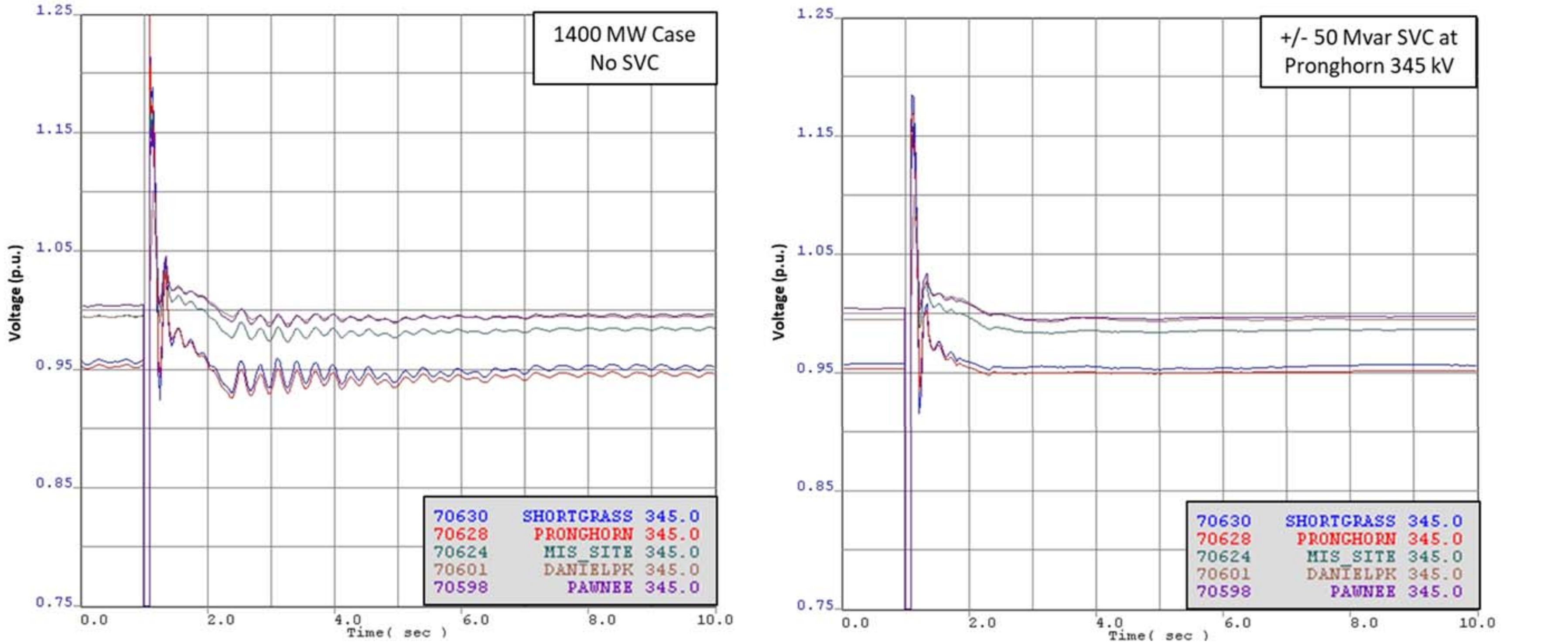

Figure 4.4-11. Voltage plots showing nearby bus voltage for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the light spring 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

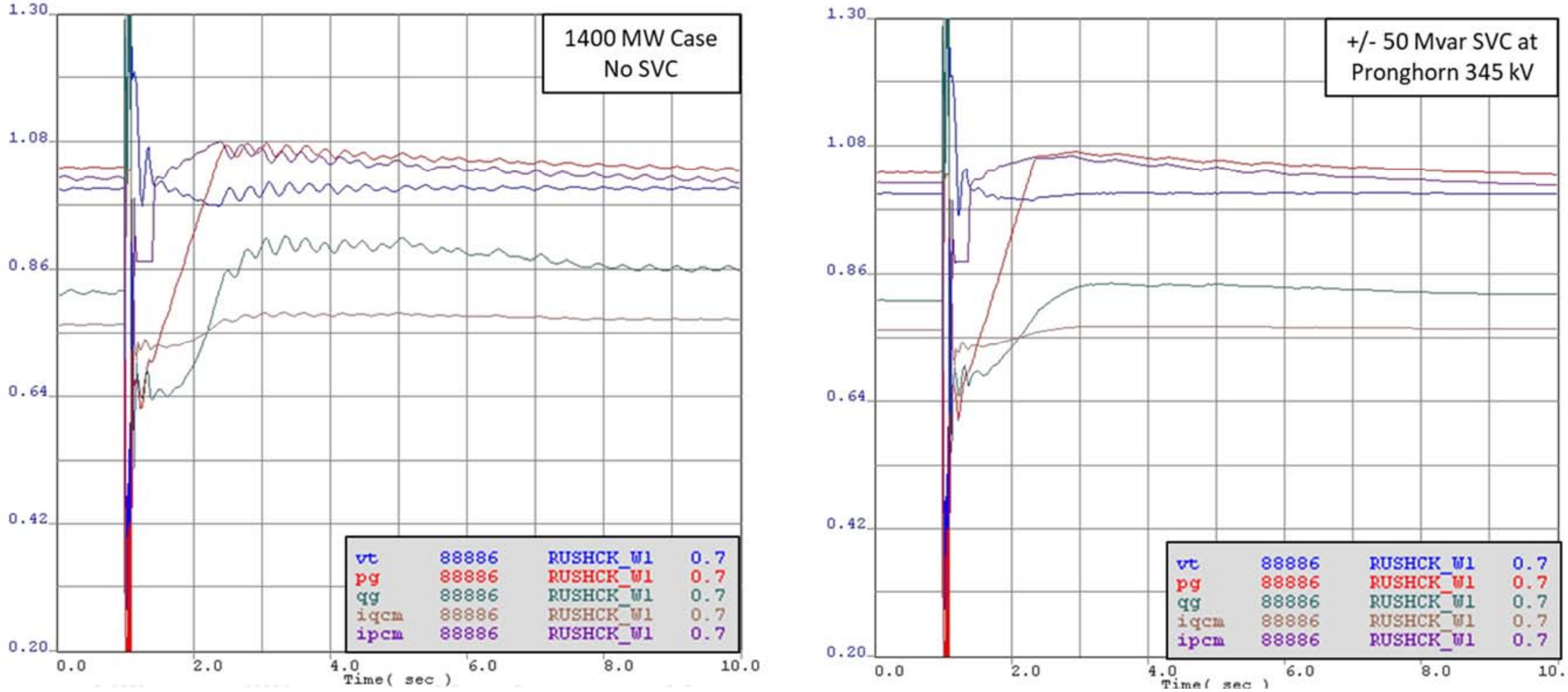

Figure 4.4-12. Response of the Rush Creek I unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the light spring 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

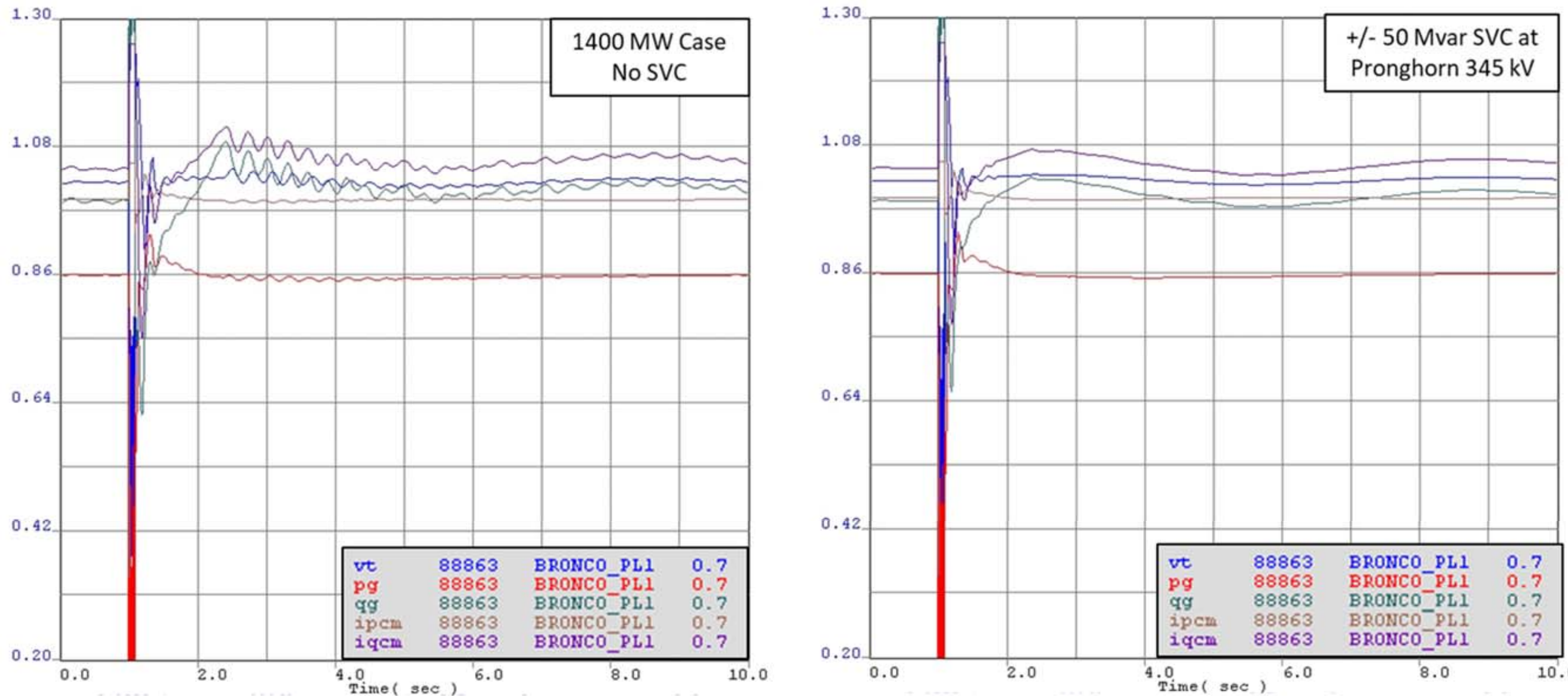

Figure 4.4-13. Response of the Bronco Plains unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the light spring 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

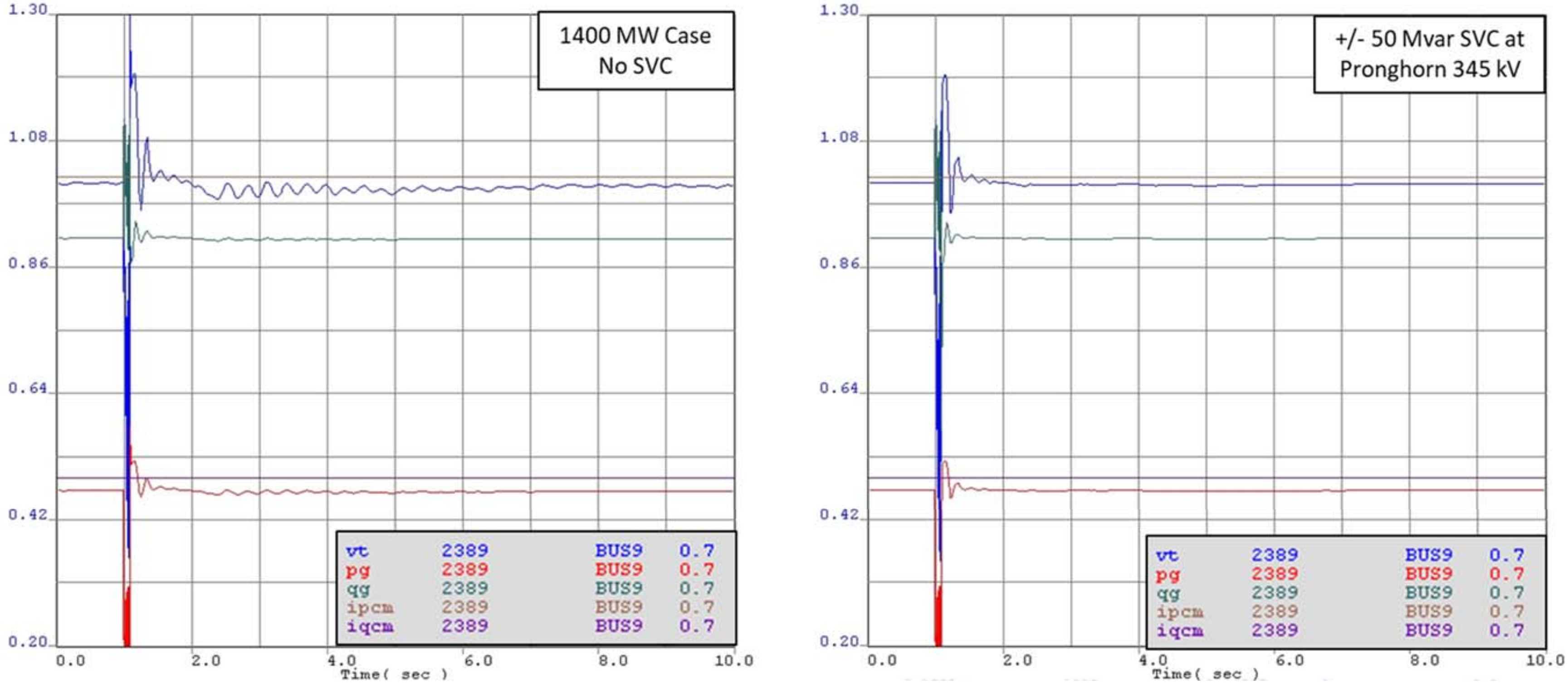

Figure 4.4-14. Response of the Cheyenne Ridge West unit for the limiting N-1/Stuck Breaker Contingency (loss of the Missile Site – Smoky Hill 345 kV line) for the light spring 1400 MW case with and without a dynamic device at the Missile Site 345 kV bus.

Table 4.4-4
Summary Results for the N-1 and Stuck Breaker Dynamic Analysis with no Mitigation for the 1400 MW Light Load Case

Ref. No.	Contingecy Description	Fault Type	Is the System Stable?	Final Buses Below 90%		Final Buses above 1.10 p.u.		Tripped Generation	
				# of Buses	Bus List	# of Buses	Bus List	# of Gens	Bus List
1	Missile Site - Daniels Park 345 kV line	N-1	Yes	0	N/A	0	N/A	0	70710 PTZLOGN1 W1 201
2	Pronghorn - Shortgrass 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
3	Missile Site - Pronghorn 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
4	Daniels Park - Comanche 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
5	Cheyenne Ridge West - Cheyenne Ridge East 345 kV line	N-1	Yes	0	N/A	0	N/A	0	N/A
6	Missile Site - Smoky Hill 345 kV line	N-1	Yes	0	N/A	0	N/A	0	70710 PTZLOGN1 W1 201
7	Missile Site - Pawnee 345 kV line Missile Site - Pawnee 345 kV line	SB	Yes	0	N/A	0	N/A	0	70710 PTZLOGN1 W1 201
8	Pronghorn - Shortgrass 345 kV line Pronghorn - Rush Creek W1 345 kV line	SB	Yes	0	N/A	0	N/A	0	N/A
9	Missile Site - Daniels Park 345 kV line Daniels Park 345/230 kV transformer	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
10	Missile Site - Pawnee 345 kV line Missile Site - Smoky Hill 345 kV line	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
11	Smoky Hill - Missile Site 345 kV Smoky Hill - Harvest Mile 345 kV	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
12	Pronghorn – Shortgrass 345 kV Shortgrass – Cheyenne Ridge W 345 kV	SB	Yes	0	N/A	0	N/A	0	N/A
13	Daniels Park – Comanche 345 kV Daniels Park 345 kV Capacitor Bank	SB	Yes	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201

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Table 4.4-5
Summary Results for the N-1 and Stuck Breaker Dynamic Analysis with a +/- 50 Mvar SVC at Pronghorn 345 kV for the 1400 MW Light Load Case

Ref. No.	Contingecy Description	Fault Type	Is the System Stable? (Yes or No)	Pronghorn 345 kV		Final Buses Below 90%		Final Buses above 1.10 p.u.		Tripped Generation	
				Final Bus Voltage (p.u.)	Final SVC Output B (p.u.)	# of Buses	Bus List	# of Buses	Bus List	# of Gens	Bus List
1	Missile Site - Daniels Park 345 kV line	N-1	Yes	0.95	0.06	0	N/A	0	N/A	0	70710 PTZLOGN1 W1 201
2	Pronghorn - Shortgrass 345 kV line	N-1	Yes	1.02	-0.05	0	N/A	0	N/A	0	N/A
3	Missile Site - Pronghorn 345 kV line	N-1	Yes	N/A	N/A	0	N/A	0	N/A	0	N/A
4	Daniels Park - Comanche 345 kV line	N-1	Yes	0.96	-0.14	0	N/A	0	N/A	0	N/A
5	Cheyenne Ridge West - Cheyenne Ridge East 345 kV line	N-1	Yes	0.98	-0.50	0	N/A	0	N/A	0	N/A
6	Missile Site - Smoky Hill 345 kV line	N-1	Yes	0.95	0.26	0	N/A	0	N/A	0	70710 PTZLOGN1 W1 201
7	Missile Site - Pawnee 345 kV line Missile Site - Pawnee 345 kV line	SB	Yes	0.95	0.20	0	N/A	0	N/A	0	70710 PTZLOGN1 W1 201
8	Pronghorn - Shortgrass 345 kV line Pronghorn - Rush Creek W1 345 kV line	SB	Yes	1.04	-0.50	0	N/A	0	N/A	0	N/A
9	Missile Site - Daniels Park 345 kV line Daniels Park 345/230 kV transformer	SB	Yes	0.95	0.03	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
10	Missile Site - Pawnee 345 kV line Missile Site - Smoky Hill 345 kV line	SB	Yes	0.95	0.48	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
11	Smoky Hill - Missile Site 345 kV Smoky Hill - Harvest Mile 345 kV	SB	Yes	0.95	0.31	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201
12	Pronghorn – Shortgrass 345 kV Shortgrass – Cheyenne Ridge W 345 kV	SB	Yes	1.02	-0.05	0	N/A	0	N/A	0	N/A
13	Daniels Park – Comanche 345 kV Daniels Park 345 kV Capacitor Bank	SB	Yes	0.96	-0.11	0	N/A	0	N/A	1	70710 PTZLOGN1 W1 201

4.5 Sensitivity Analyses

Sensitivity analyses were performed to bound and provide insight to the dynamic analysis results. The following sensitives were examined:

- Wind Plant Gain Sensitivity
- Steady-State versus Dynamic Discrepancies
- Most Severe Single Contingency (Frequency Excursion Study)

Wind Plant Controller AVR (REPCA) Gain Sensitivity

As a sensitivity, several different integral and proportional gains were examined to determine if the instability observed for the limiting N-1 contingency (loss of the Missile Site – Smoky Hill 345 kV line) was due to poorly tuned gains or another underlining issue. Gains were adjusted for the Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains units simultaneously. The objective of this sensitivity is to determine the cause of the observed oscillations and to determine the controllability of the controller.

