LINE 5283 REVIEW

LEETSDALE – ELATI LINE UPRATE PROJECT

Xcel Energy
Transmission Planning West
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Summary

The Leetsdale to Monroe to Elati 230kV line, also referred to as Line 5283 is an underground 230 kV transmission line in the Denver Metro area. This area of Denver is highly congested with residential and commercial build out. The line is currently limited to 319 MVA for summer normal conditions and 398 MVA for summer emergency conditions. Line 5283 connects the Leetsdale – Monroe – Elati substations with terminating breakers at Leetdale and Elati. There are circuit switchers in place at Monroe substation to protect the transformers.

Line 5283 was originally in-serviced in 1990 and utilizes High Pressure Fluid Filled (HPFF) pipe for insulation. The original design limited line capacity to 1000 A (398 MVA), but this has since been derated due to heating from nearby distribution feeders, and the line crossing of Line 9955 from Leetsdale to Harrison, to 800 A (319 MVA). The HPFF design is relatively dated for PSCo facilities, with most underground lines in-serviced since 2002 utilizing cross-linked polyethylene (XPLE) insulation. Due to the condition and health of the HPFF, and the secondary components needed to support the fluid pressure, the Company desires to retire these items from the system due to their maintenance and environmental risks associated with fluid filled cables.

Line 5283 is found to overload during times of high renewable generation and low generation at the Cherokee gas plant, particularly after the outage of Line 5709 from Arapahoe to Greenwood. This overload will restrict the ability of renewable generation from the South and East to serve load in the Denver Metro area. Additionally, the retirement of Cherokee 4 in 2027 increases the flows on 5283 by necessitating more power coming in from outside of the Denver Metro area to serve load within the area. Therefore, the line needs to be uprated to have adequate capacity for the coming retirement of Cherokee 4 and to meet the renewable generation needs for reaching the Company's 80x30 carbon reduction goal.

Findings

This report is a compilation of study efforts which have identified this segment as requiring replacement due to the line exceeding the normal rating. Included in this report are two different scenarios which drive the need for this conductor replacement. In general, a reduction in generation at Cherokee and an increase in renewable injection drive the need for the line uprate.

Operating Case Reliability Analysis

For high renewable generation scenarios incorporating the retirement of Cherokee 4, line 5283 tends to overload for the loss of the Greenwood – Arapahoe segment of the recently in-serviced Greenwood – Arapahoe – Denver Terminal transmission line.

2024 Heavy Summer

The WECC 2024 Heavy Summer 3 case was evaluated as a starting case and excluded Cherokee 4 from the original generation dispatch. To create the Heavy Summer (HS) Benchmark case, the starting case was modified to dispatch Cherokee 4 and balance generation in an otherwise standard dispatch priority. To create the HS Stressed case, Cherokee 4 was turned off, wind generation along the Rush Creek Gen-Tie was increased to 70% of its total generation capacity, and other conventional generation was balanced following standard dispatch priority. Overloads on Line 5283 and associated outages are listed in Table 1. Appendix A contains PSCo dispatch information.

TABLE 1 – 2024 HEAVY SUMMER OVERLOADS

Overloaded Facility	Type	Owner	Rating (MVA) Normal/Emerg.*		Benchmark Case		Stressed Case		Contingency Definition
					MVA Flow	% Loading	MVA Flow	% Loading	
LEETSDALE – MONROE ckt 1 230 kV Line 5283	Line	PSCo	319	Normal	266.8	83.7	327.3	**102.7**	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood
LEETSDALE– MONROE ckt 1 230 kV Line 5283	Line	PSCo	398	Emerg.	325.6	81.8	404.5	**101.6**	P4 Leetsdale 115 kV Bus-Tie Breaker Failure

For PSCo's planning criteria, the Normal rating of a line is used when planning for single contingency (N-1) events, and the Emergency rating of a line is used when planning for multiple contingency (N-2) events.

2024 HEAVY WINTER

Further analysis was carried out on a 2024 Heavy Winter (HW) operating case developed by Real-Time Planning. For the 2023 summer season, the MVA rating for line 5283 was tested for several operating conditions. This testing found the highest rating of 5283 was achieved when Line 9955 (which crosses Line 5283 at two locations) was deenergized.

Two scenarios were run on the 24 Heavy Winter case: one with Line 9955 switched in thereby limiting the rating of line 5283, and one with Line 9955 switched out so Line 5283 could achieve its full capacity. Line 5283 overloads in both scenarios. Table 2 shows overloads from contingency analysis on the 24 HW case with Line 9955 energized, and Table 3 shows overloads from contingency analysis on the 24 HS case with Line 9955 deenergized.

TABLE 2 – 2024 HEAVY WINTER OVERLOADS, LINE 9955 IN-SERVICE

Overloaded Facility	Type	Owner	Rating (MVA) Normal/Emerg.		24 HW Case, 9955 Energized		Contingency Definition
					MVA Flow	% Loading	
ELATI – MONROE ckt 1 230 kV Line 5283	Line	PSCo	319	Normal	342.9	**107.6**	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood
LEETSDALE – MONROE ckt 1 230 kV Line 5283	Line	PSCo	319	Normal	378.6	**121.6**	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood

TABLE 3 – 2024 HEAVY WINTER OVERLOADS, LINE 9955 OUT-OF-SERVICE

Overloaded Facility	Type	Owner	Rating (MVA) Normal/Emerg.		24 HW Case, 9955 Deenergized		Contingency Definition
					MVA Flow	% Loading	
ELATI – MONROE ckt 1 230 kV Line 5283	Line	PSCo	398	Normal	365.3	93.2	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood
LEETSDALE– MONROE ckt 1 230 kV Line 5283	Line	PSCo	398	Normal	410.4	**104.7**	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood

High Renewable Scenario

More evidence of this limitation can be seen in the benchmark cases for the high renewable scenario before any resources from the Approved Portfolio are incorporated. In these cases, conventional generation is significantly reduced to account for high renewable penetration. Table 4 shows dispatch levels for major conventional units and renewable resources.

Table 4 – ERP Dispatch Assumptions

Fossil (MW)					Wind	Solar	Battery Storage
Cherokee	RMEC	FSV	PAWN	COMA			
570	200	330	200	450	Balance Net Load = Gross Load – (Solar+Fossil)	90% of Rated	0

Due to the drastic reduction of conventional generation, wind is dispatched at above 90% of its maximum capacity for to balance for load. Overloads on Line 5283 seen in contingency analysis on these cases are shown in Table 5.

Table 5 – High Renewable Dispatch Benchmark Case Overloads

Overloaded Facility	Type	Owner	Rating (MVA) Normal/Emerg.		26 HS Benchmark		27 HS Benchmark		28 HS Benchmark		Contingency Definition
					MVA Flow	% Loading	MVA Flow	% Loading	MVA Flow	% Loading	
LEETSDALE – MONROE ckt 1 230 kV Line 5283	Line	PSCo	319	Normal	315.7	**99.1**	373.4	**117.2**	367.1	**115.2**	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood
ELATI – MONROE ckt 1 230 kV Line 5283	Line	PSCo	319	Normal	253.2	79.5	311.3	97.7	305.4	95.8	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood

Appendix B contains further details on case dispatch. Including resources from the Approved Portfolio which further exacerbates the overload violation, shown in Table 6.

Table 6 – High Renewable Study Cases Overloads

Overloaded Facility	Type	Owner	Rating (MVA) Normal/Emerg.		26 HS Study		27 HS Study		28 HS Study		Contingency Definition
					MVA Flow	% Loading	MVA Flow	% Loading	MVA Flow	% Loading	
LEETSDALE– MONROE ckt 1 230 kV Line 5283	Line	PSCo	319	Normal	386.7	**121.3**	463.7	**145.5**	495.9	**155.6**	P1 loss of 230 kV Line 5709 from

											Arapahoe to Greenwood
ELATI – MONROE ckt 1 230 kV Line 5283	Line	PSCo	319	Normal	331.7	**104.1**	406.5	**127.5**	440.8	**138.3**	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood
DENVER TERM – ELATI ckt 1 230 kV Line 5625	Line	PSCo	307	Normal	266.9	86.9	341.8	**111.3**	378.3	**123.2**	P1 loss of 230 kV Line 5709 from Arapahoe to Greenwood

CONCLUSION

Several scenarios analysis and study show thermal overload violations on Line 5283, generally due to the loss of Line 5709 from Arapahoe to Greenwood, or a breaker failure at Leetsdale. All these scenarios involve reducing the output of Cherokee and offsetting it with increased renewable generation. Therefore, to meet the Company's 80x30 target, or mitigate an operating condition in which Cherokee is unavailable, Line 5283 must be uprated to 796 MVA to remove limitations on renewable generation, provide operational flexibility, and minimize construction in the area in the long-term.