The limiting N-1, the loss of the Missile Site – Smoky Hill 345 kV line, was examined for this sensitivity. Note the limiting N-1 showed the worse oscillations for the contingencies examined, and was used for illustration purposes. Other contingencies resulted in similar results and it is anticipated that the findings from this sensitivity are applicable for the other results. The following gain settings were examined:

- Kp = 0.5 Ki = 0
- Kp = 1 Ki = 0
- Kp = 5 Ki = 0
- Kp = 0.5 Ki = 0.1
- Kp = 0.5 Ki = 1
- Kp = 0.5 Ki = 10
- Kp = 1 Ki = 0.1
- Kp = 1 Ki = 1
- Kp = 1 Ki = 10

Below summarizes the findings for the wind plant gain sensitivity:

- Oscillations were observed for contingency conditions that resulted in the need to tune the gains of the power plant controllers to help with system stability. Refer to Figure 4.5-1 for comparison plots of nearby bus voltages before and after the gains of Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains power plant controllers (REPC_a) were tuned.
    - Kp = 0.5 and Ki=10 were the gains provided by Xcel Energy for the updated plant data.

- o It was determined that by adjusting the gains to Kp = 1 and Ki = 1, the oscillations were reduced in amplitude.

- This sensitivity shows that there is a narrow range for the controller gains for a stable solution. It is common to see voltage control issues when wind plants are weakly interconnected.
  - For example off shore wind plants often use a dynamic device to perform voltage control.
  - The stability models used in this study represent idealized wind plant performance and do not capture the reduced controllability and possible degraded performance under weak grid conditions as experienced by the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants. Tuning the wind plants for weak grid conditions will typically result in slower performance, reducing the contribution of the wind plants to voltage regulation, especially during the critical post fault recovery period. Before the wind plants are finalized, it is recommended that Xcel Energy work closely with the wind turbine manufacturers to evaluate wind plant dynamic performance using detailed OEM "user-models" of the wind turbine generators adequate for the low short-circuit ratio observed along the Missile Site gen-tie line under actual conditions.

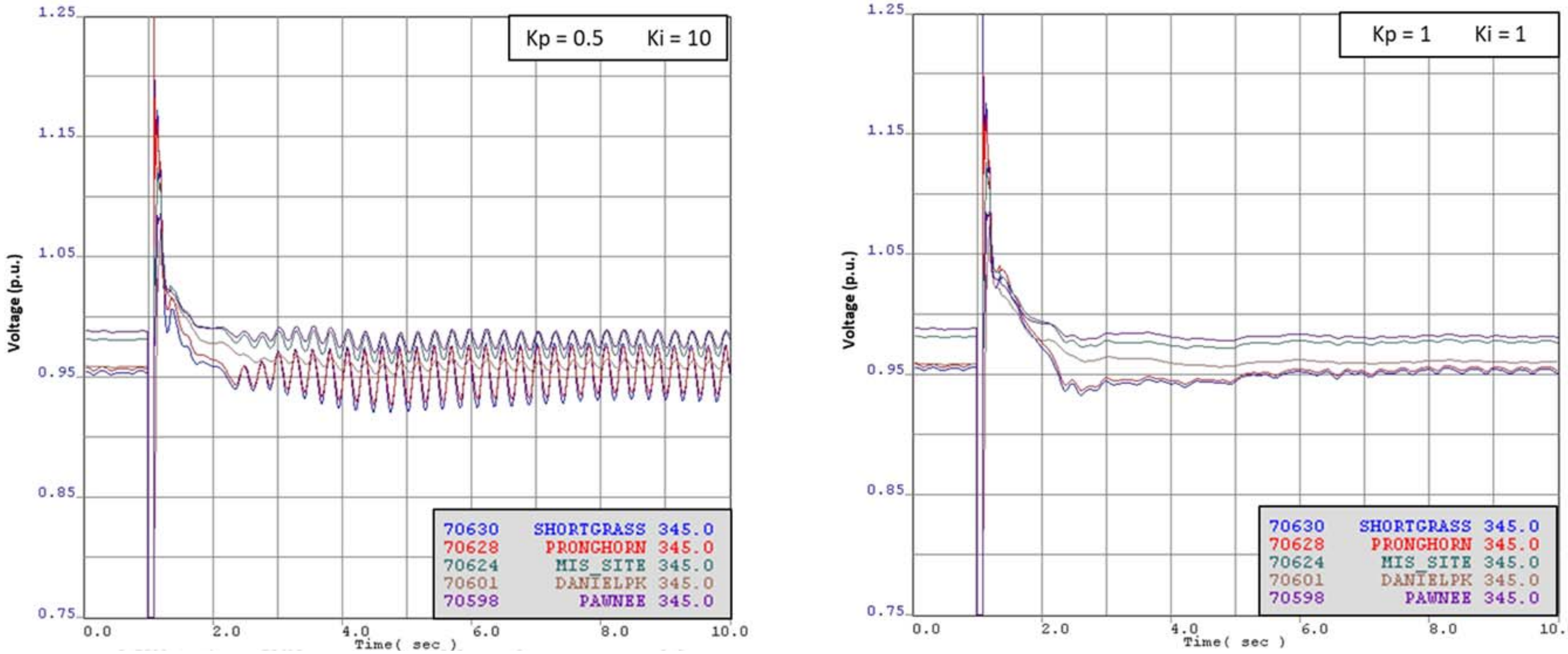


Figure 4.5-1. Comparison plots of nearby bus voltages before and after the gains of Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne East, and Bronco Plains were tuned.

Steady-State versus Dynamic Discrepancies

Once the steady-state analysis and the dynamic analysis were completed, it was observed that different amounts of reactive power support was needed to result in acceptable voltages that met WECC criteria (final voltages between 0.90 and 1.10 p.u for contingency conditions). The objective of this sensitivity was to identify the discrepancy that resulted in needing less reactive power support in the time domain than for the steady-state analysis.

The limiting N-2 (described in more detail in Section 6 of this report), the loss of the Missile Site – Daniels Park and Missile Site – Smoky Hill 345 kV lines, was examined for this sensitivity. Note the limiting N-2 showed the biggest difference in results as described above, and used for illustration purposes. Other contingencies resulted in similar results and it is anticipated that the findings from this sensitivity are applicable for the other results. Below summarizes the findings for the steady-state versus dynamic discrepancies:

- Without additional reactive power support both the steady-state and dynamic N-2 cases diverged.
  - For the steady-state case, 588 Mvar at Missile Site and 419 Mvar at Harvest Mile of additional support is needed for the case to converge.
  - For the dynamic case, 150 Mvar at Missile Site and 150 Mvar at Harvest Mile of additional support is needed for the case to remain stable.
- Because several nearby generators were able to provide more short-term reactive support in the time domain than their steady-state limits, this short-term reactive support allowed the network solution to converge with less additional dynamic support. Refer to Table 4.5-1 for a list of nearby generators, their steady-state reactive power range, and the final reactive power output for the limiting N-2. The table shows that nearby generators exceed their steady-state ranges in the time domain analysis. Refer to Figure 4.5-2 for plots of the response of the nearby generators for the limiting N-2 contingency. It is recommended that Xcel Energy verifies the units' capabilities to ensure the necessary short-term reactive power support is available.

Table 4.5-1
Summary Results of Discrepancies in the Reactive Power Ranges for Generation in the Study Area

Ref. No.	Bus Number	Bus Name	Reactive Power Range		Final Q in the Time Domain (Mvar)	Within the Steady-State Range?
			Qmax (Mvar)	Qmin (Mvar)		
1	70616	Titan	16.4	-16.4	20.9	No
2	70622	Missile Site	0.0	0.0	48.9	No
3	70777	Comanche	239.9	-257.0	262.2	No
4	70635	Limon1	65.7	-65.7	64.8	Yes
5	70636	Limon2	65.7	-65.7	48.9	Yes
6	70637	Limon3	65.7	-65.7	41.7	Yes
7	70310	Pawnee	115.0	-81.0	273	No
8	70710	PTZLOGN 1	65.7	-65.7	65.2	Yes
9	70812	PTZLOGN 2	39.2	-39.2	33.8	Yes
10	70813	PTZLOGN 3	25.9	-25.9	17.3	Yes
11	70714	PTZLOGN 4	49.0	-73.0	56.5	No

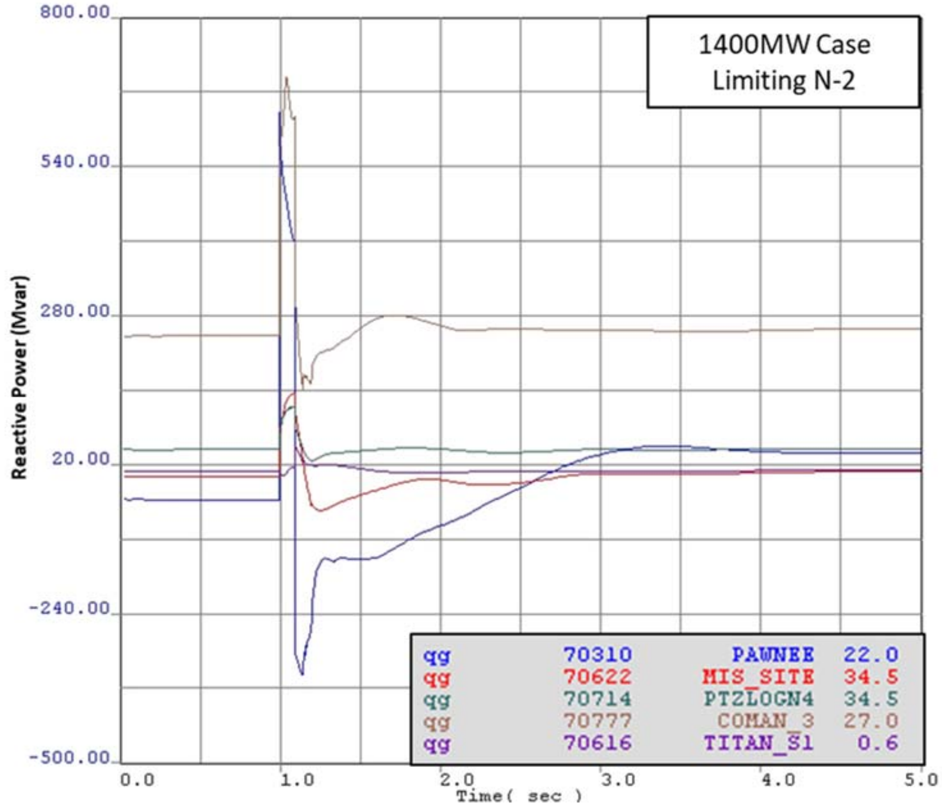


Figure 4.5-2. Plots of the reactive power for generators in the immediate study area for the limiting N-2 Contingency for the heavy summer 1400 MW case.

Most Severe Single Contingency (Frequency Excursion Study)

This analysis evaluated transient stability as measured by frequency excursions for the N-1 condition when the full 1400 MW of generation drops offline (the loss of the Pronghorn – Missile Site 345 kV line).

The heavy summer 1400 MW and the light spring 1400 MW cases were examined for the no fault contingency involving the loss of the Pronghorn – Missile Site 345 kV line, which results in disconnecting all wind plants of interest (1400 MW of generation). Refer to Table 4.5-2 for criteria used for the frequency excursion analysis based on PRC-024-1. Below explains the findings for the frequency excursion analysis:

- No frequency excursions of concern or transient stability issues were observed for PSCo's Balancing Authority Area 70.
    - The worst frequency dip for the 21SP case was 59.7 Hz at Cedar Creek 1A.
    - The worst frequency peak for the 21SP case was 60.2 Hz at Cedar Creek 1A.
    - The worst frequency dip for the 28HS case was 59.8 Hz at VALMONT6.
    - The worst frequency peak for the 28HS case was 60.1 Hz at VALMONT6.
- Refer to Figures 4.5-3 and 4.5-4 for frequency and voltage plots for the Missile Site 345 kV bus for the no fault case when the 1400 MW of generation is dropped for the heavy summer and light spring cases.

Table 4.5-2
Criteria used for the Frequency Excursion Analysis from Standard PRC-024-1 — Generator Frequency and Voltage Protective Relay Settings

Western Interconnection

High Frequency Duration		Low Frequency Duration	
Frequency (Hz)	Time (Sec)	Frequency (Hz)	Time (sec)
≥61.7	Instantaneous trip	≤57.0	Instantaneous trip
≥61.6	30	≤57.3	0.75
≥60.6	180	≤57.8	7.5
<60.6	Continuous operation	≤58.4	30
		≤59.4	180
		>59.4	Continuous operation

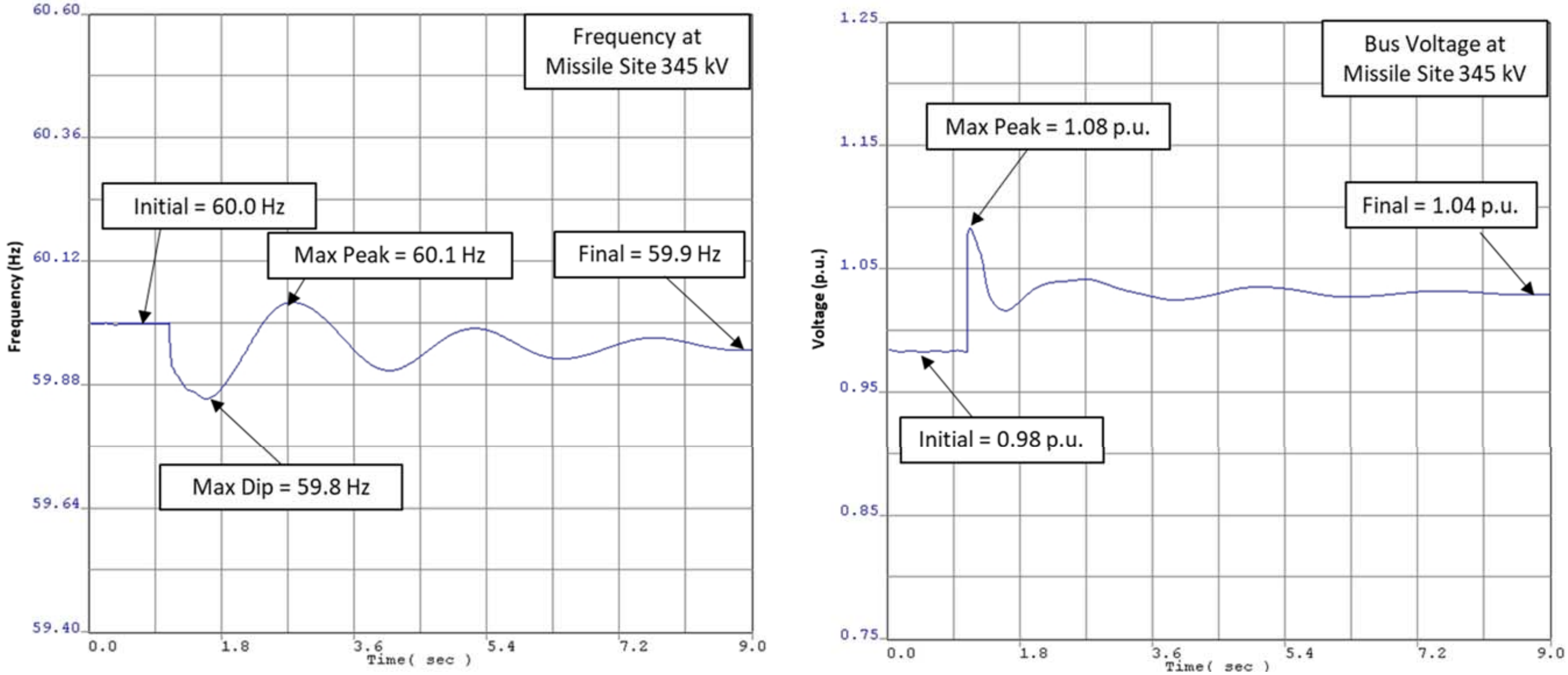


Figure 4.5-3. Frequency and voltage plots of the Missile Site 345 kV bus for the no fault case when the 1400 MW of generation is dropped for the heavy summer 1400 MW case.