APPENDIX A – 24 OPERATIONAL CASES DISPATCH

Bus Name / kV	Id	WECC Start	HS Benchmark	HS Stressed	Heavy Winter
ALAMOSA_PV 34.500	S3	24.0	24.0	24.0	24.3
ALMSACT1 13.800	G1	17.0	17.0	17.0	0.0
ALMSACT2 13.800	G2	15.0	15.0	15.0	0.0
ARAP5&6 13.800	G5	38.0	38.0	38.0	29.0
ARAP5&6 13.800	G6	38.0	38.0	38.0	29.0
ARAP7 13.800	ST	44.0	44.0	44.0	61.0
ARRIBA_W1 0.6900	W1	38.0	38.0	70.0	N/A**
ARRIBA_W2 0.6900	W2	38.0	38.0	70.0	N/A**
BIGHORN_S 0.6300	S1	198.0	198.0	198.0	194.3
BRONCO_W1 0.6900	W1	55.7	55.7	102.7	242.9
BRONCO_W2 0.6900	W2	61.3	61.3	112.8	N/A**
CABCRKA 13.800	HA	160.0	160.0	160.0	0.0
CABCRKB 13.800	HB	160.0	160.0	160.0	0.0
CEDAR2_W1 0.6600	W1	47.5	47.5	47.5	101.2
CEDAR2_W2 0.6900	W2	38.3	38.3	38.3	61.1
CEDAR2_W3 0.6600	W3	9.5	9.5	9.5	15.3
CEDARCK_1A 34.500	W1	83.6	83.6	83.6	178.1
CEDARCK_1B 34.500	W2	30.4	30.4	30.4	64.8
CEDARPT_W1 0.6900	W1	47.2	47.2	47.2	100.4
CEDARPT_W2 0.6900	W2	47.9	47.9	47.9	102.0
CHEROK2 15.500	SC	0.0	0.0	0.0	0.0
CHEROK4 22.000	G4	0.0	360.0	0.0	179.0
CHEROKEE5 18.000	G5	173.0	173.0	173.0	179.2
CHEROKEE6 18.000	G6	172.0	172.0	172.0	178.0
CHEROKEE7 18.000	ST	230.0	230.0	230.0	44.8
CHEYRGE_W1 0.6900	W1	20.5	20.5	37.8	93.1
CHEYRGE_W2 0.6900	W2	41.8	41.8	77.0	93.1
CHEYRGE_W3 0.6900	W3	25.1	25.1	46.2	N/A**
CHEYRGW_W1 0.6900	W1	51.8	51.8	95.5	108.5
CHEYRGW_W2 0.6900	W2	50.2	50.2	92.4	108.5
CO_GRN_E 0.5750	W1	30.8	30.8	30.8	N/A**
CO_GRN_W 0.5750	W2	30.8	30.8	30.8	N/A**
COMAN_2 24.000	C2	317.4	343.9	337.5	225.0
COMAN_3 27.000	C3	750.0	750.0	750.0	450.0
COMAN_S1 0.4180	S1	96.0	96.0	96.0	97.2
FRUITA 13.800	G1	0.0	0.0	0.0	0.0
FT_LUPTN_12 13.800	G1	0.0	0.0	0.0	0.0
FT_LUPTN_12 13.800	G2	0.0	0.0	0.0	0.0

FTNVL1&2 13.800	G1	0.0	0.0	0.0	0.0
FTNVL1&2 13.800	G2	0.0	0.0	0.0	0.0
FTNVL3&4 13.800	G3	0.0	0.0	0.0	0.0
FTNVL3&4 13.800	G4	0.0	0.0	0.0	0.0
FTNVL5&6 13.800	G5	0.0	0.0	0.0	0.0
FTNVL5&6 13.800	G6	0.0	0.0	0.0	0.0
GLDNWST_W1 0.6900	W1	94.8	94.8	94.8	201.6
GSANDHIL_PV 34.500	S1	15.2	15.2	15.2	0.0
LAMAR_DC 230.00	DC	170.0	170.0	170.0	0.0
LIMON1_W 34.500	W1	76.4	76.4	76.4	162.7
LIMON2_W 34.500	W2	76.4	76.4	76.4	162.7
LIMON3_W 34.500	W3	76.4	76.4	76.4	122.9
MANCHEF1 16.000	G1	132.0	132.0	132.0	0.0
MANCHEF2 16.000	G2	131.0	131.0	131.0	0.0
MTNBRZ_W1 0.6900	W1	60.0	60.0	60.0	136.8
MTNBRZ_W2 0.6900	W2	5.2	5.2	5.2	N/A**
NEPTUNE_B1 0.4800	B1	0.0	0.0	0.0	0.0
NEPTUNE_S1 0.6600	S1	200.4	200.4	200.4	202.4
PAWNEE 22.000	C1	528.0	528.0	528.0	200.0
PLNENDG1_1 13.800	G0	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G1	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G2	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G3	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G4	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G5	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G6	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G7	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G8	0.0	0.0	0.0	-0.3
PLNENDG1_1 13.800	G9	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G0	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G1	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G2	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G3	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G4	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G5	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G6	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G7	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G8	0.0	0.0	0.0	-0.3
PLNENDG1_2 13.800	G9	0.0	0.0	0.0	-0.3
PLNENDG2_1 13.800	G1	0.0	0.0	0.0	-0.3

PLNENDG2_1 13.800	G2	0.0	0.0	0.0	-0.3
PLNENDG2_1 13.800	G3	0.0	0.0	0.0	-0.3
PLNENDG2_1 13.800	G4	0.0	0.0	0.0	-0.3
PLNENDG2_1 13.800	G5	0.0	0.0	0.0	-0.3
PLNENDG2_1 13.800	G6	0.0	0.0	0.0	-0.3
PLNENDG2_1 13.800	G7	0.0	0.0	0.0	-0.3
PLNENDG2_2 13.800	G1	0.0	0.0	0.0	-0.3
PLNENDG2_2 13.800	G2	0.0	0.0	0.0	-0.3
PLNENDG2_2 13.800	G3	0.0	0.0	0.0	-0.3
PLNENDG2_2 13.800	G4	0.0	0.0	0.0	-0.3
PLNENDG2_2 13.800	G5	0.0	0.0	0.0	-0.3
PLNENDG2_2 13.800	G6	0.0	0.0	0.0	-0.3
PLNENDG2_2 13.800	G7	0.0	0.0	0.0	-0.3
PTZLOGN1 34.500	W1	76.4	76.4	76.4	162.7
PTZLOGN2 34.500	W2	45.6	45.6	45.6	97.2
PTZLOGN3 34.500	W3	30.2	30.2	30.2	64.0
PTZLOGN4 34.500	W4	66.5	66.5	66.5	141.7
QF_B4-4T 13.800	G4	0.0	0.0	0.0	20.0
QF_B4-4T 13.800	G5	0.0	0.0	0.0	20.0
QF_B4D4T 12.500	ST	0.0	0.0	0.0	7.0
QF_BCP2T 13.800	G3	0.0	0.0	0.0	0.0
QF_BCP2T 13.800	ST	0.0	0.0	0.0	0.0
QF_CPP1T 13.800	G1	0.0	0.0	0.0	0.1
QF_CPP1T 13.800	G2	0.0	0.0	0.0	0.1
QF_CPP3T 13.800	ST	0.0	0.0	0.0	0.1
RDGCREST 34.500	W1	11.3	11.3	11.3	18.1
RMEC1 15.000	G1	138.0	138.0	138.0	141.1
RMEC2 15.000	G2	132.0	132.0	132.0	136.0
RMEC3 23.000	ST	253.2	253.2	253.2	2.9
RUSHCK1_W1 0.6900	W1	76.5	76.5	141.0	162.7
RUSHCK1_W2 0.6900	W2	61.9	61.9	114.0	131.2
RUSHCK2_W3 0.6900	W3	79.0	79.0	145.6	168.4
SLVS_IBRDRLA34.500	S2	24.0	24.0	24.0	40.5
SPNDLE1 18.000	G1	138.0	80.0	80.0	143.1
SPNDLE2 18.000	G2	136.0	80.0	0.0	16.9
SPRNGCAN1_W10.5700	W1	24.6	24.6	24.6	28.0
SPRNGCAN2_W20.6900	W2	23.8	23.8	23.8	28.0
SPRUCE1 18.000	G1	132.0	132.0	132.0	136.5
SPRUCE2 18.000	G2	132.0	132.0	132.0	29.5
ST.VR_2 18.000	G2	158.0	158.0	158.0	133.4