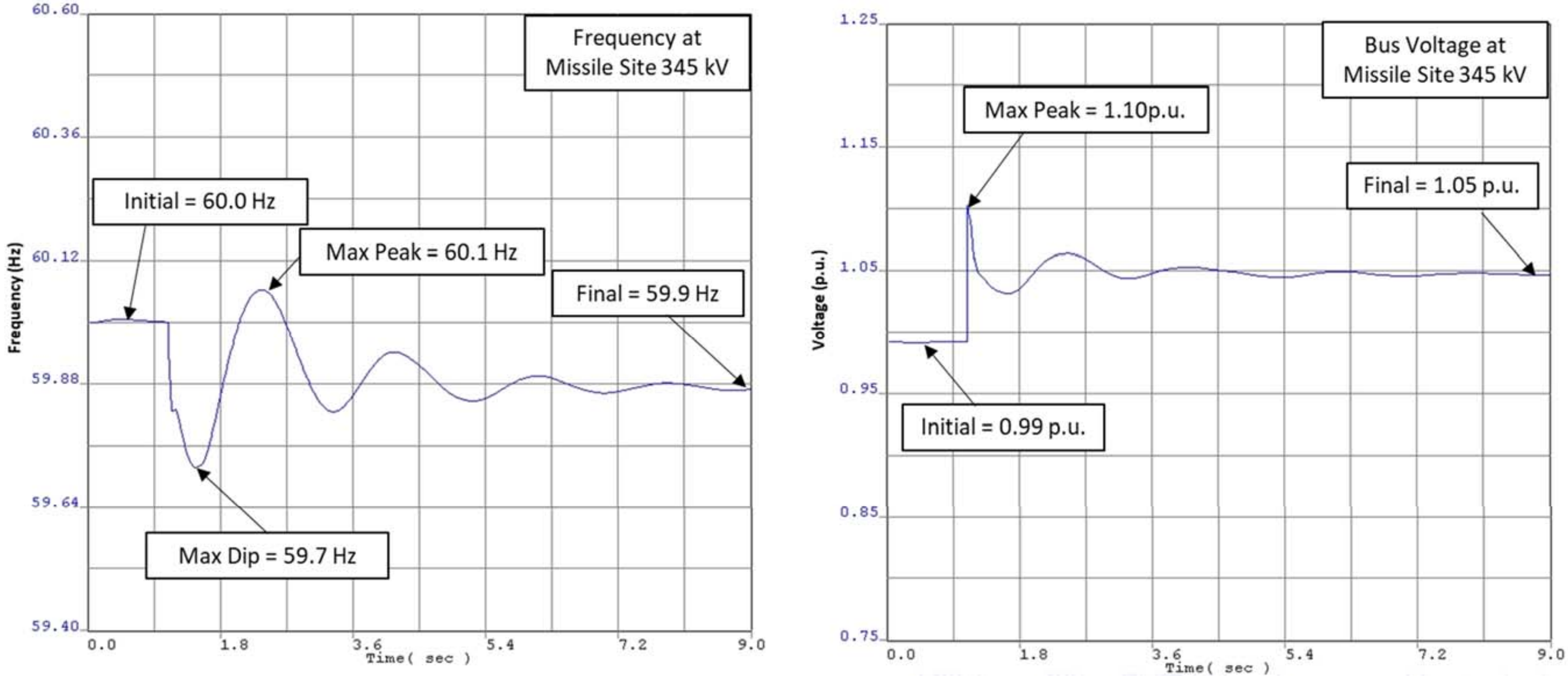


Figure 4.5-4. Frequency and voltage plots of the Missile Site 345 kV bus for the no fault case when the 1400 MW of generation is dropped for the light spring 1400 MW case.

4.6 Summary for the Dynamic Analysis

The primary objective of the dynamic analysis was to determine if dynamic reactive compensation is required for the increase in wind generation along the Gen-Tie, or if the reactive compensation identified as necessary in the steady-state analysis is able to adequately provide the reactive support required by the system during dynamic events.

- Without any dynamic reactive support, the system remained stable, no delayed voltage recovery was observed, and all bus voltages recovered between 0.90 p.u. and 1.10 p.u. However, oscillations of concern were observed for several contingencies. It is anticipated that these oscillations are caused by the weak interconnection point and controllability of the power plant controllers of the inverter-based wind generation plants of interest.
- With the addition of a +/- 50 Mvar Static Var Compensator (SVC) at the Pronghorn 345 kV bus no oscillations of concern were significantly improved.
  - Note the steady-state analysis (Section 3) determined that a minimum of 130 Mvars of reactive power support was required at the Pronghorn 345 kV bus. The reactive compensation can be installed as a combination of static and dynamic support. This study examined a +/- 50 Mvar SVC as a minimum dynamic compensation, but other combinations of the reactive compensation can be used as a form of mitigation. For example, the size of the dynamic compensation can be increased and the static compensation can be decreased as long as the net compensation is at least 130 Mvar.
  - The notable improvement in oscillation damping represents the significant contribution of the SVC to voltage regulation on the tie line. Actual performance of the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants under weak grid conditions may be worse than idealized stability models indicate, therefore additional dynamic reactive compensation beyond the +/- 50 Mvar SVC would be highly beneficial to regulate voltage along the tie line.
  - The stability models used in this study represent idealized wind plant performance and do not capture the reduced controllability and possible degraded performance under weak grid conditions as experienced by the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants. Tuning the wind plants for weak grid conditions will typically result in slower performance, reducing the contribution of the wind plants to voltage regulation, especially during the critical post fault recovery period. Before the wind plants are finalized, it is recommended that Xcel Energy work closely with the wind turbine manufacturers to evaluate wind plant dynamic performance using detailed OEM “user-models” of the wind turbine generators adequate for the low short-circuit ratio observed along the Missile Site gen-tie line under actual conditions.

Figure 4.6-1 shows a one-line diagram of the immediate study area and the reactive power devices needed to meet voltage criteria for base case and for N-1 and stuck breaker contingency conditions for the dynamic analysis. Note less reactive power compensation is needed for the dynamic analysis to meet WECC voltage criteria (final voltages between 0.90 p.u. and 1.10 p.u.). It is recommended that Xcel Energy confirms that the following units have the expected capability to ensure the needed reactive power support is available.

- Titan Solar
- Cedar Point
- Comanche
- Pawnee
- Peetz Logan 4

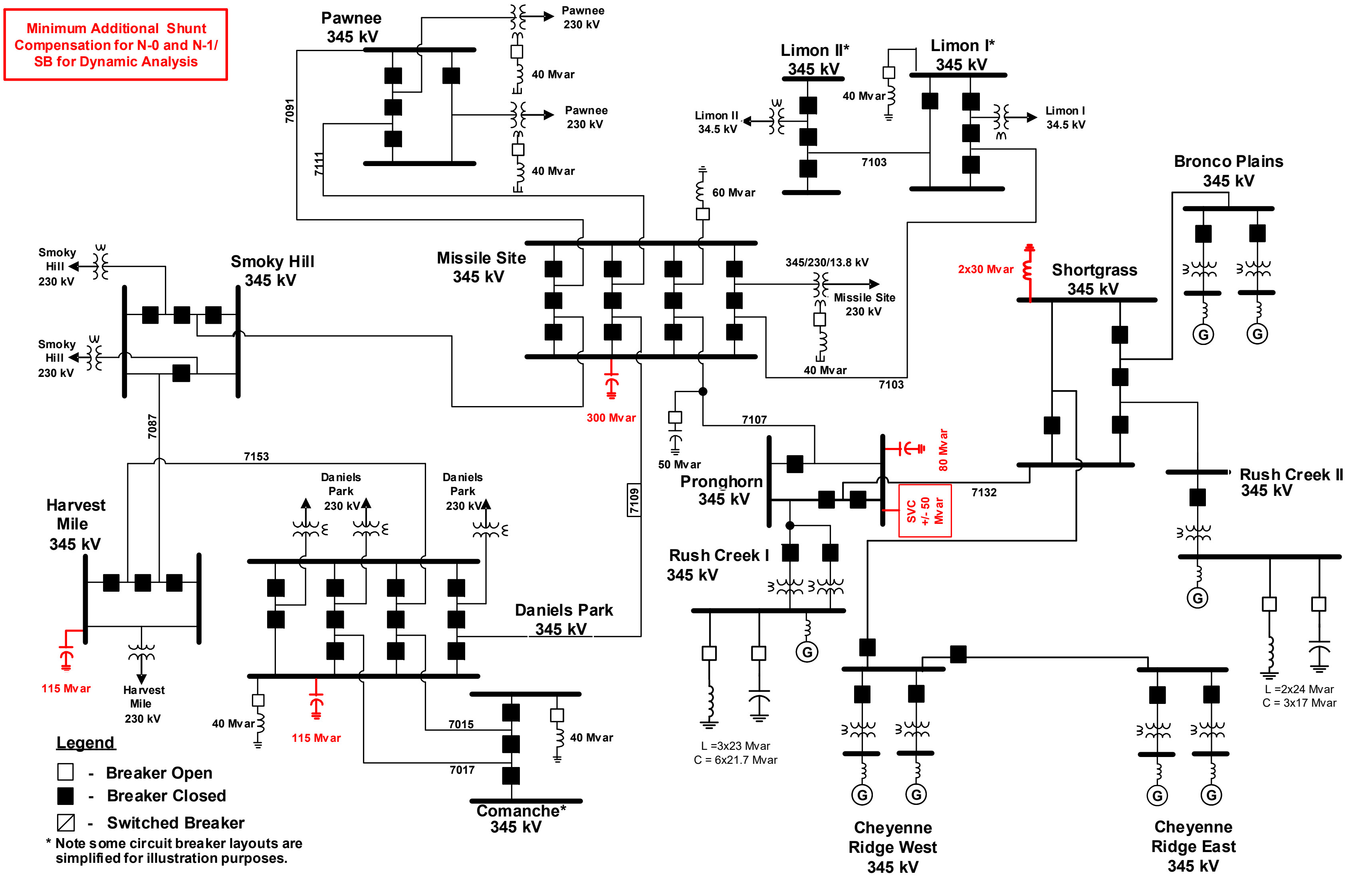


Figure 4.6-1. One-line diagram of the wind generation and immediate study area with static and dynamic reactive power compensation.

SECTION 5
PV AND QV ANALYSIS

5.1 Background and Introduction

A PV and QV analysis was performed to determine the transfer capability and reactive power margin of load serving buses in the Missile Site area. The PV analysis was used to determine the transfer capability and determine if active power margins exist in the study area. The QV analysis was used to determine the reactive power margins and determine if sufficient reactive power exists for the buses with the criteria outlined by WECC and used by Xcel Energy for the Missile Site area.

PV and QV curves are two methods of determining the steady-state loadability limits related to steady-state voltage stability. In a large meshed network PV curves are useful for examining the post disturbance voltage at key buses for various levels of power transfer in an area.

The PV curve can be used to quantify the power margin between the existing system operating condition and voltage collapse or in the case of this study the margin until the system cannot maintain steady-state voltage criteria. Figure 5.1-1 provides an example of a classical PV curve which highlights how real power margin is calculated. In creating a PV curve the load in a specific area or the power flow over a transfer path is varied and the voltage at key buses is monitored. The system load/interface flow is increased incrementally until voltage collapse occurs (the nose point of the curve). Theoretically the curve returns to zero volts after the knee point. In a simulation environment (i.e., PSLF) the PV simulations are performed until the case diverges. This point of divergence is used as the nose point.

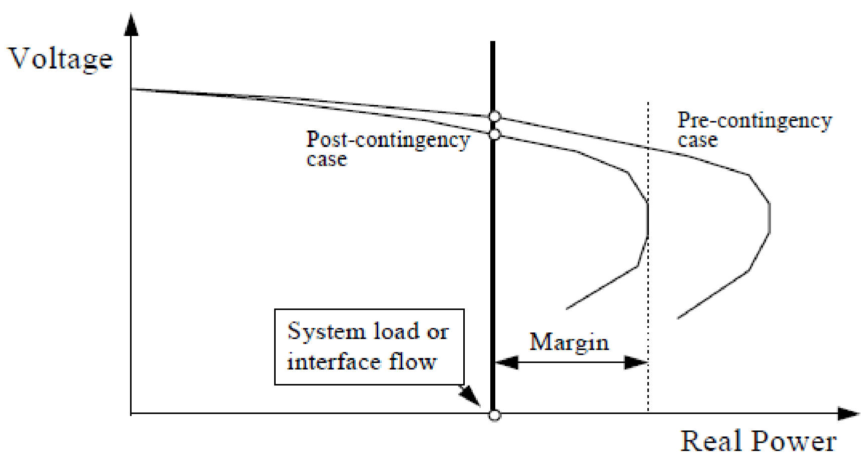


Figure 5.1-1 Example PV Curve (WECC Voltage Criteria May 1998).

For a QV analysis, voltage versus reactive power plots are created for a specific substation. These plots provide a method of viewing the reactive power margin at a given substation at a given system loading, for a specific contingency. In creating a QV plot an imaginary synchronous condenser is added at the study bus. The reference voltage of the imaginary synchronous condenser is varied between a high and low voltage value (1.5 p.u. to 0 p.u. in the case of the example plot shown in Figure 5.1-2) the reactive power output of the imaginary synchronous condenser is recorded as the reference voltage is varied. In a QV curve the Y-axis indicates the amount of additional reactive power that is necessary to regulate the bus to the specific voltage value. Positive Q indicates capacitive reactive power and negative Q indicates inductive reactive power. For the example shown in Figure 5.1-2, for the P=0 curve approximately 0.6 p.u. capacitive reactive power are necessary to regulate the voltage of the bus to 1.4 p.u. In reading a QV curve the downward slope (right side) of the QV curve is determined purely by the system strength of the study bus. The example curves shown in Figure 5.1-2 are theoretical and neglect the impact of switched shunts and transformer taps. In a real system transformer taps will flatten the curve towards the bottom, as shown in Figure 5.1-3. Typically QV curves are used to assist in the sizing of reactive compensation devices. For the purposes of this analysis, the QV curves will be used to validate that the recommended reactive compensation solutions can adequately regulate the voltage at key buses to at least 0.95 p.u. for base case conditions or 0.90 p.u. for contingency conditions.

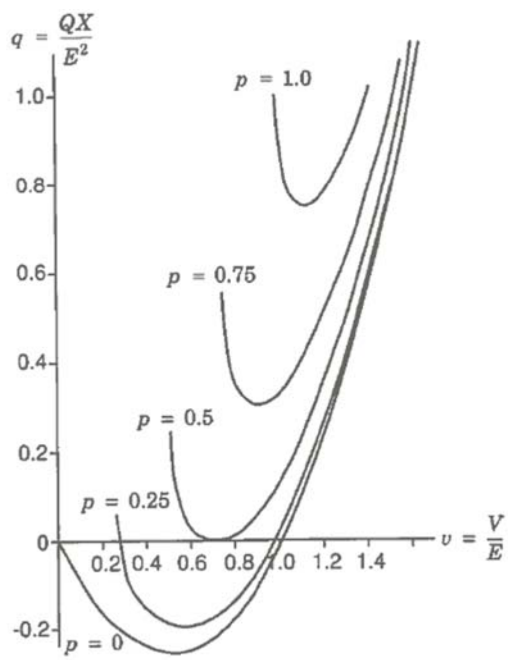


Figure 5.1-2 Example QV Curve (Power System Voltage Stability. Taylor C.W. 1994).

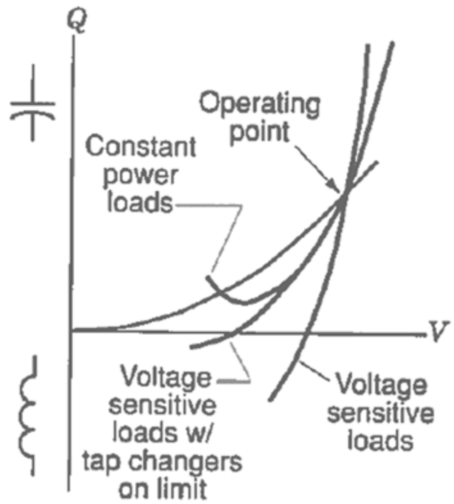


Figure 5.1-3 Example QV Curve Showing the Impact of Voltage Sensitive Load and Tap Changers (Power System Voltage Stability. Taylor C.W. 1994)

5.2 Approach for the PV and QV Analysis

The primary objective of the PV analysis is to quantify the power margin between the existing system operating condition and voltage collapse, and the primary objective of the QV analysis is to determine the reactive power margin for specific loading or system conditions.

The steady-state analysis determined that the heavy summer 1400 MW case was the limiting case and the dynamic analysis determined that a dynamic reactive power device (an SVC for purposes of this study) is needed at either the Missile Site 345 kV or Pronghorn 345 kV bus. A PV and QV analysis was examined for the heavy summer case to determine the transfer capability of the Gen-Tie line and the reactive power margin at Missile Site 345 kV and Pronghorn 345 kV.

Base case conditions and the limiting contingency was examined for this analysis. Note the case list examined was selected using the results from the steady-state analysis and the dynamic analysis. Table 5.2-1 shows the status of existing shunts for the case examined for informational purposes, and Table 5.2-2 shows the additional reactive support included in the case for the PV and QV analysis.

Table 5.2-1
Dispatch of Existing Reactive Power Devices Modeled for the PV and QV Analysis

Case Name	Pre-Existing Static Support						
	Missile Tap 230 kV (70621)	Missile Cap 345 kV (88888)	Missile Site 345 kV (70624)	Limone I 345 kV (70625)	Daniels Park 345 kV (70601)	Rush Creek W1 34.5 kV (70629)	Rush Creek W2 34.5 kV (70631)
Heavy Summer – High wind – Gen-Tie 1400 MW	150	50	0	40	0	130.2	51

Table 5.2-2
Dispatch of Additional Reactive Power Devices Modeled for the PV and QV Analysis Determined Necessary from the Steady-State Analysis

Case Name	Additional Static Support			
	Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
Heavy Summer – High wind – Gen-Tie 1400 MW	115	115	130	300

5.3 PV Analysis Results

The PV analysis was performed on the heavy summer 1400 MW case with the reactive power devices determined necessary in the steady-state analysis to satisfy base case (N-0) criteria (shown in Table 5.2-2).

In creating a PV curve, the load in a specific area or the power flow over a transfer path is varied and the voltage at key buses is monitored. The system load/interface flow was increased incrementally at the Gen-Tie until voltage collapse occurred or until the system was unable to maintain the WECC voltage criteria.

- For base case conditions, with the additional reactive support needed to satisfy base case conditions, no voltage violations were observed for present system loading conditions (1400 MW). The PV analysis shows that for base case conditions there is less than a 100 MW margin until base case voltage criteria is not met (bus voltages are below 0.95 p.u.).
    - Figure 5.3-1 shows the bus voltages and system response when system load conditions are varied for base case conditions.
- The limiting stuck breaker contingency, the loss of the Missile Site – Smoky Hill and Missile Site – Pawnee 345 kV lines was examined for this analysis. For the limiting contingency, with the additional reactive support needed to satisfy base case conditions, no voltage violations were observed for present system loading conditions (1400 MW). The PV analysis shows that for base case conditions there is a 20 MW margin until case divergent issues were observed.
    - Figure 5.3-2 shows the bus voltages and system response when system load conditions are varied for the limiting contingency.

The PV analysis shows that there is minimal acceptable active power margin with the recommended reactive power devices.