ST.VR_3 18.000	G3	145.0	145.0	145.0	171.5
ST.VR_4 18.000	G4	140.0	140.0	140.0	51.1
ST.VR_5 18.000	G5	145.0	0.0	0.0	0.0
ST.VR_6 18.000	G6	140.0	0.0	0.0	0.0
ST.VRAIN 22.000	ST	316.0	316.0	316.0	89.0
SUNMTN_S1 0.6300	S1	162.2	162.2	162.2	163.5
SUNPOWER 34.500	S1	41.6	41.6	41.6	42.1
TBI_GEN 0.5750	W1	28.5	28.5	28.5	N/A**
THNDWLF_B1 0.4800	B1	0.0	0.0	0.0	0.0
THNDWLF_S1 0.6600	S1	160.0	160.0	160.0	161.9
TITAN_S1 0.6300	S1	42.8	42.8	42.8	0.0
VALMNT6 13.800	G6	0.0	0.0	0.0	-1.0
VALMNT7 13.800	G7	0.0	0.0	0.0	0.0
VALMNT8 13.800	G8	0.0	0.0	0.0	-0.8

***Generators in the Heavy Winter case with N/A as the dispatch are artifacts of topology differences between the HS and HW cases, but their capacity is generally accounted for with other existing generators in the HW model.*

APPENDIX B – HIGH RENEWABLE BENCHMARK CASES DISPATCH

Bus Name / kV	Id	2026 ERP BM	2027 ERP BM	2028 ERP BM
ALAMOSA_PV 34.500	S3	27.0	27.0	27.0
ALMSACT1 13.800	G1	17.0	18.8	0.0
ALMSACT2 13.800	G2	15.0	17.7	0.0
ARAP5&6 13.800	G5	38.0	38.2	38.2
ARAP5&6 13.800	G6	38.0	38.7	38.7
ARAP7 13.800	ST	44.0	44.1	44.1
ARRIBA_W1 0.6900	W1	92.0	96.1	100.1
ARRIBA_W2 0.6900	W2	92.0	96.1	100.1
BIGHORN_S 0.6300	S1	222.8	222.8	222.8
BRONCO_W1 0.6900	W1	134.9	145.0	146.6
BRONCO_W2 0.6900	W2	148.3	158.0	161.2
CABCRKA 13.800	HA	160.0	160.0	160.0
CABCRKB 13.800	HB	160.0	160.0	160.0
CEDAR2_W1 0.6600	W1	115.0	120.0	125.0
CEDAR2_W2 0.6900	W2	92.7	96.8	100.8
CEDAR2_W3 0.6600	W3	23.0	24.0	25.0
CEDARCK_1A 34.500	W1	202.4	211.2	220.0
CEDARCK_1B 34.500	W2	73.6	76.8	80.0
CEDARPT_W1 0.6900	W1	114.3	119.2	124.2
CEDARPT_W2 0.6900	W2	115.9	121.0	126.0
CHEROK2 15.500	SC	0.0	0.0	0.0
CHEROK4 22.000	G4	215.0	N/A*	N/A*
CHEROKEE5 18.000	G5	125.0	170.0	170.0
CHEROKEE6 18.000	G6	125.0	170.0	170.0
CHEROKEE7 18.000	ST	105.0	230.0	230.0
CHEYRGE_W1 0.6900	W1	49.7	51.8	54.0
CHEYRGE_W2 0.6900	W2	101.2	105.6	110.0
CHEYRGE_W3 0.6900	W3	60.7	63.4	66.0
CHEYRGW_W1 0.6900	W1	125.5	130.9	136.4
CHEYRGW_W2 0.6900	W2	121.4	126.7	132.0
CO_GRN_E 0.5750	W1	74.5	77.8	81.0
CO_GRN_W 0.5750	W2	74.5	77.8	81.0
COMAN_3 27.000	C3	450.0	450.0	450.0
COMAN_S1 0.4180	S1	108.0	108.0	108.0
FRUITA 13.800	G1	15.0	0.0	0.0
FT_LUPTON_1213.800	G1	35.0	0.0	0.0

FT_LUPTON_1213.800	G2	35.0	0.0	0.0
FTNVL1&2 13.800	G1	30.0	39.2	39.2
FTNVL1&2 13.800	G2	30.0	39.2	39.2
FTNVL3&4 13.800	G3	30.0	39.2	39.2
FTNVL3&4 13.800	G4	30.0	39.2	39.2
FTNVL5&6 13.800	G5	30.0	39.2	39.2
FTNVL5&6 13.800	G6	30.0	39.2	39.2
GLDNWST_W1 0.6900	W1	229.5	239.5	249.4
GSANDHIL_PV 34.500	S1	17.1	17.1	17.1
LAMAR_DC 230.00	DC	170.0	0.0	0.0
LIMON1_W 34.500	W1	184.9	200.0	201.0
LIMON2_W 34.500	W2	184.9	200.0	201.0
LIMON3_W 34.500	W3	184.9	200.0	201.0
MANCHEF1 16.000	G1	135.0	132.3	132.3
MANCHEF2 16.000	G2	134.0	131.6	131.6
MTNBRZ_W1 0.6900	W1	145.3	151.6	157.9
MTNBRZ_W2 0.6900	W2	12.7	13.2	13.8
NEPTUNE_B1 0.4800	B1	0.0	0.0	0.0
NEPTUNE_S1 0.6600	S1	292.5	225.4	225.4
PAWNEE 22.000	C1	209.6	202.9	215.1
PLNENDG1_1 13.800	G0	5.1	0.0	0.0
PLNENDG1_1 13.800	G1	5.1	0.0	0.0
PLNENDG1_1 13.800	G2	5.1	0.0	0.0
PLNENDG1_1 13.800	G3	5.1	0.0	0.0
PLNENDG1_1 13.800	G4	5.1	0.0	0.0
PLNENDG1_1 13.800	G5	5.1	0.0	0.0
PLNENDG1_1 13.800	G6	5.1	0.0	0.0
PLNENDG1_1 13.800	G7	5.1	0.0	0.0
PLNENDG1_1 13.800	G8	5.1	0.0	0.0
PLNENDG1_1 13.800	G9	5.1	0.0	0.0
PLNENDG1_2 13.800	G0	5.1	0.0	0.0
PLNENDG1_2 13.800	G1	5.1	0.0	0.0
PLNENDG1_2 13.800	G2	5.1	0.0	0.0
PLNENDG1_2 13.800	G3	5.1	0.0	0.0
PLNENDG1_2 13.800	G4	5.1	0.0	0.0
PLNENDG1_2 13.800	G5	5.1	0.0	0.0
PLNENDG1_2 13.800	G6	5.1	0.0	0.0
PLNENDG1_2 13.800	G7	5.1	0.0	0.0
PLNENDG1_2 13.800	G8	5.1	0.0	0.0
PLNENDG1_2 13.800	G9	5.1	0.0	0.0

PLNENDG2_1 13.800	G1	7.7	0.0	0.0
PLNENDG2_1 13.800	G2	7.7	0.0	0.0
PLNENDG2_1 13.800	G3	7.7	0.0	0.0
PLNENDG2_1 13.800	G4	7.7	0.0	0.0
PLNENDG2_1 13.800	G5	7.7	0.0	0.0
PLNENDG2_1 13.800	G6	7.7	0.0	0.0
PLNENDG2_1 13.800	G7	7.7	0.0	0.0
PLNENDG2_2 13.800	G1	7.7	0.0	0.0
PLNENDG2_2 13.800	G2	7.7	0.0	0.0
PLNENDG2_2 13.800	G3	7.7	0.0	0.0
PLNENDG2_2 13.800	G4	7.7	0.0	0.0
PLNENDG2_2 13.800	G5	7.7	0.0	0.0
PLNENDG2_2 13.800	G6	7.7	0.0	0.0
PLNENDG2_2 13.800	G7	7.7	0.0	0.0
PTZLOGN1 34.500	W1	184.9	104.5	104.5
PTZLOGN2 34.500	W2	110.4	62.4	62.4
PTZLOGN3 34.500	W3	73.1	41.3	41.3
PTZLOGN4 34.500	W4	161.0	91.0	91.0
QF_B4-4T 13.800	G4	23.5	23.5	23.5
QF_B4-4T 13.800	G5	24.5	24.5	24.5
QF_B4D4T 12.500	ST	68.6	68.6	68.6
QF_BCP2T 13.800	G3	33.4	33.4	33.4
QF_BCP2T 13.800	ST	35.3	35.3	35.3
QF_CPP1T 13.800	G1	23.5	23.5	23.5
QF_CPP1T 13.800	G2	23.5	23.5	23.5
QF_CPP3T 13.800	ST	26.5	26.5	26.5
RDGCREST 34.500	W1	27.3	28.5	29.7
RMEC1 15.000	G1	100.0	100.0	100.0
RMEC2 15.000	G2	100.0	100.0	100.0
RMEC3 23.000	ST	0.0	0.0	0.0
RUSHCK1_W1 0.6900	W1	185.3	200.0	201.4
RUSHCK1_W2 0.6900	W2	149.9	160.0	162.9
RUSHCK2_W3 0.6900	W3	191.4	206.0	208.0
SLVS_IBRDRLA34.500	S2	27.0	27.0	27.0
SPNDLE1 18.000	G1	120.0	140.2	140.2
SPNDLE2 18.000	G2	110.0	137.8	137.8
SPRNGCAN1_W10.5700	W1	59.6	62.2	64.8
SPRNGCAN2_W20.6900	W2	57.6	60.1	62.7
SPRUCE1 18.000	G1	135.5	133.8	133.8
SPRUCE2 18.000	G2	135.5	132.8	132.8

ST.VR_2 18.000	G2	160.0	160.0	160.0
ST.VR_3 18.000	G3	170.0	170.0	170.0
ST.VR_4 18.000	G4	0.0	0.0	0.0
ST.VR_5 18.000	G5	0.0	0.0	0.0
ST.VR_6 18.000	G6	0.0	0.0	0.0
ST.VRAIN 22.000	ST	0.0	0.0	0.0
SUNMTN_S1 0.6300	S1	182.4	182.4	182.4
SUNPOWER 34.500	S1	46.8	46.8	46.8
TBI_GEN 0.5750	W1	69.0	72.0	75.0
THNDWLF_B1 0.4800	B1	0.0	0.0	0.0
THNDWLF_S1 0.6600	S1	225.0	180.0	180.0
TITAN_S1 0.6300	S1	48.2	48.2	48.2
VALMNT6 13.800	G6	40.0	0.0	45.7
VALMNT7 13.800	G7	40.0	0.0	39.9
VALMNT8 13.800	G8	40.0	0.0	41.0

APPENDIX C – HIGH RENEWABLE STUDY CASES DISPATCH

Bus Name	Id	26 Study	27 Study	28 Study
ALMSACT2 13.800	G2	0.0	0.0	0.0
APT_DSLS 4.1600	G1	0.0	0.0	0.0
ARRIBA_W1 0.6900	W1	100.1	85.1	68.1
ARRIBA_W2 0.6900	W2	100.1	85.1	68.1
BAC_MSA GEN113.800	G1	86.1	75.0	75.0
BAC_MSA GEN213.800	G1	86.1	75.0	75.0
BAC_MSA GEN413.800	G1	40.0	40.0	40.0
BAC_MSA GEN413.800	G2	40.0	40.0	40.0
BAC_MSA GEN413.800	S1	0.0	0.0	0.0
BAC_MSA GEN513.800	G1	40.0	0.0	0.0
BAC_MSA GEN513.800	G2	40.0	0.0	0.0
BAC_MSA GEN513.800	S1	24.8	0.0	0.0
BAC_MSA GEN613.800	G1	32.0	0.0	0.0
BIGHORN_S 0.6300	S1	222.8	222.8	222.8
BRONCO_W1 0.6900	W1	146.6	124.6	99.7
BRONCO_W2 0.6900	W2	161.2	137.0	109.6
BUSCHRNCH_LO0.7000	W1	19.8	30.9	30.9
BUSCHRWTG1 0.7000	W1	9.5	15.0	15.0
CABCRKA 13.800	HA	0.0	0.0	0.0
CABCRKB 13.800	HB	0.0	0.0	0.0
CEDAR2_W1 0.6600	W1	125.0	106.3	85.0
CEDAR2_W2 0.6900	W2	100.8	85.7	68.5
CEDAR2_W3 0.6600	W3	25.0	21.3	17.0
CEDARPT_W1 0.6900	W1	124.2	105.6	84.5
CEDARPT_W2 0.6900	W2	126.0	107.1	85.7
CHEROK2 15.500	SC	0.0	0.0	0.0
CHEROKEE5 18.000	G5	175.0	170.0	170.0
CHEROKEE6 18.000	G6	175.0	170.0	170.0
CHEROKEE7 18.000	ST	220.0	230.0	230.0
CHEYRGE_W1 0.6900	W1	54.0	45.9	36.7
CHEYRGE_W2 0.6900	W2	110.0	93.5	74.8
CHEYRGE_W3 0.6900	W3	66.0	56.1	44.9
CHEYRGW_W1 0.6900	W1	136.4	115.9	92.8
CHEYRGW_W2 0.6900	W2	132.0	112.2	89.8
CO_GRN_E 0.5800	W1	81.0	68.9	55.1
CO_GRN_W 0.5800	W2	81.0	68.9	55.1
COMAN_3 27.000	C3	450.0	450.0	450.0

COMAN_S1 0.4180	S1	108.0	108.0	108.0
ERP_0011 34.500	G	N/A	0.0	0.0
ERP_0149 34.500	B	N/A	N/A	0.0
ERP_0149 34.500	S	N/A	N/A	81.0
ERP_0217 34.500	B	N/A	N/A	0.0
ERP_0217 34.500	S	N/A	N/A	319.5
ERP_0249 34.500	B	N/A	N/A	0.0
ERP_0251 34.500	B	N/A	N/A	0.0
ERP_0254 34.500	W	N/A	247.4	197.9
ERP_0282 34.500	B	N/A	N/A	0.0
ERP_0303 34.500	B	N/A	N/A	0.0
ERP_0303 34.500	S	N/A	N/A	270.0
ERP_0467 34.500	B	N/A	N/A	0.0
ERP_0474 34.500	S	N/A	N/A	180.0
ERP_0589 34.500	B	N/A	N/A	0.0
ERP_0989 34.500	G	N/A	N/A	0.0
ERP_1000 34.500	G	N/A	N/A	0.0
ERP_1002 34.500	S	N/A	N/A	301.5
ERP_1010 34.500	B	0.0	0.0	0.0
ERP_1010 34.500	S	292.5	292.5	292.5
ERP_1015 34.500	W	N/A	382.5	306.0
ERP_1024 34.500	W	N/A	512.6	410.0
ERP_1029 34.500	W	N/A	425.0	340.0
ERP_1085 34.500	B	N/A	N/A	0.0
ERP_1125 34.500	S	N/A	N/A	103.5
FTNVL1&2 13.800	G1	0.0	0.0	0.0
FTNVL1&2 13.800	G2	0.0	0.0	0.0
FTNVL3&4 13.800	G3	0.0	0.0	0.0
FTNVL3&4 13.800	G4	0.0	0.0	0.0
FTNVL5&6 13.800	G5	0.0	0.0	0.0
FTNVL5&6 13.800	G6	0.0	0.0	0.0
GLDNWST_W1 0.7000	W1	249.4	212.0	169.6
GSANDHIL_PV 34.500	S1	17.1	17.1	17.1
HUNTER_CR_S 34.500	S1	67.4	67.5	63.0
JMSHAFR1 13.800	G1	36.3	0.0	0.0
JMSHAFR1 13.800	G2	35.0	18.2	18.2
JMSHAFR2 13.800	ST	5.0	24.5	24.5
JMSHAFR3 13.800	G3	33.0	19.7	19.7
JMSHAFR3 13.800	ST	13.2	23.4	23.4
JMSHAFR4 13.800	G4	12.8	0.0	0.0