Base Case Heavy Summer High Wind 1400 MW							
Power Level (MW)	Harvest Mile 345 kV	Pawnee 345 kV	Smoky Hill 345 kV	Daniels Park 345 kV	Missile Site 345 kV	Pronghorn 345 kV	Shortgrass 345 kV
1390	0.965	0.989	0.964	0.960	0.983	0.965	0.967
1400	0.964	0.989	0.964	0.960	0.983	0.964	0.966
1410	0.964	0.988	0.963	0.959	0.982	0.962	0.964
1420	0.963	0.987	0.963	0.959	0.981	0.961	0.963
1430	0.963	0.987	0.962	0.958	0.980	0.959	0.962
1440	0.962	0.986	0.962	0.958	0.979	0.958	0.961
1450	0.962	0.986	0.961	0.957	0.978	0.956	0.959
1460	0.961	0.985	0.961	0.957	0.977	0.955	0.958
1470	0.960	0.985	0.960	0.957	0.976	0.953	0.956
1480	0.960	0.984	0.959	0.956	0.976	0.952	0.955
1490	0.959	0.984	0.959	0.956	0.975	0.950	0.953
1500	0.959	0.983	0.958	0.955	0.974	0.949	0.952
1510	0.958	0.982	0.957	0.955	0.973	0.947	0.950
1520	0.957	0.982	0.957	0.954	0.972	0.945	0.949
1530	0.957	0.981	0.956	0.954	0.970	0.943	0.946
1540	0.956	0.980	0.955	0.953	0.969	0.940	0.943
1550	0.955	0.979	0.954	0.952	0.968	0.938	0.940
1560	0.954	0.978	0.953	0.951	0.966	0.934	0.934
1570	0.952	0.977	0.952	0.950	0.964	0.929	0.927
1580	0.951	0.975	0.950	0.949	0.961	0.923	0.920

Note: Cells highlighted in red do not met WECC criteria (above 0.95 p.u.) for base case (N-0) conditions.

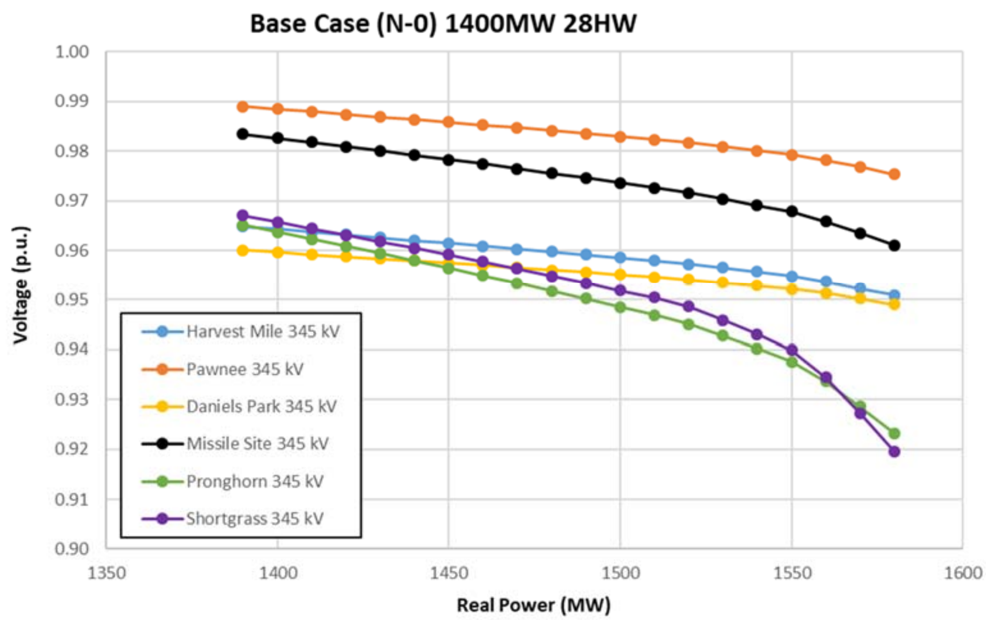


Figure 5.3-1. PV curve for base case conditions for the heavy summer high wind 1400 MW case.

Limiting Contingency Heavy Summer High Wind 1400 MW							
Power Level (MW)	Harvest Mile 345 kV	Pawnee 345 kV	Smoky Hill 345 kV	Daniels Park 345 kV	Missile Site 345 kV	Pronghorn 345 kV	Shortgrass 345 kV
1390	0.93	0.96	0.93	0.92	0.94	0.94	0.95
1400	0.93	0.96	0.93	0.91	0.94	0.93	0.95
1410	0.92	0.95	0.92	0.91	0.93	0.93	0.95
1420	0.92	0.94	0.92	0.90	0.92	0.92	0.94

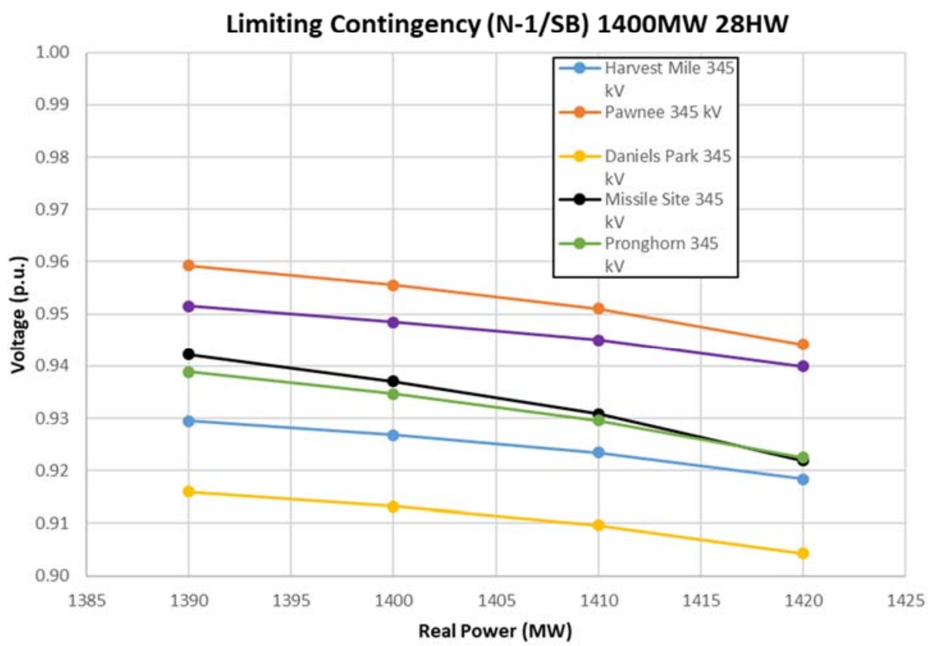


Figure 5.3-2. PV curve for the limiting stuck breaker contingency for the heavy summer high wind 1400 MW case.

5.4 QV Analysis Results

The QV analysis was performed on the heavy summer 1400 MW case with the reactive power devices determined necessary in the steady-state analysis to satisfy base case (N-0) criteria (shown in Table 5.2-2).

For the QV analysis an imaginary synchronous condenser was added at Pronghorn 345 kV and Missile Site 345 kV separately. The reference voltage of the synchronous condenser was varied between a high and low voltage value and the reactive power output of the synchronous condenser was recorded. Positive reactive power indicates that additional capacitive reactive power are necessary to regulate at the set voltage. In the context of this study this is an un-obtainable operating condition and a form of mitigation is needed. Negative reactive power indicates that sufficient capacitive reactive power exist to regulate at the set voltage (the synchronous condenser is operating inductively). This is an obtainable operating point and no mitigation is needed.

Missile Site 345 kV QV Analysis

- For base case conditions, with the additional reactive support needed to satisfy base case conditions it was determined that there is a sufficient amount of reactive power support at Missile Site 345 kV for the minimum voltage requirement (0.95 p.u.). MEPPI determined that the Missile Site 345 kV bus needs to be at a minimum of 0.98 p.u. pre-contingency to allow for the contingencies to converge. The QV curve shows that there is a sufficient amount of reactive power support at Missile Site 345 kV for the desired base case bus voltage of 0.98 p.u. but very little margin exists.
    - Figure 5.4-1 shows the bus voltages and the reactive power needs for base case conditions for a QV analysis at Missile Site 345 kV.
- The limiting stuck breaker contingency, the loss of the Missile Site – Smoky Hill and Missile Site – Pawnee 345 kV lines, was examined for this analysis. For the limiting contingency, with the additional reactive support needed to satisfy base case conditions it was determined that there is a sufficient amount of reactive power support at Missile Site 345 kV for the minimum voltage requirement (0.90 p.u.), but very little margin exists.
    - Figure 5.4-2 shows the bus voltages and the reactive power needs for the limiting stuck breaker contingency for a QV analysis at Missile Site 345 kV.

The QV analysis at the Missile Site 345 kV bus shows that there is minimal reactive power margin with the recommended reactive power devices.

With Additional Static VAR Support		
Ref. No.	Bus Voltage (p.u.)	Reactive Power (MW) Missile Site 345 kV
1	0.95	-301
2	0.96	-218
3	0.97	-119
4	0.98	-10
5	0.99	101
6	1.00	204
7	1.01	304
8	1.02	407
9	1.03	512
10	1.04	612
11	1.05	733

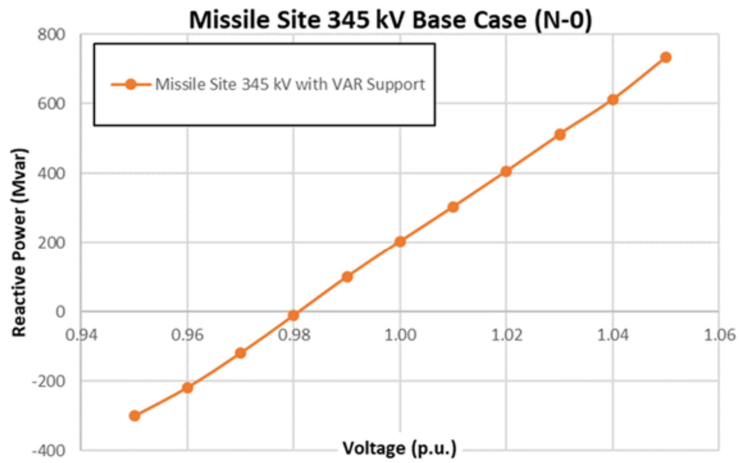


Figure 5.4-1. QV curve for base case conditions for a QV analysis at Missile Site 345 kV.

With Additional Static VAR Support		
Ref. No.	Bus Voltage (p.u.)	Reactive Power (MW) Missile Site 345 kV
1	0.90	-19
2	0.91	-23
3	0.92	-19
4	0.93	-4
5	0.94	21
6	0.95	52
7	0.96	108
8	0.97	180
9	0.98	261
10	0.99	345
11	1.00	430
12	1.01	519
13	1.02	610
14	1.03	703
15	1.04	788
16	1.05	875

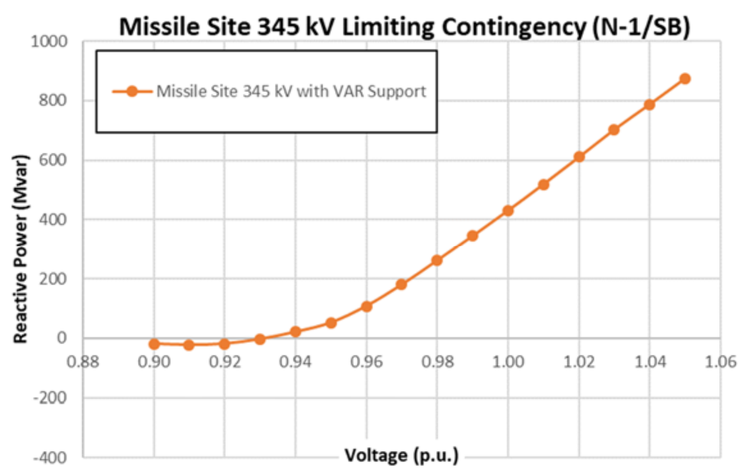


Figure 5.4-2. QV curve for the limiting stuck breaker contingency for a QV analysis at Missile Site 345 kV.

<u>Pronghorn 345 kV QV Analysis</u>

- For base case conditions, with the additional reactive support needed to satisfy base case conditions it was determined that there is a sufficient amount of reactive power support at Pronghorn 345 kV for the minimum voltage requirement (0.95 p.u.), but there is very little margin.
  - Figure 5.4-3 shows the bus voltages and the reactive power needs for base case conditions for a QV analysis at Pronghorn 345 kV.

- The limiting stuck breaker contingency, the loss of the Missile Site – Smoky Hill and Missile Site – Pawnee 345 kV lines, was examined for this analysis. For the limiting contingency, with the additional reactive support needed to satisfy base case conditions it was determined that there is a sufficient amount of reactive power support at Pronghorn 345 kV for the minimum voltage requirement (0.90 p.u.), but there is very little margin.
  - Figure 5.4-4 shows the bus voltages and the reactive power needs for the limiting contingency for a QV analysis at Pronghorn 345 kV.

The QV analysis at the Pronghorn 345 kV bus shows that there is minimal reactive power margin with the recommended reactive power devices.

With Additional Static VAR Support		
Ref. No.	Bus Voltage (p.u.)	Reactive Power (MW) Pronghorn 345 kV
1	0.95	-38
2	0.96	13
3	0.97	65
4	0.98	119
5	0.99	174
6	1.00	234
7	1.01	286
8	1.02	343
9	1.03	402
10	1.04	449
11	1.05	487

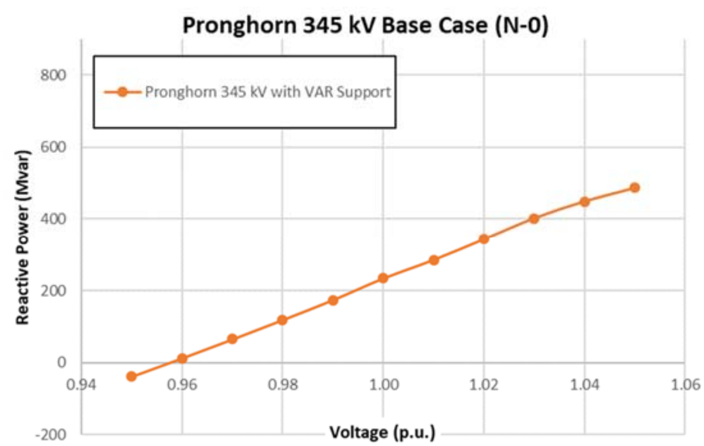


Figure 5.4-3. QV curve for base case conditions for a QV analysis at Pronghorn 345 kV.

With Additional Static VAR Support		
Ref. No.	Bus Voltage (p.u.)	Reactive Power (MW) Pronghorn 345 kV
1	0.90	-27
2	0.91	-24
3	0.92	-9
4	0.93	18
5	0.94	47
6	0.95	82
7	0.96	124
8	0.97	171
9	0.98	220
10	0.99	272
11	1.00	325
12	1.01	379
13	1.02	435
14	1.03	493
15	1.04	539
16	1.05	575

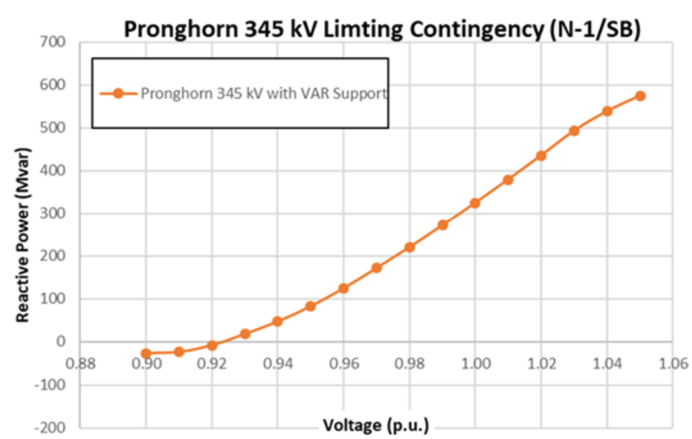


Figure 5.4-4. QV curve for the limiting contingency for a QV analysis at Pronghorn 345 kV.

5.5 Summary for the PV and QV Analysis

The primary objective of the PV analysis was to quantify the power margin between the existing system operating condition and voltage collapse. The PV analysis shows that there is minimal acceptable active power margin with the recommended reactive power devices.

- The PV analysis shows that for base case conditions there is less than a 100 MW margin until base case voltage criteria is not met (bus voltages are below 0.95 p.u.).
- The PV analysis shows that for the limiting contingency there is a 20 MW margin until case divergent issues were observed.

The primary objective of the QV analysis was to determine the reactive power margin for specific loading or system conditions. QV scans were examined at the Missile Site 345 kV and Pronghorn 345 kV buses. The QV analysis shows that there is minimal acceptable reactive power margin with the recommended reactive power devices.

- The QV analysis shows that for base case conditions, there is a sufficient amount of reactive power support at Missile Site 345 kV for the desired base case bus voltage of 0.98 p.u. but there is very little margin.
- The QV analysis shows that for the limiting contingency, there is a sufficient amount of reactive power support at Missile Site 345 kV for the minimum voltage requirement (0.90 p.u.), but there is very little margin.
- The QV analysis shows that for base case conditions, there is a sufficient amount of reactive power support at Pronghorn 345 kV for the minimum voltage requirement (0.95 p.u.), but there is very little margin.
- The QV analysis shows that for the limiting contingency, there is a sufficient amount of reactive power support at Pronghorn 345 kV for the minimum voltage requirement (0.90 p.u.), but there is very little margin.

SECTION 6
SENSITIVITY ANALYSIS

6.1 Background and Introduction

Sensitivity analyses were performed to provide insight to the relationship between the size of the interconnection and the need for reactive power mitigation and to the planning for a severe N-2 contingency. The following sensitives were examined for the steady-state and dynamic analysis:

- Limiting N-2 Contingency Analysis
- Reduced Dispatch Analysis

6.2 Limiting N-2 Contingency Analysis

Approach

Additional reactive support recommended in this study was based on N-1 and stuck breaker contingencies. For informational purposes limiting N-2 contingencies were examined for the steady-state and dynamic analysis.

Metrics and Violations

The study area of interest was defined as Area 70. WECC Criterion TPL-001-WECC-CRT-3.1 were applied to Bulk Electric System buses (100 kV and above) to evaluate the contingencies. The following metrics were used to flag thermal and voltage violations for the steady-state analysis:

- Thermal Loading Violations:
  - Any loading of branches and transformers greater than 100% of Rate B in Area 70 for bus voltage levels 100 kV and above for contingency conditions.
- Voltage Violations:
  - System stability was monitored for all buses
  - System stability was monitored for all nearby generation with focus placed on the Rush Creek W1, Rush Creek W2, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains wind plants
    - Tripping of plants were flagged
    - Tripping of any generation in the study area was flagged
  - Buses were flagged if the final voltages were less than 0.90 p.u. or greater than 1.10 p.u. in Area 70 for contingency conditions.

Contingency List

The following N-2 contingencies were examined for the steady-state analysis:

- Loss of both the Missile Site – Smoky Hill 345 kV line and the Missile Site – Daniels Park 345 kV line sharing a common structure
- Loss of both the Missile Site – Pawnee 345 kV lines sharing a common structure

N-2 Analysis Results

It was observed that additional reactive power support is needed for N-2 contingency conditions.