JMSHAFR4 13.800	G5	14.1	0.0	0.0
KIOWA_CR_S 34.500	S1	49.1	49.1	49.1
KNUTSON1 13.800	G1	40.4	0.0	0.0
KNUTSON2 13.800	G2	40.3	0.0	0.0
LAMAR_DC 230.00	DC	0.0	0.0	0.0
LIMON1_W 34.500	W1	201.0	170.9	136.7
LIMON2_W 34.500	W2	201.0	170.9	136.7
LIMON3_W 34.500	W3	201.0	170.9	136.7
MANCHEF1 16.000	G1	0.0	0.0	0.0
MANCHEF2 16.000	G2	0.0	0.0	0.0
MTNBRZ_W1 0.6900	W1	157.9	134.2	107.4
MTNBRZ_W2 0.6900	W2	13.8	11.7	9.4
NEPTUNE_B1 0.4800	B1	0.0	0.0	0.0
NEPTUNE_S1 0.6600	S1	292.5	225.4	225.4
PAWNEE 22.000	C1	379.2	233.5	231.1
PEAKVIEWLO 0.7000	W1	20.0	31.2	31.2
PIONEER_CR_S0.6450	S1	73.0	73.0	73.0
PTZLOGN2 34.500	W2	120.0	62.4	81.6
PTZLOGN3 34.500	W3	79.5	41.3	54.1
PTZLOGN4 34.500	W4	175.0	91.0	119.0
PUB_DSLS 4.1600	G1	0.0	0.0	0.0
R.F.DSLS 4.1600	G1	0.0	0.0	0.0
RAWHIDE 24.000	C1	280.0	280.0	280.0
RAWHIDEA 13.800	GA	0.0	0.0	0.0
RAWHIDEB 13.800	GB	0.0	0.0	0.0
RAWHIDEC 13.800	GC	0.0	0.0	0.0
RAWHIDED 13.800	GD	0.0	0.0	0.0
RAWHIDEF 18.000	GF	0.0	0.0	0.0
RD_1_GEN 0.6900	W1	171.0	182.0	197.0
RH_PV_GEN 0.6000	PV	30.0	30.0	30.0
RMEC1 15.000	G1	100.0	100.0	100.0
RMEC2 15.000	G2	100.0	100.0	100.0
RMEC3 23.000	ST	0.0	0.0	0.0
RPS_PV_GEN 0.4180	PV	20.0	20.0	20.0
RUSHCK1_W1 0.6900	W1	201.4	171.2	137.0
RUSHCK1_W2 0.6900	W2	162.9	138.5	110.8
RUSHCK2_W3 0.6900	W3	208.0	176.8	141.4
SEV_GEN 0.6600	S1	150.0	150.0	150.0
SI_GEN 0.6000	1	10.1	29.0	29.0
SLVS_IBRDRLA34.500	S2	27.0	27.0	27.0

SP_GEN 0.6200	PV	0.0	90.2	90.2
SPANPKS2_GEN0.6000	PV	0.0	36.2	36.2
SPRNGCAN1_W10.5700	W1	64.8	55.1	44.1
SPRUCE1 18.000	G1	0.0	0.0	0.0
SPRUCE2 18.000	G2	0.0	0.0	0.0
ST.VR_2 18.000	G2	110.0	110.0	110.0
ST.VR_3 18.000	G3	110.0	110.0	110.0
ST.VR_4 18.000	G4	110.0	110.0	110.0
ST.VR_5 18.000	G5	0.0	0.0	0.0
ST.VR_6 18.000	G6	0.0	0.0	0.0
ST.VRAIN 22.000	ST	0.0	0.0	0.0
SUN_MTN_S1 0.6600	S1	182.4	182.4	182.4
SUNPOWER 34.500	S1	46.8	46.8	46.8
TBII_GEN 0.6900	W	25.3	39.0	39.0
THNDWLF_B1 0.4800	B1	0.0	0.0	0.0
THNDWLF_S1 0.6600	S1	225.0	180.0	180.0
TITAN_S1 0.6300	S1	48.2	48.2	48.2
TRK_CRK_ES1 0.7000	1	N/A	0.0	0.0
TRK_CRK_PV 0.6000	1	N/A	200.0	200.0
VALMNT7 13.800	G7	0.0	0.0	0.0
VALMNT8 13.800	G8	0.0	0.0	0.0

APPENDIX D – ALTERNATIVE PROJECTS STUDY

BARR

ELECTRANIX
SPECIALISTS IN POWER SYSTEM STUDIES

Leetsdale – Elati 230kV Underground Cable

Replacement Alternatives

Prepared for
Xcel Energy

October 2023

225 East 16th Avenue, Suite 500
Denver, CO 80203
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Leetsdale – Elati 230kV Underground Cable Replacement Alternatives

October 2023

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1 Executive Summary

Xcel Energy is studying the impacts of the Power Pathways project on the transmission system in the Denver Metro Area. Segment 5 of the Power Pathways project will terminate at the Harvest Mile Substation located southeast of the downtown area. Adding generation in this location, along with increased load in the Metro area, will result in the overloading of several transmission lines.

Xcel Energy performed studies that indicate the 230kV underground cable between the Leetsdale and Elati Substations will be overloaded under certain contingency conditions with these additions. Barr Engineering Co. and Electranix studied several options to mitigate this overloading. The mitigation options considered include the following:

- Adding a new/replacement higher rated 230 kV cable
- Adding a series reactor (to increase the impedance of the existing cable path to reduce flows in the existing cable path but increase flows in other parallel paths)
- Adding a phase shifting transformer (to reduce flows in the existing cable path but increasing flows in other parallel paths)
- Introducing a new Battery Energy Storage (BESS) device near the overloaded line

Electranix performed PSS/E power flow studies for the existing system and for all mitigation options. Barr Engineering Co. reviewed the feasibility of each of these options and prepared indicative pricing. The study results, and challenges associated with the installation of the studied options and indicative pricing are presented herein.

Based on this study, the recommendation is to replace the cable to increase the path rating. This is the only feasible option to address the root of the problem. All the other mitigation options will either not provide a solution or create overload for the parallel circuits. Shifting the power flow from this 230kV circuit will not increase the overall path rating and will cause overloading in parallel circuits.

2 Substation Information

The existing 230kV circuit runs between the Leetsdale, Monroe, and Elati Substations in Denver.

The Leetsdale Substation (Figure 2-1) is located in an urban area and bounded by a residential neighborhood, a major four-lane thoroughfare, and a high school sports field. The fenced area of the station has no open space, and the existing control enclosure is full.

A small, unfenced area to the west of the station could potentially be utilized to add equipment. However, there may be considerable challenges for permitting this addition as it removes the existing setback near the residential area. It is important to note the proposed equipment does emit some noise, which may make this permitting effort even more difficult next to a residential neighborhood.

There are also significant grading and fencing that would be required to add equipment in the unfenced area. The options to add equipment all utilize this unfenced area to the west of the station. Still, there has been no investigation into the difficulty of trying to permit an expansion of the substation.

Figure 2-1 Leetsdale Substation

The Monroe Substation (Figure 2-2) is an open air substation located in the Cherry Creek area. The substation is in a primarily residential location and is surrounded by a large wall. There is no available space in the substation to add equipment, and there is no opportunity to expand the station.

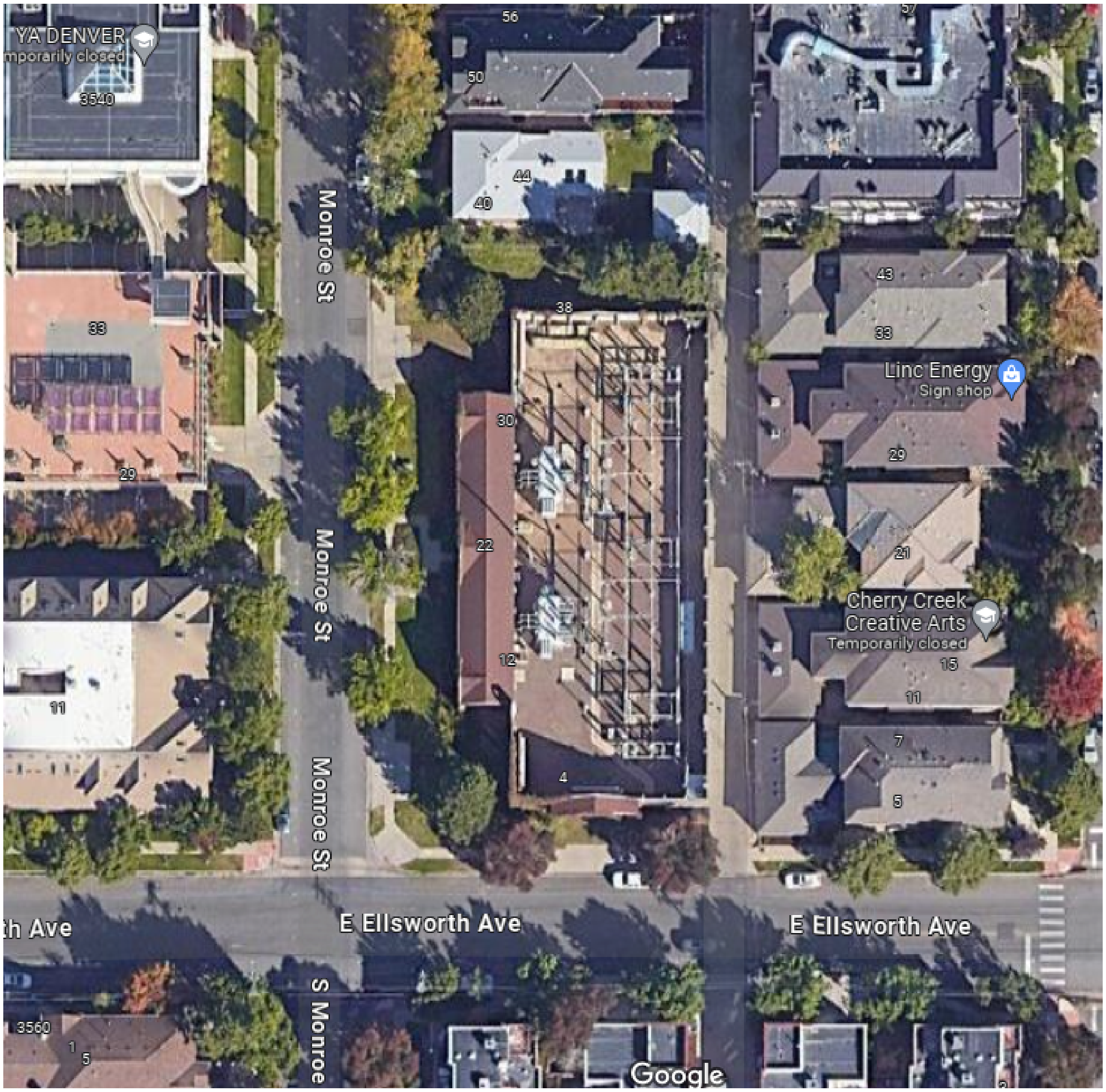

Figure 2-2 Monroe Substation

The Elati Substation (Figure 2-3) is located in downtown Denver and was constructed as a gas-insulated substation (GIS) because of the limited availability of land in the area. All transmission and distribution lines come into the station underground. There is no available space at this station to add equipment, and there is no opportunity to expand the station.

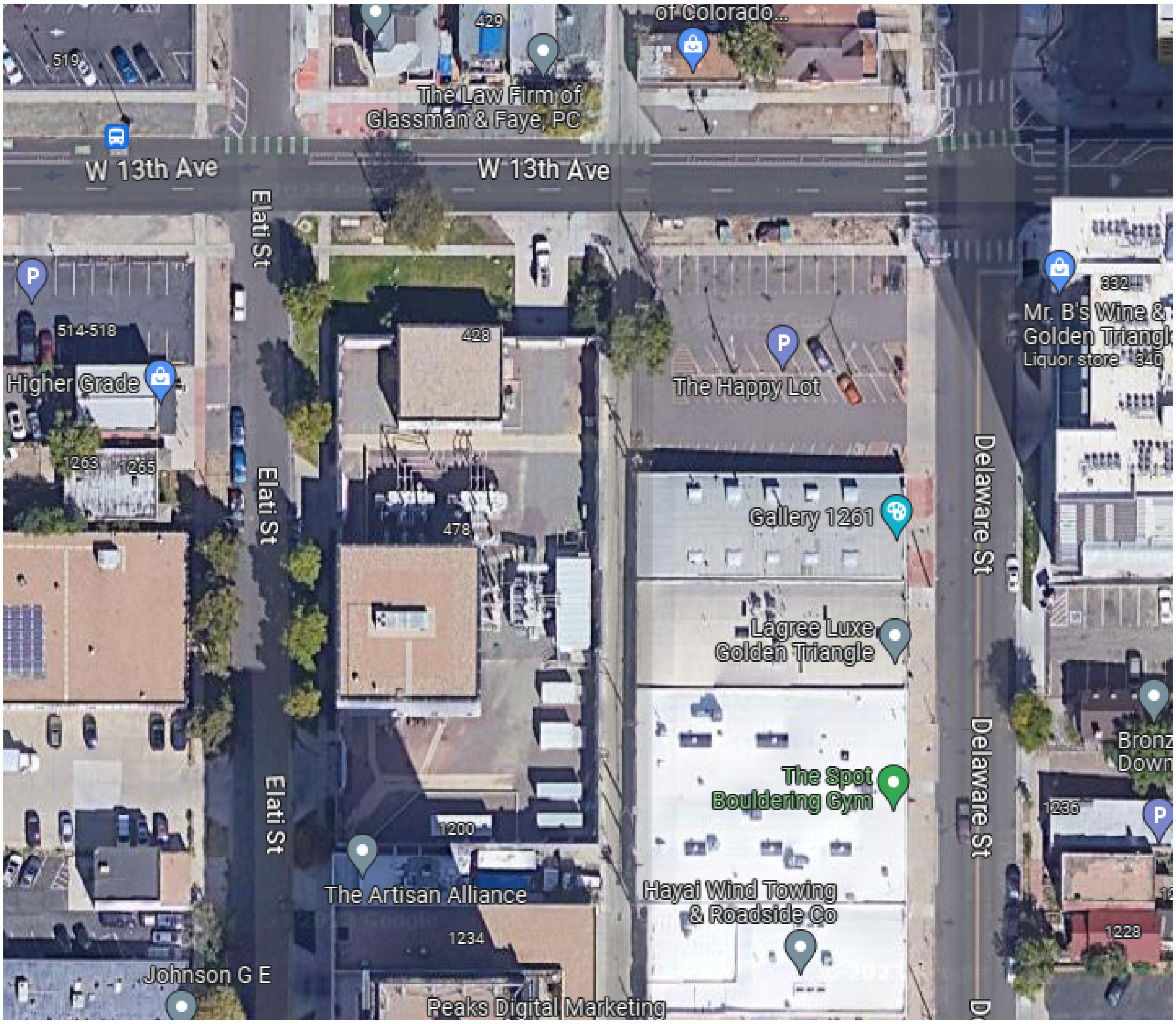

Figure 2-3 **Elati Substation**

3 Study Discussion

3.1 PSS/E Model Development and Assumptions

The studies in this report were performed using the PSS/E program version 34.9.5. The base PSS/E case (29HS2ap_HWind2.sav) was provided by Xcel Energy Services.

The following modifications were made to the base case (based on instructions from Xcel Energy):

1. A dummy bus (970260: LEETSDALE_T) was introduced between Leetsdale and Monroe 230 kV (see Figure 3-1) to study other mitigation options (series reactors, phase shifters, etc.)
2. Four overload mitigation options were added and enabled one at a time (details of each mitigation option are discussed in Section 3.2.2 to 3.2.5):
    a. The cable between Leetsdale and Elati is upgraded.
    b. A reactor is connected in series with Leetsdale – Elati cable.
    c. A phase shifting transformer is connected in series with Leetsdale – Elati cable.
    d. A BESS is introduced at the Leetsdale bus.
3. Line ratings of the followings lines were uprated as per Xcel Energy - see reference [1]:
    a. The rating of the Greenwood – Monaco 230 kV line is uprated from 405 MVA to its full conductor rating of 503 MVA.
    b. The rating of the Leetsdale – Sullivan 230 kV line is uprated from 396 to 503 MVA, and the Sullivan – Monaco 230 kV line is uprated from 396 to 470 MVA.
    c. The rating of the Daniels Park – Prairie – Greenwood 230 kV line is uprated from 478 MVA to its full conductor rating of 576 MVA.
4. A 100 MW/20 MVAr load is added at the Denver Terminal 230 kV bus.

Notes

The followings changes were included in the base case from Xcel Energy: These changes were applied to induce a flow across the area of study. In this case, it was the Leetsdale to Monroe underground cable.