- The limiting N-2 contingency, the loss of the Missile Site – Smoky Hill and Missile Site – Daniels Park 345 kV results in low voltages, thermally overloaded lines, and potential voltage collapse. It was determined that even with a large amount of reactive support, thermal overloads of concern were observed along several 230 kV lines which has the potential to result in voltage collapse.
- To achieve a converged case for the limiting N-2 contingency, an increase in reactive power support is needed at Missile Site 345 kV and at Harvest Mile 345 kV. Even with the additional reactive power, nearby transformers and 345 kV lines are thermally overloaded, which will not be mitigated with additional reactive power support, it is anticipated that an additional line or transformer will be needed.
- It is not recommended to mitigate the limiting N-2 contingency with additional reactive power compensation only.

Refer to Table 6.2-1 and Table 6.2-2 for the minimum amount of additional reactive power needed to meet voltage criteria for contingency conditions for the summer heavy loaded case and the light spring case, respectively.

Tables 6.2-3 through 6.2-6 list all branches that were thermally overloaded in Area 70. These are listed for informational purposes only. The purpose of this analysis was to determine the reactive power needs to support the increase in wind generation in the Missile Site area, which has minimal impact on the power flow on the equipment. Note no thermal overloads were observed for the heavy summer 0 MW or light spring 0 MW cases.

The limiting N-2 contingencies were examined in the time domain and it was observed that even with the recommended reactive support (based on the steady-state and dynamic analysis to meet the N-0, N-1, and stuck breaker contingencies as described in Section 2 and Section 3), the limiting N-2 resulted in the system becoming unstable. At this time, no mitigation was found for the limiting N-2. Refer to Table 6.2-7 for a summary table for the N-2 analysis. Figure 6.2-1 shows plots for the limiting N-2 contingency.

Table 6.2-1
Additional Reactive Power Needs to Maintain Steady-State Bus Voltages for Contingency Conditions for the Light Spring High Wind Case

Ref. No.	Contingency Description	Bus Description	Post-Contingency Reactive Power Needs (Mvar)		
			Light Spring High wind 1400 MW	Light Spring High wind 1600 MW	Light Spring High wind 0 MW
1	Missile Site - Smokey Hill 345 kV Missile Site - Daniels Park 345 kV	Harvest Mile 345 kV (70597)	0	0	0
2		Missile Site 345 kV (70624)	0	0	0
3		Pronghorn 345 kV (70628)	129	358	0

Note: Highlighted cells in the above tables indicate that additional reactive power compensation is needed. Positive values represent capacitive and negative values represent inductive compensation.

Table 6.2-2
Additional Reactive Power Needs to Maintain Steady-State Bus Voltages for Contingency Conditions for the Heavy Summer High Wind Case

Ref. No.	Contingency Description	Contingency Type	Bus Description	Post-Contingency Reactive Power Needs (Mvar)		
				Heavy Summer High wind 1400 MW	Heavy Summer High wind 1600 MW	Heavy Summer High wind 0 MW
1	Missile Site - Smoky Hill 345 kV Missile Site - Daniels Park 345 kV	N-2	Harvest Mile 345 kV (70597)	419	555	0
2			Missile Site 345 kV (70624)	588	874	0
3			Pronghorn 345 kV (70628)	0	0	0

Reactive Device at Harvest Mile 345 kV is set to regulate a post-contingency voltage of 0.96 p.u.
Reactive Device at Missile Site 345 kV is set to regulate a post-contingency voltage of 0.98 p.u.
Reactive Device at Pronghorn 345 kV is set to regulate a post-contingency voltage of 0.95 p.u.

Note: Highlighted cells in the above tables indicate that additional reactive power compensation is needed. Positive values represent capacitive and negative values represent inductive compensation.

Table 6.2-3
Thermal Overloads for the Heavy Summer High Wind 1400 MW Case for Contingency Conditions

Heavy Summer – High wind – Gen-Tie 1400 MW													
Ref. No.	From Bus No.	From Bus Name	From kV	To Bus No.	To Bus Name	To kV	Ckt ID	Contingency Description	Fault Type	Rating*	Power Flow p.u.	Power Flow MVA	Power Flow I
1	70139	DANIELPK	230	70623	MIS_SITE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	2000 A	1.42	1040	2839
2	70192	FTLUPTON	230	70311	PAWNEE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	1327 A	1.14	547	1505
3	73192	STORY	230	70311	PAWNEE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	1588 A	1.65	970	2613
4	70624	MIS_SITE	345	70623	MIS_SITE	230	T1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	756 MVA	1.22	923	1609
5	70712	PTZLOGN2	34.5	70711	PTZLOGN	230	U2	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	125 MVA	1.01	126	2410

*For the base case rating 1 was used for contingencies cases rating 2 was used.

Table 6.2-4
Thermal Overloads for the Heavy Summer High Wind 1600 MW Case for Contingency Conditions

Heavy Summer – High wind – Gen-Tie 1600 MW													
Ref. No.	From Bus No.	From Bus Name	From kV	To Bus No.	To Bus Name	To kV	Ckt ID	Contingency Description	Fault Type	Rating*	Power Flow p.u.	Power Flow MVA	Power Flow I
4	70139	DANIELPK	230	70623	MIS_SITE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	2000 A	1.42	1040	2839
5	70192	FTLUPTON	230	70311	PAWNEE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	1327 A	1.14	547	1505
21	73192	STORY	230	70311	PAWNEE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	1588 A	1.65	970	2613
22	70624	MIS_SITE	345	70623	MIS_SITE	230	T1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	756 MVA	1.22	923	1609
23	70712	PTZLOGN2	34.5	70711	PTZLOGN	230	U2	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	125 MVA	1.01	126	2410

*For the base case rating 1 was used for contingencies cases rating 2 was used.

Table 6.2-5
Thermal Overloads for the Light Spring High Wind 1400 MW Case for Contingency Conditions

Light Spring – High wind – Gen-Tie 1400 MW													
Ref. No.	From Bus No.	From Bus Name	From kV	To Bus No.	To Bus Name	To kV	Ckt ID	Contingency Description	Fault Type	Rating*	Power Flow p.u.	Power Flow MVA	Power Flow I
1	73192	STORY	230	70311	PAWNEE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	1588 A	1.20	717	1908
2	88884	CHEYRDGE E	345	88883	CHEYRDGE E	34.5	T1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	140 MVA	1.01	138	237
3	88884	CHEYRDGE E	345	88883	CHEYRDGE E	34.5	T2	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	140 MVA	1.01	138	237

*For the base case rating 1 was used for contingencies cases rating 2 was used.

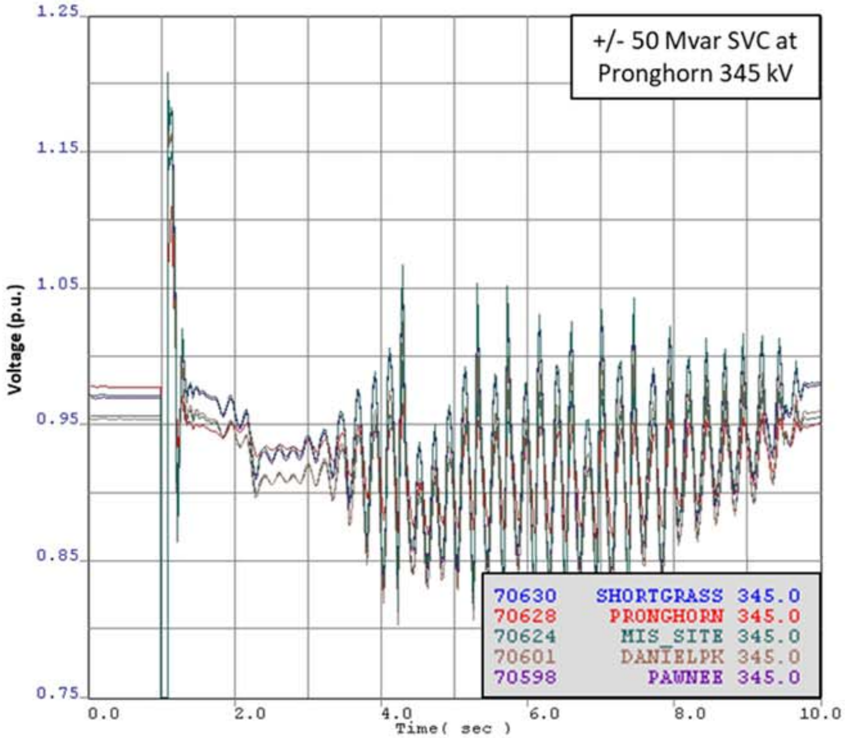
Table 6.2-6
Thermal Overloads for the Light Spring High Wind 1600 MW Case for Contingency Conditions

Light Spring – High wind – Gen-Tie 1600 MW													
Ref. No.	From Bus No.	From Bus Name	From kV	To Bus No.	To Bus Name	To kV	Ckt ID	Contingency Description	Fault Type	Rating*	Power Flow p.u.	Power Flow MVA	Power Flow I
1	70139	DANIELPK	230	70623	MIS_SITE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	2000 A	1.02	774	2030
2	73192	STORY	230	70311	PAWNEE	230	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	1588 A	1.38	800	2189
3	70624	MIS_SITE	345	88888	MISCAPS	345	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	2739 A	1.08	1524	2967
4	88888	MISCAPS	345	70628	PRONGHORN	345	1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	2739 A	1.09	1531	2979
5	88884	CHEYRDGE E	345	88883	CHEYRDGE E	34.5	T1	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	140 MVA	1.01	137	236
6	88884	CHEYRDGE E	345	88883	CHEYRDGE E	34.5	T2	Loss of Missile Site - Smoky Hills 345 kV and Missile Site - Daniels Park 345 kV	N-2	140 MVA	1.01	137	236

*For the base case rating 1 was used for contingencies cases rating 2 was used.

Table 6.2-7
Summary Results for the N-2 Dynamic Analysis with a +/- 50 Mvar SVC at Pronghorn 345 kV

Ref. No.	Contingecy Description	Fault Type	Is the System Stable? (Yes or No)	Pronghorn 345 kV		Final Buses Below 90%		Final Buses above 1.10 p.u.		Tripped Generation	
				Final Bus Voltage (p.u.)	Final SVC Output B (p.u.)	# of Buses	Bus List	# of Buses	Bus List	# of Gens	Bus List
14	Missile Site - Smoky Hill 345 kV line Missile Site - Daniels Park 345 kV line	N-2	No	N/A	N/A	0	N/A	0	N/A	0	N/A
15	Missile Site - Pawnee 345 kV line Missile Site - Pawnee 345 kV line	N-2	Yes	0.96	0.01	0	N/A	0	N/A	0	N/A



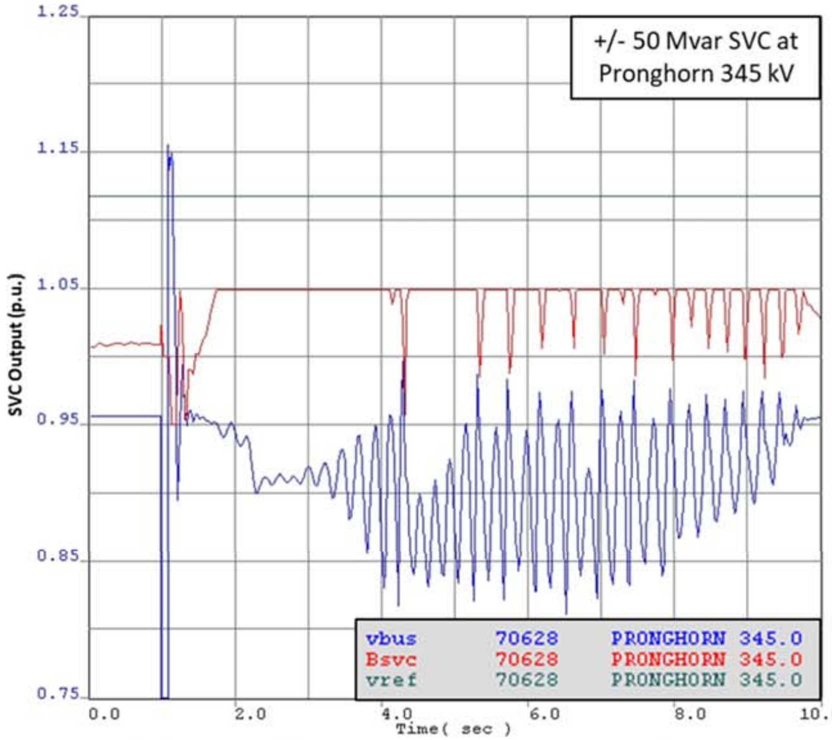


Figure 6.2-1. Response of the dynamic device and nearby buses for the limiting N-2 Contingency for the heavy summer 1400 MW case with a dynamic device at the Pronghorn 345 kV bus.

6.3 Reduced Dispatch Analysis

Approach

With the completion of the steady-state analysis and the dynamic analysis it was determined that static compensation is needed to meet WECC voltage criteria for base case and contingency conditions with the wind generation along the Gen-Tie line at 1400 MW. The objective of the reduced dispatch analysis was to analyze the impact of reduced generation levels along the Gen-Tie to determine how the power transfer affects the need for reactive power compensation. The objective of the reduced dispatch analysis is to examine the results of key cases identified during the steady-state and dynamic analysis with reduced generation dispatch along the Gen-Tie line for the heavy summer case to determine the maximum power transfer before the need for reactive power compensation. The following dispatches were examined:

- 1200 MW (total)
- 1000 MW (total)

All reactive compensation needed to meet base case (N-0) conditions for the steady-state analysis or the dynamic analysis was removed for this analysis.

Nearby generation was scaled (turned on for this analysis) to accommodate the re-dispatched cases. Xcel Energy recommended that the Natural Gas Fort St. Vain Station (70407 ST.VR_2, 70407 ST.VR_3, 70408 ST.VR_4, 70950 ST.VR_5, and 70951 ST.VR_6) was used for re-dispatching purposes.

Metrics and Violations

The study area of interest was defined as Area 70. WECC Criterion TPL-001-WECC-CRT-3.1 were applied to Bulk Electric System buses (100 kV and above) to evaluate the contingencies. The following metrics were used to flag thermal and voltage violations for the steady-state analysis:

- Thermal Loading Violations:
  - Any loading of branches and transformers greater than 100% of Rate A in Area 70 for bus voltage levels 100 kV and above for base case conditions (N-0).
  - Any loading of branches and transformers greater than 100% of Rate B in Area 70 for bus voltage levels 100 kV and above for contingency conditions.
- Voltage Violations:
  - System stability was monitored for all buses
  - System stability was monitored for all nearby generation with focus placed on the Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains collector stations
    - Tripping of plants were flagged
    - Tripping of any generation in the study area was flagged

- Buses were flagged if the final voltages were less than 0.95 p.u. or greater than 1.05 p.u. in Area 70 for base case conditions (N-0).
- Buses were flagged if the final voltages were less than 0.90 p.u. or greater than 1.10 p.u. in Area 70 for contingency conditions.

Contingency List

The following key contingencies identified from the steady-state analysis and dynamic analysis, (Sections 1 and 2) were examined.

- The following N-1 contingency was examined:
  - Loss of the Missile Site – Pronghorn 345 kV line
- The following stuck breaker contingency was examined:
  - Stuck breaker at Missile Site 345 kV resulting in the loss of the Missile Site – Pawnee 345 kV line and Missile Site – Smoky Hill 345 kV line
- The following N-2 contingency was examined:
  - Loss of the Missile Site – Smoky Hill 345 kV line and Missile Site – Daniels Park 345 kV line

Reduced Dispatch Analysis Results

The new generation along the Gen-tie was reduced to determine the impact of decreasing the additional generation with respect to additional reactive power compensation. The Rush Creek units are in-service so the 1400 MW was decreased using the Bronco Plains and Cheyenne Ridge units. The Natural Gas Fort St. Vain Station was used for the re-dispatching of the 200 MW and 400 MW. The following cases were examined:

- 1200 MW (total) - No reactive power compensation
- 1000 MW (total) - No reactive power compensation

1200 MW Re-Dispatch

Refer to Table 6.3-1 for a summary of the results for the reduced dispatch analysis for base case and the limiting N-1 and stuck breaker contingencies examined.

- When the wind plants are reduced to 1200 MW (total), low voltages at Daniels Park and Harvest Mile that did not meet base case (N-0) voltage criteria were observed. With the addition of 70 Mvar at Daniels Park 345 kV all low voltages were mitigated.
- With the generation reduced, no oscillations of concern were observed in the time domain analysis. Refer to Figure 6.3-1 for a comparison plot of the limiting contingency for the heavy summer case dispatched at 1400 MW (without an SVC) and for the heavy summer case dispatched to 1200 MW.

The limiting N-2 contingency was examined with the generation reduced to 1200 MW and with the additional 70 Mvar capacitor at Daniels Park. Even with the reduced generation, low voltages, thermally overloaded lines, and potential voltage collapse were observed.

1000 MW Re-Dispatch

Refer to Table 6.3-2 for a summary of the results for the reduced dispatch analysis for base case and the limiting N-1 and stuck breaker contingencies examined.

- When the wind plants are reduced to 1000 MW (total), no voltages of concern were observed and all voltages met WECC criteria.
- With the generation reduced, no oscillations of concern were observed in the time domain. Refer to Figure 6.3-2 for a comparison plot of the limiting contingency for the heavy summer case dispatched at 1400 MW (without an SVC) and for the heavy summer case dispatched to 1000 MW with no additional reactive compensation.

The limiting N-2 contingency was examined with the generation reduced to 1000 MW. Even with the reduced generation, low voltages, thermally overloaded lines, and potential voltage collapse were observed.

Table 6.3-1
Summary Results for the Steady-State Analysis for the 1200 MW Curtailment

Ref. No.	Case Description	Contingency Conditions	Additional Static Support (Mvar)				Bus Voltages (p.u.)			
			Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)	Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
1	1200 MW case (28HS1a)	**N-0** Base Case	0	0	0	0	0.944	0.947	0.959	0.964
2		**N-1** Missile Site - Pronghorn 345 kV line	0	0	0	0	0.962	0.969	N/A	0.992
3		**SB** Smoky Hill - Missile Site & Missile Site - Pawnee 345 kV lines	0	0	0	0	0.892	0.904	0.919	0.903
4		**N-0** Base Case	70	0	0	0	0.950	0.951	0.961	0.967
5		**N-1** Missile Site - Pronghorn 345 kV line	70	0	0	0	0.968	0.973	N/A	0.995
6		**SB** Smoky Hill - Missile Site & Missile Site - Pawnee 345 kV lines	70	0	0	0	0.905	0.915	0.928	0.916

Note: Cells highlighted in red do not met WECC criteria (above 0.95 p.u.) for base case (N-0) conditions.