1. 600 MW of future generation is added to the Smoky Hill 345 kV bus. Smoky Hill does not accommodate generation but was used as an injection point onto the system.
2. 400 MW of future generation is added to the CANAL_XING 345 kV bus. Canal Crossing likely will see future generation but an estimate of 400MW was added to encourage flow through the study area.
3. Generators at the Cherokee station are disconnected.
4. Cabin Creek pump loads are set to maximum load values – i.e., 162 MW each (Cabin Creek A and B).

[redacted]

Figure 3-1 Modified PSS/E Network Topology around Leetsdale - Elati

3.2 Studied Options

Power flow studies were performed for the existing system and for all potential mitigation options. Each of the potential mitigation options was studied with a total of 10 contingencies applied.

3.2.1 Do Nothing/No Upgrade

With the base case studies, the Leetsdale – Elati 230kV cable circuit will be overloaded in 5 of the 10 studied contingency cases.

3.2.2 Cable Circuit Upgrade

The existing cable between Leetsdale and Elati is replaced by a new cable with a rating of 700 MVA. The cross section of the cable topology and the PSCAD model (for the calculation of cable parameters) are shown in Figure 3-2 and Figure 3-3, respectively.

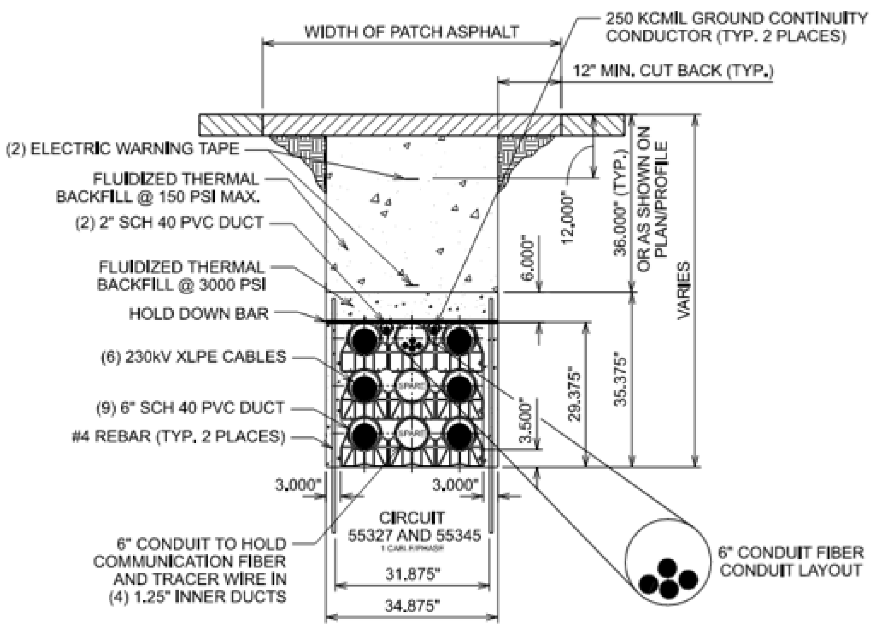

Figure 3-2 Cross Section of the New Cable between Leetsdale and Elati

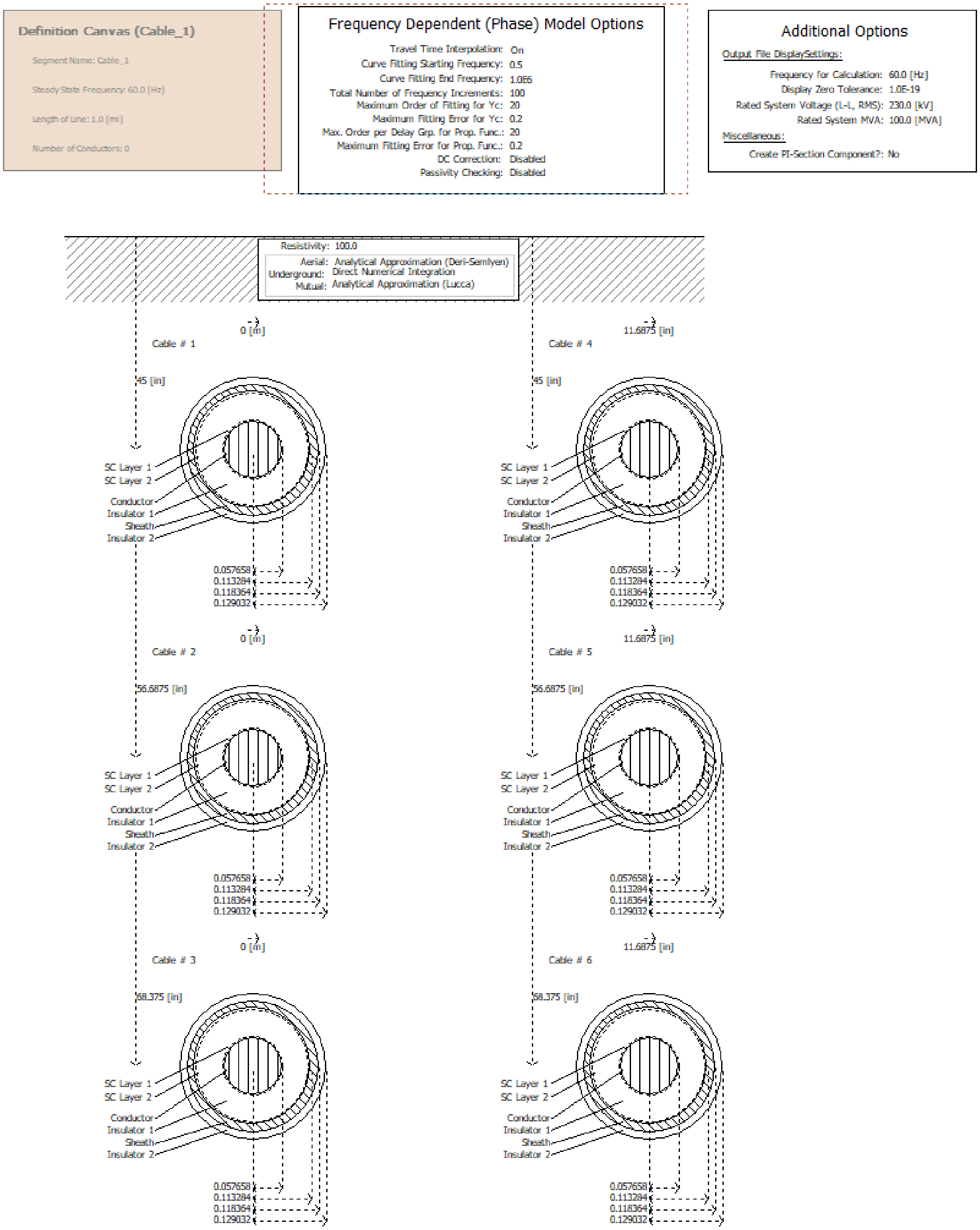

Figure 3-3 PSCAD Model of the New Cable between Leetsdale and Elati

The parameters of the new cable are calculated using the above PSCAD model, and the results are shown in Table 1 below.

Table 1 Parameters of New Cable between Leetsdale and Elati

Cable Section	Cable Parameters (pu) on 230 kV and 100 MVA Base		
	R	X	B
Leetsdale to Monroe	0.000016	0.000088	0.032915
Monroe to Elati	0.000049	0.000264	0.098744

Replacing the cable removed all of the overloading in the studied cases. It should be noted there are still overloads in other studied lines with a replaced cable.

3.2.2.1 Cost

Xcel Energy estimated the cost to replace this cable circuit to be about $200M.

3.2.3 Series Reactor

The studied option was to install an air-core, series reactor at the Leetsdale Substation connected in series with the Leetsdale – Elati circuit. The reactance is assumed to be the same as the existing cable between Leetsdale and Elati, and the resistance as zero; i.e., Xpu = 0.002680 pu and Rpu = 0.0 on 230 kV and 100 MVA base.

The fenced area at the Leetsdale substation is fully utilized, so any new equipment would require a substation expansion to the west. The use of this area would require significant permitting and substantial grading. Locating equipment in this undeveloped area would require connection via underground cable.

This option relieved the cable overload in all but one contingency case. Because the installation does not mitigate all cable overloads, it does not appear to be a viable option. Additionally, the addition of a series reactor causes other transmission paths to overload.