Table 6.3-2
Summary Results for the Steady-State Analysis for the 1000 MW Curtailment

Ref. No.	Case Description	Contingency Conditions	Additional Static Support (Mvar)				Bus Voltages (p.u.)			
			Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)	Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
1	1000 MW Case (28HS1a)	**N-0** Base Case	0	0	0	0	0.955	0.960	0.991	0.981
2		**N-1** Missile Site - Pronghorn 345 kV line	0	0	0	0	0.965	0.972	N/A	0.994
3		**SB** Smoky Hill - Missile Site & Missile Site - Pawnee 345 kV lines	0	0	0	0	0.926	0.935	0.979	0.962

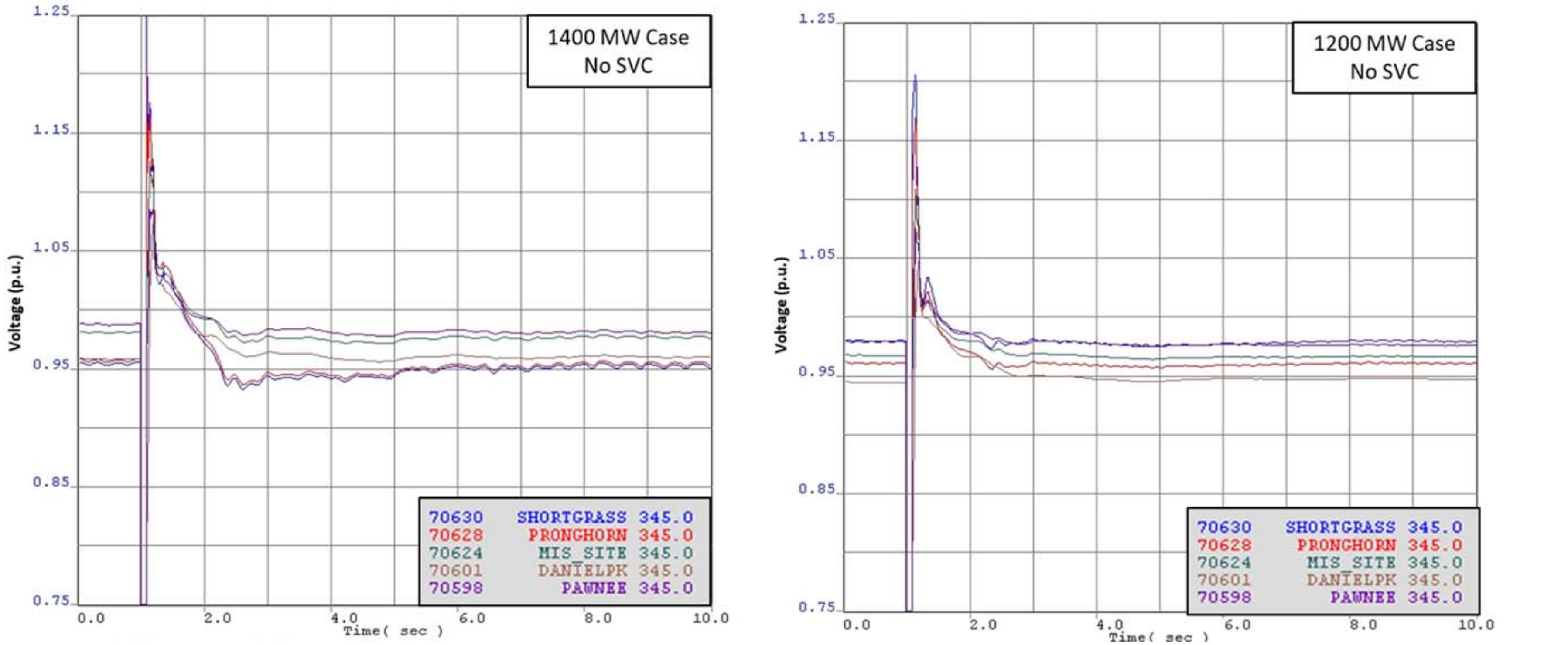


Figure 6.3-1. Comparison plot of the limiting contingency for the heavy summer case dispatched at 1400 MW (without an SVC) and for the heavy summer case dispatched to 1200 MW.

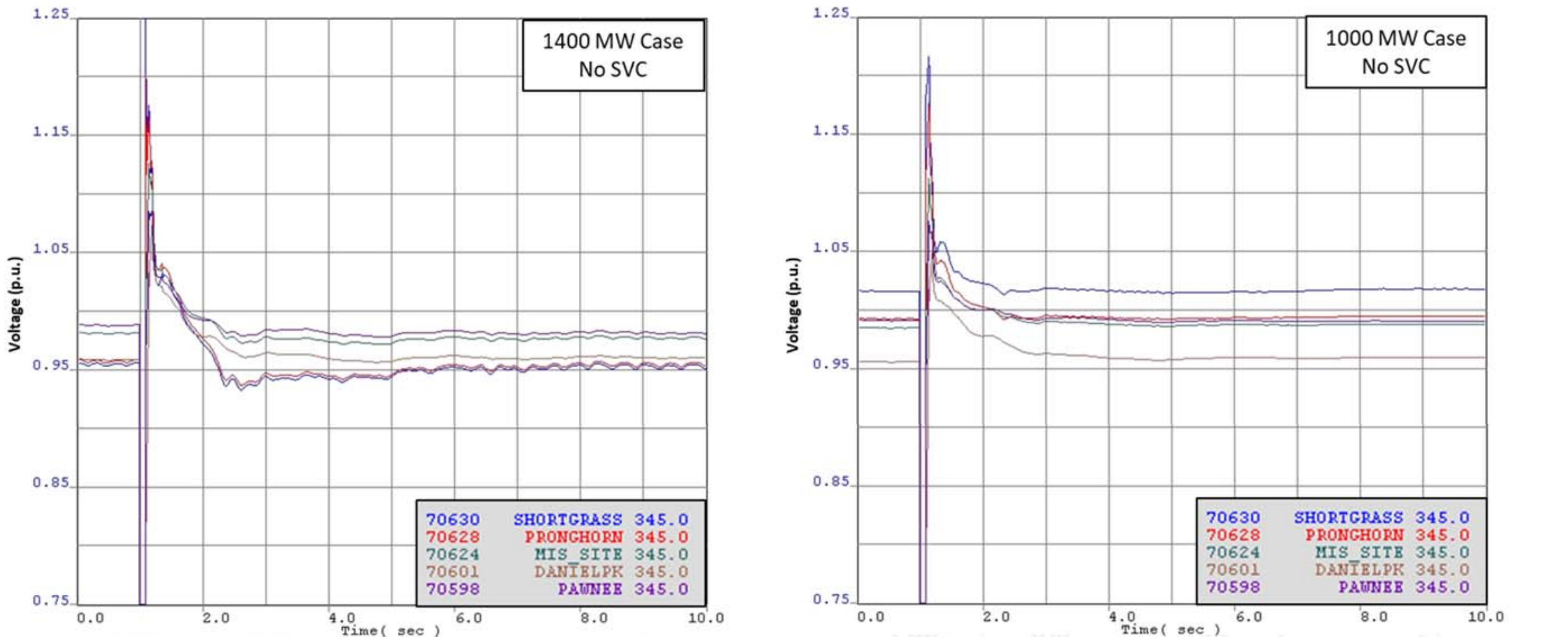


Figure 6.3-2. Comparison plot of the limiting contingency for the heavy summer case dispatched at 1200 MW (without an SVC) and for the heavy summer case dispatched to 1000 MW with no additional mitigation.

6.4 Sensitivity Analyses Summary

The primary objective of the N-2 analysis was to analyze the impact and plan for a severe N-2 contingency. For informational purposes limiting N-2 contingencies were examined for the steady-state and dynamic analysis within this sensitivity.

- The limiting N-2 contingency, the loss of the Missile Site – Smoky Hill and Missile Site – Daniels Park 345 kV sharing a common structure resulted in thermally overloaded lines/transformers and potential voltage collapse. It was determined that shunt compensation was not a feasible mitigation option for the limiting N-2 because of the thermal overloads in Xcel Energy's 230 kV system.
- It is recommended for Xcel to further investigate mitigation techniques for the limiting N-2 contingency with a transmission solution or transfer trip scheme.

The primary objective of the reduced dispatch analysis was to analyze the impact of reducing the additional generation connecting along the Gen-Tie on the Xcel system to determine the maximum power transfer before the need for reactive power compensation.

- It was determined that if the generation is reduced to 1200 MW, an additional 70 Mvar of static support is needed at Daniels Park to meet WECC Criterion for base case (N-0), N-1, and stuck breaker conditions.
- It was determined that if the generation is reduced to 1000 MW no additional static support is needed to meet WECC Criterion for base case (N-0), N-1, and stuck breaker conditions.

APPENDIX A
STEADY-STATE ANALYSIS WITH THE INITIAL POWER FLOW CASES

A.1 Background and Introduction

A steady-state contingency analysis was performed to determine the amount of steady-state reactive power compensation needed for the interconnection of the CEPP generation, focusing on the additional wind generation to the Gen-Tie to meet planning criteria. Contingencies specified by Xcel Energy were examined, and all contingencies that resulted in non-convergence, thermal overloads, or voltage criteria violations were flagged.

To determine the impact of the new generation and to identify any need for reactive power compensation, Xcel provided MEPPI with a heavy loaded summer and a lightly loaded spring case. Cases were examined with the wind generation offline (0 MW), the wind generation at full output (1400 MW total), and a sensitivity where the wind generation was increased for future growth (1600 MW total).

After the steady-state analysis was completed, Xcel Energy provided an update to the Cheyenne Ridge East and Cheyenne Ridge West collector systems. The steady-state analysis was completed using the power flow cases described in this Appendix. Key cases were then re-examined with the updated case, which are described in Section 3 of this report titled Steady-State Analysis.

A.2 Review and Construction of the Steady-State Models

The study area of interest was defined as PSCo Balancing Area 70. Figure A.2-1 shows a one-line diagram of the immediate study area. The generation of interest is the wind generation connected to the radial line off the Missile Site 345 kV substation (Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains).

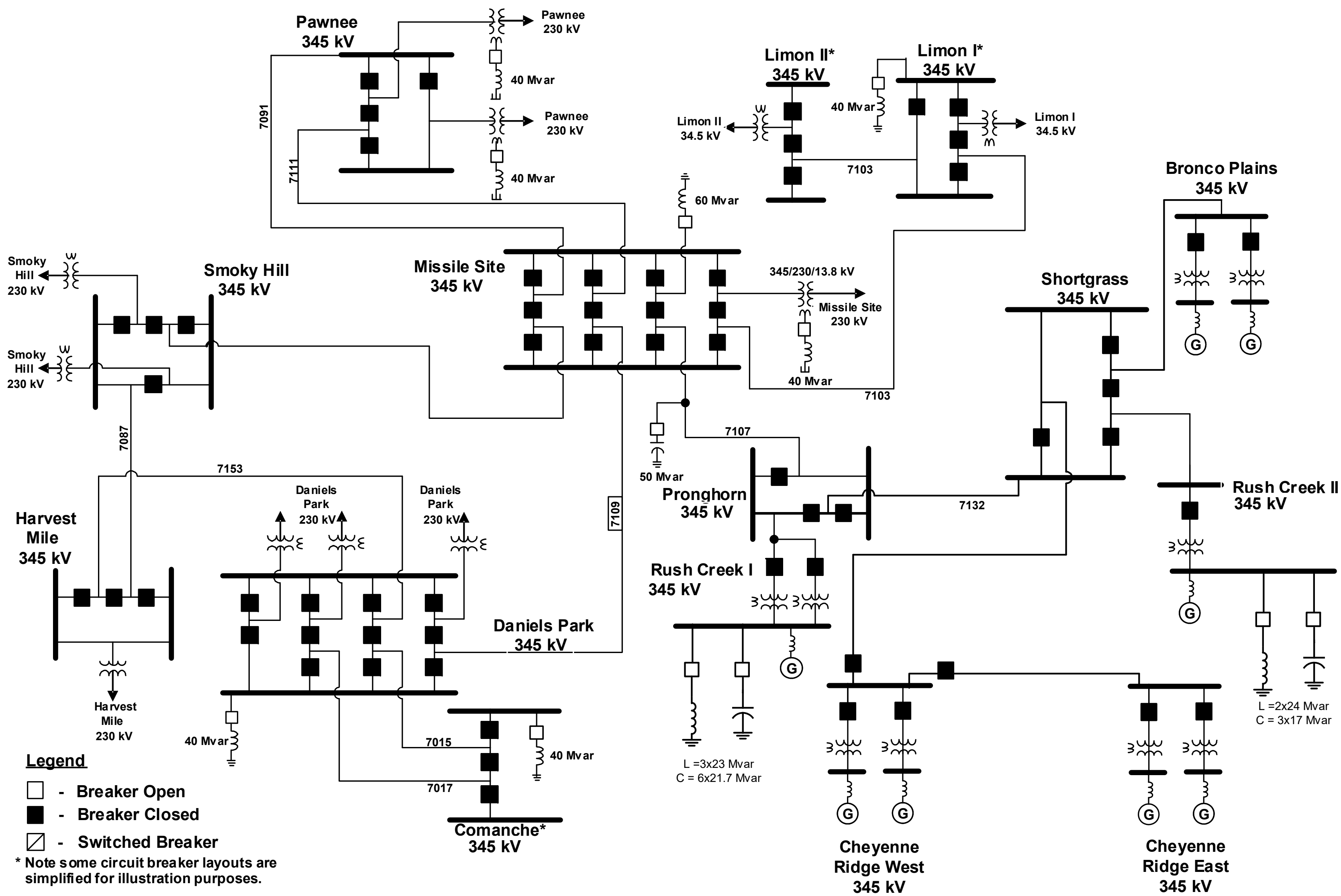


Figure A.2-1. One-line diagram of the wind generation and immediate study area.

The generation of interest is the wind generation connected to the radial line off the Missile Site 345 kV substation (Rush Creek I, Rush Creek II, Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains). The wind plants were represented by modeling the main plant transformers, the equivalent collector system, an aggregate wind turbine transformer, and an aggregate wind turbine generator, which was provided by Xcel Energy. Refer to Tables A.2-1 through A.2-3 for the interconnection data used to represent the wind plants of interest.

- Table A.2-1 shows the transformer data for the wind plants of interest
- Table A.2-2 shows the line data for the wind plants of interest
- Table A.2-3 shows the wind turbine data for the wind plants of interest

The new wind generation facilities are each required to provide voltage regulation with the capability of providing at a minimum 0.95 power factor leading and lagging at the high voltage (345 kV) terminals of the plant main transformer. As part of the review of the power flow cases, it was determined that the wind generation plants of interest did not meet power factor requirements. Based on steady-state power flow calculations, additional compensation was needed for the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants. Note the Cheyenne Ridge West, Cheyenne Ridge East, and Bronco Plains plants will be expected to maintain a 0.95 power factor (leading and lagging) at the high side of their respective 345/34.5 kV transformers and were adjusted to meet the power factor requirements. Refer to Table A.2-3 for the adjusted reactive power ranges.

Table A.2-1
Transformer Data for the Wind Plants of Interest

Ref. No.	From Bus			To Bus			Ckt ID	MVA Base	R (p.u.)	X (p.u.)
	No.	Name	Voltage (kV)	No.	Name	Voltage (kV)				
1	70628	PRONGHORN	345	70629	RUSHCK_W1	34.5	T1	138.0	0.0024	0.1000
2	70628	PRONGHORN	345	70629	RUSHCK_W1	34.5	T2	138.0	0.0024	0.1000
3	70629	RUSHCK_W1	34.5	88886	RUSHCK_W1	0.69	T1	430.0	0.0063	0.0758
4	70630	SHORTGRASS	345	70631	RUSHCK_W2	34.5	T1	138.0	0.0024	0.1000
5	70631	RUSHCK_W2	34.5	88887	RUSHCK_W2	0.69	T1	248.0	0.0063	0.0758
6	70633	BRONCOPLNS	345	88882	BRONCO_PL	34.5	1	102.0	0.0022	0.0867
7	70633	BRONCOPLNS	345	88882	BRONCO_PL	34.5	2	102.0	0.0022	0.0867
8	88864	BRONCO_PL1	34.5	88863	BRONCO_PL1	0.69	1	336.0	0.0266	0.1999
9	70632	CHEYRDGE W	345	88885	CHEYRDGE W	34.5	1	140.0	0.0024	0.0850
10	70632	CHEYRDGE W	345	88885	CHEYRDGE W	34.5	1	140.0	0.0024	0.0850
11	88884	CHEYRDGE E	345	88883	CHEYRDGE E	34.5	1	140.0	0.0024	0.0850
12	88884	CHEYRDGE E	345	88883	CHEYRDGE E	34.5	1	140.0	0.0024	0.0850

Table A.2-2
Line Data for the Wind Plants of Interest

Ref. No.	From Bus			To Bus			R (p.u.)	X (p.u.)	B (p.u.)
	No.	Name	Voltage (kV)	No.	Name	Voltage (kV)			
1	70628	PRONGHORN	345	70630	SHORTGRASS	345	0.00124	0.01928	0.33396
2	70633	BRONCOPLNS	345	70630	SHORTGRASS	345	0.00070	0.00666	0.12457
3	88882	BRONCO_PL	34.5	88864	BRONCO_PL1	34.5	0.00143	0.00068	0.02631
4	70630	SHORTGRASS	345	70632	CHEYRDGE W	345	0.00149	0.02678	0.49595
5	70632	CHEYRDGE W	345	88884	CHEYRDGE E	345	0.00023	0.00416	0.07699

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Table A.2-3
Wind Turbine Data for the Wind Plants of Interest

Ref. No.	Bus No.	Bus Name	Scheduled Voltage (p.u.)(1)	Max P @ POI(2) (MW)	Required PF @ POI	Required Q @ POI (MVAr)	Plant Losses (Mvar)	Initial Generator Qmax (Mvar)	Initial Generator Qmin (Mvar)	Plant Shunt Shunt Cap (Mvar)	Plant Shunt Shunt L (Mvar)	Plant Capability Capacitive (Mvar)	Plant Capability Inductive (Mvar)	Adjusted Final Qmax (Mvar)	Adjusted Final Qmin (Mvar)	Description(3)
1	88886	RUSHCK_W1	1.00	376	0.95	123.59	-44.00	77.16	-77.16	130.20	-69.00	163.36	-190.16	77.16	-77.16	meets
2	88887	RUSHCK_W2	1.00	218	0.95	71.65	-2.67	41.00	-44.00	51.00	-48.00	89.33	-94.67	41.00	-44.00	meets
3	88863	BRONCO_PL1	1.02	290	0.95	95.32	-92.89	144.00	-144.00	0.00	0.00	51.11	-236.89	188.21	-144.00	adjusted
4	88885	CHEYRDGE W	1.00	232	0.95	76.25	-17.67	77.00	-77.00	0.00	0.00	59.33	-94.67	93.92	-77.00	adjusted
5	88883	CHEYRDGE E	1.00	268	0.95	88.09	-22.85	88.00	-88.00	0.00	0.00	65.15	-110.85	110.94	-88.00	adjusted

(1) Generators were set to regulate their own bus voltage.

(2) The POI is considered at the high-side of the 345/34.5 kV transformers for power factor purposes

(3) Highlighted cells indicate plants that are not capable of meeting power factor requirements and were adjusted to maintain a 0.95 power factor (leading and lagging) at the high-side of their respective 345/34.5 kV transformers.

A.3 Approach for the Steady-State Analysis

The primary objective of the steady-state analysis is to identify potential voltage concerns per WECC Criterion. MEPPI monitored the study area (Area 70) for thermal overloads and voltage violations. The results of the 1400 MW, 1600 MW, and 0 MW cases (Gen-Tie line wind dispatch) were compared to determine the impact of increased generation on the contingency events, voltage profiles, and reactive power requirements. The steady-state analysis was performed with the objective of identifying the minimum amount of reactive compensation required to mitigate voltage/thermal violations to accommodate the additional wind generation along the Gen-Tie line. Where thermal violations were observed they were flagged and discussed with Xcel Energy to determine if mitigation such as reconductoring lines was a feasible mitigation strategy.

The following power flow cases were used for the analysis:

- Heavy Summer – High wind – Gen-Tie 1400 MW
  - Constructed based on the 28HS1a_CEP_LowWind 0MW.sav and 28HS1a_CEP_HighWIND 1600MW.sav cases with Xcel Energy's guidance.
- Heavy Summer – High wind – Gen-Tie 1600 MW (sensitivity)
  - 28HS1a_CEP_HighWIND 1600MW.sav
- Heavy Summer – Low wind – Gen-Tie 0 MW
  - 28HS1a_CEP_LowWind 0MW.sav
- Light Spring – High wind – Gen-Tie 1400 MW
  - 21LSP1a_CEP_HighWind 1400MW.sav
- Light Spring – High wind – Gen-Tie 1600 MW (sensitivity)
  - 21SP1a_CEP_HighWind 1600MW.sav
- Light Spring – Low wind – Gen-Tie 0 MW
  - 21LSP1a_CEP_LowWind 0MW.sav

For base case conditions (N-0) reactive power compensation was sized to meet the minimum requirements by modeling switched shunts that had a large reactive and capacitive range (with steps of +/- 5 Mvar to ensure accurate sizing) at the following key buses in the study area:

- Daniels Park 345 kV
- Harvest Mile 345 kV
- Pronghorn 345 kV
- Cheyenne Ridge West 345 kV
- Missile Site 345 kV
- Shortgrass 345 kV

Reactive compensation was added to the individual cases such that all bus voltages for base case (N-0) conditions met the specified voltage criteria (0.95 to 1.05 p.u. range). A steady-state contingency analysis was ran to identify limiting contingences that result in the need for additional static reactive power support. Note all reactive power compensation was sized to meet the minimum requirements for contingency conditions. Note these locations were identified to be limiting areas for voltage stability based on preliminary analysis performed by MEPPI.

Solution Parameters

SSTOOLs (Steady-State Analysis Tools) in PSLF 21.0_05 was used to complete the steady-state analysis. Figures A.3-1 and A.3-2 show the solution parameters used for this analysis for base case (N-0) conditions and for contingency conditions.

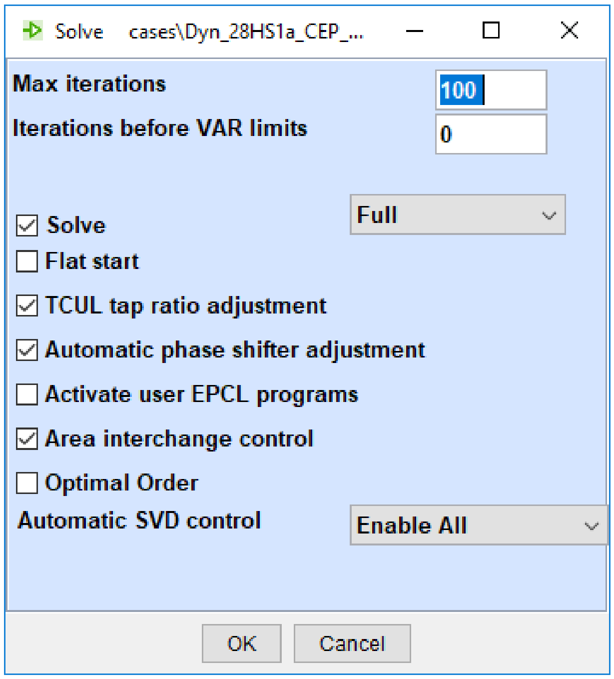

Figure A.3-1. Solution parameters for the steady-state analysis for base case (N-0) conditions.

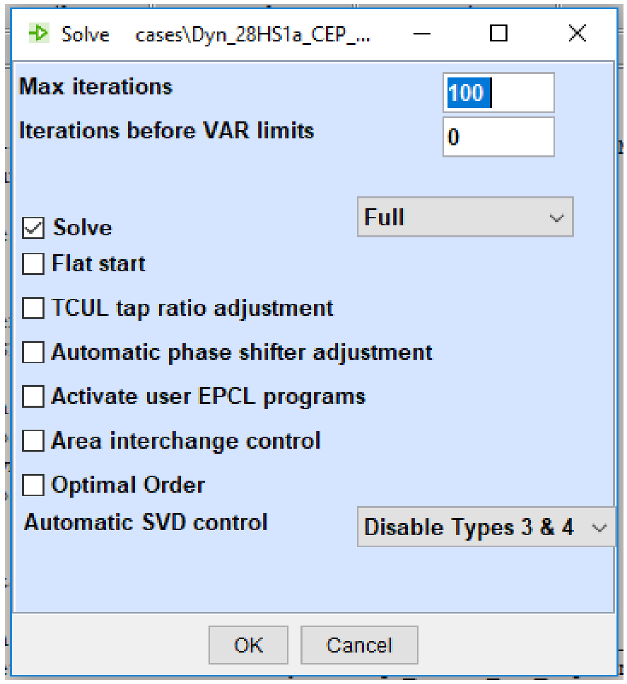

Figure A.3-2. Solution parameters for the steady-state analysis for contingency conditions.

<u>Screening Criteria</u>

The study area of interest was defined as Area 70. WECC Criterion TPL-001-WECC-CRT-3.1 was applied to Bulk Electric System (BES) buses (100 kV and above) to evaluate the contingencies. The following metrics were used to flag thermal and voltage violations for the steady-state analysis:

- Thermal Loading Violations:
  - Any loading of branches and transformers greater than 100% of Rate A in Area 70 for bus voltage levels 100 kV and above for base case conditions (N-0).
  - Any loading of branches and transformers greater than 100% of Rate B in Area 70 for bus voltage levels 100 kV and above for contingency conditions (N-1 and stuck breakers).
- Voltage Violations:
  - Buses were flagged if the voltages were less than 0.95 p.u. or greater than 1.05 p.u. in Area 70 for base case conditions (N-0).
  - Buses were flagged if the voltages were less than 0.90 p.u. or greater than 1.10 p.u. in Area 70 for contingency conditions (N-1 and stuck breakers).

<u>Contingency List</u>

The contingencies examined for this analysis were agreed upon with Xcel Energy and are listed below.

- The following N-1 contingencies were examined for the steady-state analysis:
  - Loss of the Missile Site – Pawnee 345 kV line
  - Loss of the Missile Site – Smoky Hill 345 kV line
  - Loss of the Missile Site – Pronghorn 345 kV line
  - Loss of the Missile Site – Daniels Park 345 kV line
  - Loss of the Missile Site – Limon1 345 kV line
  - Loss of the Daniels Park – Comanche 345 kV line
  - Loss of the Craig – Ault 345 kV line
  - Loss of the Missile Site 345/230 kV transformer
  - All N-1 contingencies for the generator tie lines in the Missile Site area:
    - Loss of Pronghorn – Shortgrass 345 kV line
    - Loss of Shortgrass – Bronco Plains 345 kV
    - Loss of Shortgrass to Cheyenne Ridge West 345 kV line
    - Loss of Cheyenne Ridge West – Cheyenne Ridge East 345 kV line
    - Loss of Pronghorn – Rush Creek W1 345/34.5 kV transformer
    - Loss of Shortgrass – Rush Creek W2 345/34.5 kV transformer
    - Loss of the Comanche 3 Unit
  - All N-1 contingencies for the shunt compensation in the Missile Site area
- Stuck breaker contingencies were examined for the steady-state analysis at the following substations:
  - Missile Site 345 kV
  - Smoky Hill 345 kV
  - Pronghorn 345 kV
  - Shortgrass 345 kV
  - Daniels Park 345 kV

A.4 Steady-State Analysis Results

Base Case (N-0) Analysis Results

Voltage violations were recorded for base case (N-0) conditions without additional shunt compensation. No thermal violations of concern were identified, low bus voltages (below the WECC Criteria of 0.95 p.u. for pre-contingency) were observed in the immediate study area. The following is a summary of the results of the Base Case (N-0) analysis before the addition of additional shunt reactive compensation.

- Heavy Summer – High wind – Gen-Tie 1400 MW
  - No thermal overloads were observed in the immediate study area.
    - Note in Area 70 the following branches were observed to have thermal overloads. These are listed for informational purposes only. The purpose of this analysis was to determine the reactive power needs to support the

increase in wind generation in the Missile Site area, which has minimal impact on the power flow on the equipment. After discussion with Xcel Energy it is anticipated that these overloads were caused by the re-dispatching of the case.

- CHEROKEE_S/CHEROKEE 230/115 kV transformer
- CEDARCK_1/CEDARCK_1A 230/34.5 kV transformer

- Pre-contingency bus voltages below 0.95 p.u. were observed at several 345 kV buses.

- Heavy Summer – High wind – Gen-Tie 1600 MW
    - No thermal overloads were observed in the immediate study area.
        - Note in Area 70 the following branches were observed to have thermal overloads. These are listed for informational purposes only. The purpose of this analysis was to determine the reactive power needs to support the increase in wind generation in the Missile Site area, which has minimal impact on the power flow on the equipment. After discussion with Xcel Energy it is anticipated that these overloads were caused by the re-dispatching of the case.
            - CHEROKEE_S/CHEROKEE 230/115 kV transformer
            - CEDARCK_1/CEDARCK_1A 230/34.5 kV transformer
    - Pre-contingency bus voltages below 0.95 p.u. were observed at several 345 kV buses.
- Heavy Summer – Low wind – Gen-Tie 0 MW
    - No thermal overloads were observed.
    - No bus voltages of concern were observed.
- Light Spring – High wind – Gen-Tie 1400 MW
    - No thermal overloads were observed.
    - No bus voltages of concern were observed.
- Light Spring – High wind – Gen-Tie 1600 MW
    - No thermal overloads were observed.
    - Pre-contingency bus voltages below 0.95 p.u. were observed at Pronghorn 345 kV, Shortgrass 345 kV, and Bronco Plains 345 kV.
- Light Spring – Low wind – Gen-Tie 0 MW
    - No thermal overloads were observed.
    - Pre-contingency bus voltages above 1.05 p.u. were observed at Cheyenne Ridge West 345 kV and Cheyenne Ridge East 345 kV.

It was determined that reactive compensation was needed at several locations to meet base case voltage criteria. Studies indicated that the Missile Site 345 kV bus voltage should operate above 0.95 p.u. due to solution difficulties during contingency conditions. It was determined that the Missile Site 345 kV bus needs to be at a minimum of 0.98 p.u. pre-contingency to allow for the contingencies to converge. The convergence was not explored in detail, but could be an indicator of potential voltage collapse.

- For reference purposes, Table A.4-1 shows all existing reactive compensation and the status of the devices for the immediate study area.
- Refer to Table A.4-2 for a summary of the additional reactive power compensation needed to meet base case (N-0) criteria for each examined case.
- Refer to Table A.4-3 and A.4-4 for result tables showing bus voltages with and without the additional reactive compensation for base case conditions.

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Table A.4-1
Dispatch of Existing Reactive Power Support in the Immediate Study Area

Case Name	Pre-Existing Static Support							
	Missile Tap 230 kV (70621)	Missile Cap 345 kV (88888)	Missile Site 345 kV (70624)	Missile Site 13.8 kV (71997)	Limone I 345 kV (70625)	Daniels Park 345 kV (70601)	Rush Creek W1 34.5 kV (70629)	Rush Creek W2 34.5 kV (70631)
Light Spring – High wind – Gen-Tie 1400 MW	90	50	0	0	0	0	130.2	51
Light Spring – High wind – Gen-Tie 1600 MW	150	50	0	0	0	0	130.2	51
Light Spring – High wind – Gen-Tie 0 MW	0	0	0	-40	0	-40	-69	-48
Heavy Summer – High wind – Gen-Tie 1400 MW	150	50	0	0	40	0	130.2	51
Heavy Summer – High wind – Gen-Tie 1600 MW	150	50	0	0	40	0	130.2	51
Heavy Summer – High wind – Gen-Tie 0 MW	50	0	-60	-40	0	0	-69	-48

Table A.4-2
Dispatch of Additional Reactive Power Support Needed for the Immediate Study Area (In Addition to the Existing Devices)

Case Name	Additional Static Support					
	Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Cheyrdge W 345 kV (70632)	Missile Site 345 kV (70624)	Short Grass 345 kV (70630)
Light Spring – High wind – Gen-Tie 1400 MW	0	0	0	0	0	0
Light Spring – High wind – Gen-Tie 1600 MW	0	0	125	0	0	30
Light Spring – High wind – Gen-Tie 0 MW	0	0	0	-10	0	0
Heavy Summer – High wind – Gen-Tie 1400 MW	115	115	130	0	300	0
Heavy Summer – High wind – Gen-Tie 1600 MW	115	140	170	0	385	80
Heavy Summer – High wind – Gen-Tie 0 MW	0	0	0	0	0	0

Note: Based on the Ferranti Effect Overvoltage Analysis, 2x30 MVAR shunt reactors were modeled at Shortgrass 345 kV to control the steady-state voltage along the Missile Site gen-tie line under low/no generation conditions. These were discussed after the steady-state analysis was completed. With the addition of the 2x30 Mvar shunt reactors at Shortgrass there is no need for the 10 Mvar reactor at Cheyenne Ridge West.

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Table A.4-3
Summary Results for the Heavy Summer High Wind Cases with and without Reactive Power Compensation as Mitigation for Base Case Voltage Violations

Bus Number	Bus Name	kV	Contingency Description	No Mitigation			With Additional Reactive Power Compensation		
				Heavy Summer High wind 1400 MW	Heavy Summer High wind 1600 MW	Heavy Summer High wind 0 MW	Heavy Summer High wind 1400 MW	Heavy Summer High wind 1600 MW	Heavy Summer High wind 0 MW
70598	PAWNEE	345	Base Case (N-0)	0.964	0.947	1.026	0.989	0.986	1.026
70599	SMOKYHIL	345		0.929	0.911	1.012	0.964	0.961	1.012
70601	DANIELPK	345		0.928	0.914	0.999	0.960	0.958	0.999
70623	MIS_SITE	230		0.957	0.934	1.024	0.992	0.987	1.024
70624	MIS_SITE	345		0.943	0.918	1.021	0.983	0.979	1.021
70625	LIMON1	345		0.983	0.958	1.026	1.010	1.008	1.026
70626	LIMON2	345		0.986	0.961	1.027	1.012	1.010	1.027
70627	LIMON3	345		0.990	0.965	1.027	1.014	1.012	1.027
70597	HARVEST_MI	345		0.929	0.912	1.012	0.965	0.961	1.012
70628	PRONGHORN	345		0.927	0.908	1.024	0.965	0.956	1.024
70630	SHORTGRASS	345		0.944	0.929	1.033	0.967	0.968	1.033
70632	CHEYRDGE W	345		0.978	0.972	1.042	0.986	0.987	1.042
88884	CHEYRDGE E	345		0.980	0.975	1.042	0.988	0.988	1.042
70633	BRONCOPLNS	345		0.946	0.932	1.033	0.968	0.968	1.033

Table A.4-4
Summary Results for the Light Spring High Wind Cases with and without Reactive Power Compensation as Mitigation for Base Case Voltage Violations

Bus Number	Bus Name	kV	Contingency Description	No Mitigation			With Additional Reactive Power Compensation		
				Light Spring High wind 1400 MW	Light Spring High wind 1600 MW	Light Spring High wind 0 MW	Light Spring High wind 1400 MW	Light Spring High wind 1600 MW	Light Spring High wind 0 MW
70598	PAWNEE	345	Base Case (N-0)	1.002	0.992	1.036	1.002	0.999	1.035
70599	SMOKYHIL	345		0.999	0.989	1.030	0.999	0.995	1.030
70601	DANIELPK	345		0.993	0.985	1.018	0.993	0.990	1.017
70623	MIS_SITE	230		1.009	1.003	1.036	1.009	1.011	1.035
70624	MIS_SITE	345		0.992	0.978	1.037	0.992	0.988	1.036
70625	LIMON1	345		1.013	1.007	1.034	1.013	1.011	1.033
70626	LIMON2	345		1.014	1.009	1.033	1.014	1.013	1.033
70627	LIMON3	345		1.016	1.011	1.033	1.016	1.014	1.032
70597	HARVEST_MI	345		0.999	0.989	1.030	0.999	0.995	1.030
70628	PRONGHORN	345		0.952	0.926	1.040	0.952	0.950	1.037
70630	SHORTGRASS	345		0.958	0.942	1.049	0.958	0.959	1.043
70632	CHEYRDGE W	345		0.983	0.977	1.058	0.983	0.984	1.049
88884	CHEYRDGE E	345		0.985	0.980	1.058	0.985	0.985	1.050
70633	BRONCOPLNS	345		0.959	0.944	1.049	0.959	0.960	1.044

Contingency Analysis Results

Once all bus voltages for base case (N-0) conditions met the specified criteria (0.95 to 1.05 p.u. range), a contingency analysis was ran to identify limiting contingences that may result in the need for additional static reactive power support. All reactive compensation that was added to the cases for base case conditions (listed in Table A.4-2) were modeled and imaginary generators with open reactive power limits (real power output = 0) were placed at key buses to determine the additional reactive power support for each examined contingency. The additional reactive compensation was examined at the following locations for the contingency analysis:

- Daniels Park 345 kV
- Harvest Mile 345 kV
- Pronghorn 345 kV
- Missile Site 345 kV

Note these locations were identified to be limiting areas for voltage issues based on preliminary analysis performed by MEPPI. Refer to Table A.4-5 and Table A.4-6 for the minimum amount of additional reactive power needed to meet voltage criteria for contingency conditions for the summer heavy loaded case and the light spring case, respectively. Note all contingencies listed in Section A.3 were examined for this analysis, the result tables only show the contingencies that resulted in additional reactive power compensation.

It was observed that additional reactive power support is needed for N-1 and stuck breaker contingency conditions.

- For light spring conditions:
  - For the 1600 MW case an additional -5 Mvar is needed at Pronghorn to avoid high voltages exceeding 1.10 p.u.
  - For the 1400 MW and 0 MW case, no additional reactive power support is needed.
- For heavy summer conditions:
  - For the 1600 MW case an additional 135 Mvar is needed at Missile Site and an additional 125 Mvar is needed at Pronghorn to avoid low voltages below 0.90 p.u. for the 1600 MW case.
  - For the 1400 MW case an additional 19 Mvar is needed at Harvest Mile, an additional 66 Mvar is needed at Missile Site, and an additional 41 Mvar is needed at Pronghorn to avoid low voltages below 0.90 p.u.
  - No additional reactive power support is needed for the 0 MW case.

Tables A.4-7 through A.4-9 list all branches that were thermally overloaded in Area 70. These are listed for informational purposes only. The purpose of this analysis was to determine the reactive power needs to support the increase in wind generation in the Missile Site area, which has minimal impact on the power flow on the equipment. Note no thermal overloads were observed for the heavy summer 0 MW, light spring 0 MW cases, and light spring 1400 MW cases.

Table A.4-5
Additional Reactive Power Needs to Maintain Steady-State Bus Voltages for Contingency Conditions for the Light Spring High Wind Case

Ref. No.	Contingency Description	Contingency Type	Bus Description	Post-Contingency Reactive Power Needs (Mvar)		
				Light Spring High wind 1400 MW	Light Spring High wind 1600 MW	Light Spring High wind 0 MW
1	Pronghorn - Shortgrass 345 kV	N-1	Harvest Mile 345 kV (70597)	0	0	0
2			Missile Site 345 kV (70624)	0	0	0
3			Pronghorn 345 kV (70628)	0	-5	0
4	Pronghorn - Shortgrass 345 kV Shortgrass - Cheyenne Ridge W 345 kV	SB	Harvest Mile 345 kV (70597)	0	0	0
5			Missile Site 345 kV (70624)	0	0	0
6			Pronghorn 345 kV (70628)	0	-5	0
			Max at Harvest Mile 345 kV (70597)	**0**	**0**	**0**
			Max at Missile Site 345 kV (70624)	**0**	**0**	**0**
			Max at Pronghorn 345 kV (70628)	**0**	**-5**	**0**

Note: Highlighted cells in the above tables indicate that additional reactive power compensation is needed. Positive values represent capacitive and negative values represent inductive compensation.

Table A.4-6
Additional Reactive Power Needs to Maintain Steady-State Bus Voltages for Contingency Conditions for the Heavy Summer High Wind Case

Ref. No.	Contingency Description	Contingency Type	Bus Description	Post-Contingency Reactive Power Needs (Mvar)		
				Heavy Summer High wind 1400 MW	Heavy Summer High wind 1600 MW	Heavy Summer High wind 0 MW
1	Missile Site - Smoky Hill 345 kV	N-1	Harvest Mile 345 kV (70597)	7	0	0
2			Missile Site 345 kV (70624)	0	97	0
3			Pronghorn 345 kV (70628)	0	105	0
4	Missile Site - Pronghorn 345 kV	N-1	Harvest Mile 345 kV (70597)	0	0	0
5			Missile Site 345 kV (70624)	0	0	0
6			Pronghorn 345 kV (70628)	0	76	0
7	Missile Site - Pawnee 345 kV Missile Site - Pawnee 345 kV	SB	Harvest Mile 345 kV (70597)	0	0	0
8			Missile Site 345 kV (70624)	0	0	0
9			Pronghorn 345 kV (70628)	0	72	0
10	Daniels Park - Comanche 345 kV Daniels Park 345 kV Capacitor Bank	SB	Harvest Mile 345 kV (70597)	0	0	0
11			Missile Site 345 kV (70624)	0	0	0
12			Pronghorn 345 kV (70628)	0	56	0
13	Daniels Park - Missile Site 345 kV Daniels Park 345/230 kV transformer	SB	Harvest Mile 345 kV (70597)	0	0	0
14			Missile Site 345 kV (70624)	0	0	0
15			Pronghorn 345 kV (70628)	0	76	0
16	Smoky Hill - Missile Site 345 kV Missile Site - Pawnee 345 kV	SB	Harvest Mile 345 kV (70597)	19	0	0
17			Missile Site 345 kV (70624)	66	185	0
18			Pronghorn 345 kV (70628)	0	105	0
19	Missile Site - Smoky Hill 345 kV Harvest Mile - Smoky Hill 345 kV	SB	Harvest Mile 345 kV (70597)	9	0	0
20			Missile Site 345 kV (70624)	0	98	0
21			Pronghorn 345 kV (70628)	0	105	0
22	Missile Site 345 kV Capacitor Bank	N-1	Harvest Mile 345 kV (70597)	0	0	0
23			Missile Site 345 kV (70624)	17	159	0
24			Pronghorn 345 kV (70628)	0	105	0

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Table A.4-6 (Continued)
Additional Reactive Power Needs to Maintain Steady-State Bus Voltages for Contingency Conditions for the Heavy Summer High Wind Case

Ref. No.	Contingency Description	Contingency Type	Bus Description	Post-Contingency Reactive Power Needs (Mvar)		
				Heavy Summer High wind 1400 MW	Heavy Summer High wind 1600 MW	Heavy Summer High wind 0 MW
25	Rush Creek 1 34.5 kV Capacitor Bank	N-1	Harvest Mile 345 kV (70597)	0	0	0
26			Missile Site 345 kV (70624)	0	0	0
27			Pronghorn 345 kV (70628)	0	62	0
28	Pronghorn 345 kV Capacitor Bank	N-1	Harvest Mile 345 kV (70597)	0	0	0
29			Missile Site 345 kV (70624)	0	0	0
30			Pronghorn 345 kV (70628)	41	175	0
31	Shortgrass 345 kV Capacitor Bank	N-1	Harvest Mile 345 kV (70597)	0	0	0
32			Missile Site 345 kV (70624)	0	0	0
33			Pronghorn 345 kV (70628)	0	61	0
			Max at Harvest Mile 345 kV (70597)	**19**	**0**	**0**
			Max at Missile Site 345 kV (70624)	**66**	**185**	**0**
			Max at Pronghorn 345 kV (70628)	**41**	**175**	**0**

Reactive Device at Harvest Mile 345 kV is set to regulate a post-contingency voltage of 0.94 p.u.
Reactive Device at Missile Site 345 kV is set to regulate a post-contingency voltage of 0.96 p.u.
Reactive Device at Pronghorn 345 kV is set to regulate a post-contingency voltage of 0.95 p.u.

Table A.4-7
Thermal Overloads for the Light Spring High Wind 1600 MW Case for Contingency Conditions

Light Spring – High wind – Gen-Tie 1600 MW													
Ref. No.	From Bus No.	From Bus Name	From kV	To Bus No.	To Bus Name	To kV	Ckt ID	Contingency Description	Fault Type	Rating*	Power Flow p.u.	Power Flow MVA	Power Flow I
1	70624	MIS_SITE	345	88888	MISCAPS	345	1	Loss of Missile Site - Smoky Hill 345 kV	N-1	2739 A	**1.01**	1583	2758
2								Loss of Missile Site - Daniels Park 345 kV	N-1	2739 A	**1.01**	1602	2758
3								Loss of Missile Site - Limon 1 345 kV	N-1	2739 A	**1.01**	1603	2752
4								Loss of Missile Site - Pawnee 345 kV and Missile Site - Pawnee 345 kV	SB	2739 A	**1.01**	1599	2771
5								Loss of Rush Creek 1 34.5 kV Reactive Device	N-1	2739 A	**1.01**	1616	2764
6								Loss of Pronghorn 345 kV Capacitor Bank	N-1	2739 A	**1.01**	1613	2756
7								Loss of Harvest Mile - Smoky Hill 345 kV and Missile Site - Smoky Hill 345 kV	SB	2739 A	**1.01**	1582	2759
8								Loss of Smoky Hill - Missile Site 345 kV and Missile Site - Pawnee 345 kV	SB	2739 A	**1.03**	1581	2834
9								Loss of Missile Site - Limon1 345 kV and Missile Site 345/230 kV Transformer	SB	2739 A	**1.01**	1582	2759
10								Loss of Daniles Park - Missile Site 345 kV and Daniels Park 345/230 kV Transformer	SB	2739 A	**1.01**	1602	2758
11	88888	MISCAPS	345	70628	PRONGHORN	345	1	Loss of Missile Site - Smoky Hill 345 kV	N-1	2739 A	**1.02**	1597	2782
12								Loss of Missile Site - Daniels Park 345 kV	N-1	2739 A	**1.02**	1612	2783
13								Loss of Missile Site - Limon 1 345 kV	N-1	2739 A	**1.02**	1613	2789
14								Loss of Missile Site - Pawnee 345 kV and Missile Site - Pawnee 345 kV	SB	2739 A	**1.02**	1610	2791
15								Loss of Missile Site 345/230 kV Transformer	N-1	2739 A	**1.01**	1604	2748
16								Loss of Rush Creek 1 34.5 kV Reactive Device	N-1	2739 A	**1.02**	1634	2794
17								Loss of Pronghorn 345 kV Capacitor Bank	N-1	2739 A	**1.02**	1631	2786
18								Loss of Harvest Mile - Smoky Hill 345 kV and Missile Site - Smoky Hill 345 kV	SB	2739 A	**1.02**	1596	2783
19								Loss of Smoky Hill - Missile Site 345 kV and Missile Site - Pawnee 345 kV	SB	2739 A	**1.05**	1594	2858
20								Loss of Missile Site - Limon1 345 kV and Missile Site 345/230 kV Transformer	SB	2739 A	**1.02**	1596	2784
21								Loss of Daniles Park - Missile Site 345 kV and Daniels Park 345/230 kV Transformer	SB	2739 A	**1.02**	1612	2783

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Table A.4-8
Thermal Overloads for the Heavy Summer High Wind 1400 MW Case for Contingency Conditions

Heavy Summer – High wind – Gen-Tie 1400 MW													
Ref. No.	From Bus No.	From Bus Name	From kV	To Bus No.	To Bus Name	To kV	Ckt ID	Contingency Description	Fault Type	Rating*	Power Flow		
											p.u.	MVA	I
1	70139	DANIELPK	230	70331	PRAIRIE1	230	1	Loss of Harvest Mile - Smoky Hill 345 kV and Missile Site - Smoky Hill 345 kV	SB	1199 A	**1.02**	462	1227
2	70139	DANIELPK	230	70527	SANTEFE	230	1	Loss of Missile Site - Smoky Hill 345 kV	N-1	800 A	**1.01**	304	808
3	70139	DANIELPK	230	70527	SANTEFE	230	1	Loss of Harvest Mile - Smoky Hill 345 kV and Missile Site - Smoky Hill 345 kV	SB	800 A	**1.04**	313	832
4	70139	DANIELPK	230	70527	SANTEFE	230	1	Loss of Smoky Hill - Missile Site 345 kV and Missile Site - Pawnee 345 kV	SB	800 A	**1.02**	308	818
5	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Missile Site - Limon 1 345 kV	N-1	1599 A	**1.05**	638	1670
6	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Short Grass 345 kV	N-1	1599 A	**1.12**	687	1781
7	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Comanche Generator 27 kV Unit C3	N-1	1599 A	**1.15**	687	1827
8	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Short Grass 345 kV and Pronghorn - Rush Creek 1 345 kV	SB	1599 A	**1.12**	687	1776
9	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Rush Creek 1 345 kV and Missile Site - Pronghorn 345 kV	SB	1599 A	**1.12**	687	1786
10	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Missile Site - Limon1 345 kV and Missile Site 345/230 kV Transformer	SB	1599 A	**1.05**	638	1670
11	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Short Grass 345 kV and Short Grass - Cheyridge 345 kV	SB	1599 A	**1.12**	687	1781
12	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Missile Site - Limon 1 345 kV	N-1	878 A	**1.08**	361	950
13	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Short Grass 345 kV	N-1	878 A	**1.15**	382	1014
14	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Short Grass - Cheyridge West 345 kV	N-1	878 A	**1.04**	353	916
15	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Comanche Generator 27 kV Unit C3	N-1	878 A	**1.18**	382	1035
16	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Short Grass 345 kV and Pronghorn - Rush Creek 1 345 kV	SB	878 A	**1.15**	382	1012
17	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Rush Creek 1 345 kV and Missile Site - Pronghorn 345 kV	SB	878 A	**1.16**	382	1016
18	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Missile Site - Limon1 345 kV and Missile Site 345/230 kV Transformer	SB	878 A	**1.08**	361	950
19	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Short Grass 345 kV and Short Grass - Cheyridge 345 kV	SB	878 A	**1.15**	382	1014

*For the base case rating 1 was used for contingencies cases rating 2 was used.

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Table A.4-9
Thermal Overloads for the Heavy Summer High Wind 1600 MW Case for Contingency Conditions

Heavy Summer – High wind – Gen-Tie 1600 MW													
Ref. No.	From Bus No.	From Bus Name	From kV	To Bus No.	To Bus Name	To kV	Ckt ID	Contingency Description	Fault Type	Rating*	Power Flow		
											p.u.	MVA	I
1	70139	DANIELPK	230	70331	PRAIRIE1	230	1	Loss of Harvest Mile - Smoky Hill 345 kV and Missile Site - Smoky Hill 345 kV	SB	1199 A	1.01	456	1209
2	70139	DANIELPK	230	70527	SANTEFE	230	1	Loss of Harvest Mile - Smoky Hill 345 kV and Missile Site - Smoky Hill 345 kV	SB	800 A	1.03	310	823
3	70139	DANIELPK	230	70527	SANTEFE	230	1	Loss of Smoky Hill - Missile Site 345 kV and Missile Site - Pawnee 345 kV	SB	800 A	1.01	305	811
4	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Missile Site - Limon 1 345 kV	N-1	1599 A	1.04	638	1665
5	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Short Grass 345 kV	N-1	1599 A	1.11	688	1768
6	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Comanche Generator 27 kV Unit C3	N-1	1599 A	1.08	655	1728
7	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Short Grass 345 kV and Pronghorn - Rush Creek 1 345 kV	SB	1599 A	1.11	688	1765
8	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Rush Creek 1 345 kV and Missile Site - Pronghorn 345 kV	SB	1599 A	1.12	687	1778
9	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Missile Site - Limon1 345 kV and Missile Site 345/230 kV Transformer	SB	1599 A	1.05	638	1666
10	70820	KEENESBURG	230	70821	CEDARCK_1	230	1	Loss of Pronghorn - Short Grass 345 kV and Short Grass - Cheyridge 345 kV	SB	1599 A	1.11	688	1768
11	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Missile Site - Limon 1 345 kV	N-1	878 A	1.08	361	948
12	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Short Grass 345 kV	N-1	878 A	1.15	382	1009
13	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Short Grass - Cheyenne Ridge West 345 kV	N-1	878 A	1.04	353	916
14	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Comanche Generator 27 kV Unit C3	N-1	878 A	1.12	368	981
15	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Short Grass 345 kV and Pronghorn - Rush Creek 1 345 kV	SB	878 A	1.15	382	1007
16	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Rush Creek 1 345 kV and Missile Site - Pronghorn 345 kV	SB	878 A	1.15	382	1012
17	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Missile Site - Limon1 345 kV and Missile Site 345/230 kV Transformer	SB	878 A	1.08	361	949
18	70821	CEDARCK_1	230	70822	CEDARCK_2	230	1	Loss of Pronghorn - Short Grass 345 kV and Short Grass - Cheyridge 345 kV	SB	878 A	1.15	382	1009

*For the base case rating 1 was used for contingencies cases rating 2 was used.

A.6 Summary for the Steady-State Analysis

The primary objective of the steady-state analysis was to identify potential voltage concerns per WECC Criterion.

- It was determined that reactive power compensation was needed to meet WECC voltage criteria for base case (N-0) conditions.
- It was determined that additional reactive power compensation was needed to meet WECC voltage criteria for N-1 and stuck breaker contingency conditions for the initial power flow cases.

It was determined that reactive compensation was needed at several locations to meet base case voltage criteria. Table A.6-1 shows the minimum reactive power compensation needed to satisfy the voltage criteria for the heavy summer and light spring case (0 MW and 1400 MW dispatch) for base case conditions.

Table A.6-1
Additional Reactive Power Support Needed for Base Case (N-0)

Additional Static Support			
Daniels Park 345 kV (70601)	Harvest Mile 345 kV (70597)	Pronghorn 345 kV (70628)	Missile Site 345 kV (70624)
115	115	130	300

In the initial base case studies, it was observed that additional reactive power support was needed for N-1 and stuck breaker contingency conditions for heavy summer 1400 MW conditions. For the 1400 MW case an additional 19 Mvar was needed at Harvest Mile, an additional 66 Mvar was needed at Missile Site, and an additional 41 Mvar was needed at Pronghorn to avoid low voltages below 0.90 p.u.

After the steady-state analysis was completed, Xcel Energy provided an update to the Cheyenne Ridge East and Cheyenne Ridge West collector systems. Key steady-state cases were re-examined using the updated data for the heavy summer 1400 MW case and it was determined that the steady-state reactive power compensation identified for base case conditions was sufficient for the N-1 and stuck breaker contingencies examined.