3.2.3.1 Cost

The estimated the cost to install a series reactor in this circuit is about $10M.

3.2.4 Phase Shifting Transformer

A phase shifting transformer is connected in series with Leetsdale – Elati cable. The leakage impedance of the transformer is assumed to be 0.1 pu on 230 kV and 400 MVA base (similar to the old cable thermal rating). The phase shift of the transformer is controlled to avoid overloading the Leetsdale-Elati line by adjusting the phase shifter angle (and thus transferring power to other parallel paths).

The addition of a phase shifting transformer would relieve overloads on the 230kV cable circuit, but there are overloads on other lines as the power would just be rerouted to other circuits. Thus, this will Increase flow in the parallel paths. Also, this option does not Increase the overall transfer.

The use of a phase shifting transformer to solve a circuit overload is an extremely rare application of this type of equipment. Phase shifting transformers are commonly used to solve large system power flow issues, such as loop flows. Phase shifting transformers are physically very large and would take substantial space in the substation and be very close to the residential area. Transformers do emit noise, and the ability to permit this close to the residential area would be challenging.

Phase shifting transformers also have substantial lead times with current quotes of more than five years from order.

Phase shifting transformers are very large—essentially the size of two regular transformers. It would be a challenge to be able to fit into the existing Leetsdale Substation. There may be adequate space in the station on the west side with the phase shifting transformer connected via high voltage underground cable. Significant grading and a retaining wall would be required for this installation. This location would require substation expansion up to the street. Additionally, there may be unacceptable noise levels from a large transformer this close to the edge of a substation in a residential area.

3.2.4.1 Cost

The estimated cost to install a phase shifting transformer in this circuit is about $33M.

3.2.5 Battery Energy Storage System

A 100 MW BESS is connected to the Leetsdale 230 kV bus and was operated to avoid any overload conditions on the Leetsdale-Elati line. Note that a BESS at the Elati station (i.e., closer to the normal load side of the cable) is a better location for the BESS as it is more effective in reducing overload conditions on the cable.

This size of BESS requires a large open area of land, and none of the stations (Leetsdale, Monroe, or Elati) have adequate available area to install a BESS system. Because this option is not feasible due to physical limitations, no cost estimate was prepared.

3.3 Study Methodology

A detailed ACCC power flow study was conducted to obtain worst-case overloading scenarios for the Leetsdale-Elati cable by applying contingencies in the vicinity of the cable. Contingencies up to N-1 are considered in the study. A list of the contingencies considered are tabulated in Table 2:

Table 2 List of Contingencies Considered in the Power Flow Study

No.	Contingency Name	Description	PSS/E Case Action
1	SGL_230_071	Arapahoe - Greenwood	open branch from bus [redacted] to bus [redacted] ckt 1
2	SGL_230_006	Arapahoe - Daniel Park	open branch from bus [redacted] to bus [redacted] ckt 1 open branch from bus [redacted] to bus [redacted] ckt 1
3	SGL_230_049	Barr Lake - Green Valley	open branch from bus [redacted] to bus [redacted] ckt 1
4	SGL_230_004	Waterton - Chatfield - Soda Lake	open branch from bus [redacted] to bus [redacted] ckt 1 open branch from bus [redacted] to bus [redacted] ckt 1
5	SGL_230_027	Cherokee - Henry Lake	open branch from bus [redacted] to bus [redacted] ckt 1 open branch from bus [redacted] to bus [redacted] ckt 1

No.	Contingency Name	Description	PSS/E Case Action				
6	SGL_230_010	Sulphur - Homestead - Murphy - Smoky Hill	open branch from bus open branch from bus open branch from bus	[redacted]	to bus to bus to bus	[redacted]	ckt 1 ckt 1 ckt 1
7	SGL_230_041	Denver Term - Arapahoe	open branch from bus open branch from bus	[redacted]	to bus to bus	[redacted]	ckt 1 ckt 1
8	SGL_115_036	Sandown - Leetsdale	open branch from bus	[redacted]	to bus	[redacted]	ckt 1
9	SGL_230_043	Plains End - Niwot	open branch from bus open branch from bus	[redacted]	to bus to bus	[redacted]	ckt 1 ckt 1
10	SGL_115_041	Arapahoe_A - Leetsdale	open branch from bus open branch from bus	[redacted]	to bus to bus	[redacted]	ckt 1 ckt 1

Table 3 presents overloading conditions for the following transmission lines/cables:

Table 3 List of Monitored Transmission Lines / Cables for Overloading Conditions

No.	Transmission Line / Cable				Rating
1	[redacted]	ARAPAHOE 230.00	[redacted]	DAKOTA 230.00 1	483
2	[redacted]	ARAPAHOE 230.00	[redacted]	DENVER_TERM 230.00 1	576
3	[redacted]	BUCKLEY2 230.00	[redacted]	SMOKY_HILL 230.00 1	503
4	[redacted]	BUCKLEY2 230.00	[redacted]	TOLLGATE 230.00 1	484
5	[redacted]	BUCKLEY1 230.00	[redacted]	SMOKY_HILL 230.00 2	478
6	[redacted]	CABIN_CREEK 230.00	[redacted]	IDAHO_SPRING230.00 1	473
7	[redacted]	CABIN_CREEK 230.00	[redacted]	LOOKOUT 230.00 1	473
8	[redacted]	CHEROKEE 230.00	[redacted]	LACOMBE 230.00 1	435
9	[redacted]	DAKOTA 230.00	[redacted]	DENVER_TERM 230.00 1	473
10	[redacted]	DENVER_TERM 230.00	[redacted]	ELATI1 230.00 1	307
11	[redacted]	DENVER_TERM 230.00	[redacted]	LACOMBE 230.00 1	486
12	[redacted]	DENVER_TERM 230.00	[redacted]	WEST_PS 230.00 1	486
13	[redacted]	BARKER 230.00	[redacted]	LACOMBE 230.00 1	200
14	[redacted]	BARKER 230.00	[redacted]	LACOMBE 230.00 2	200
15	[redacted]	ELATI1 230.00	[redacted]	MONROEPS 230.00 1	398
16	[redacted]	IDAHO_SPRING230.00	[redacted]	LOOKOUT 230.00 1	473
17	[redacted]	JEWELL2 230.00	[redacted]	LEETSDALE 230.00 1	478
18	[redacted]	JEWELL2 230.00	[redacted]	TOLLGATE 230.00 1	484
19	[redacted]	LEETSDALE 230.00	[redacted]	SULLIVN2 230.00 1	503
20	[redacted]	LEETSDALE 230.00	[redacted]	LEETSDALE_T 230.00 PT	0
21	[redacted]	LOOKOUT 230.00	[redacted]	WEST_PS 230.00 1	405
22	[redacted]	MEADOWHL 230.00	[redacted]	SMOKY_HILL 230.00 1	564
23	[redacted]	MONROEPS 230.00	[redacted]	LEETSDALE_T 230.00 1	398
24	[redacted]	QUINCY 230.00	[redacted]	SMOKY_HILL 230.00 1	758
25	[redacted]	SMOKY_HILL 230.00	[redacted]	SPRUCE 230.00 1	740

No.	Transmission Line / Cable	Rating
26	[redacted] SMOKY_HILL 230.00 [redacted] POWHATON 230.00 1	740
27	[redacted] SMOKY_HILL 230.00 [redacted] MURPHY 230.00 1	733
28	[redacted] SMOKY_HILL 230.00 [redacted] HARVEST_MI 230.00 1	956
29	[redacted] SMOKY_HILL 230.00 [redacted] SMOKY_HILL 345.00 T4	560
30	[redacted] SMOKY_HILL 230.00 [redacted] SMOKY_HILL 345.00 T5	560
31	[redacted] ST.VRAIN 230.00 [redacted] SPNDLE 230.00 1	478
32	[redacted] ST.VRAIN 230.00 [redacted] FSV345 345.00 T1	560
33	[redacted] ST.VRAIN 230.00 [redacted] FSV345 345.00 T2	560
34	[redacted] SPRUCE 230.00 [redacted] POWHATON 230.00 1	717
35	[redacted] PAWNEE 345.00 [redacted] CANAL_XING 345.00 1	1637
36	[redacted] PAWNEE 345.00 [redacted] CANAL_XING 345.00 2	1637
37	[redacted] SMOKY_HILL 345.00 [redacted] MISS_SITE 345.00 1	1686
38	[redacted] MISS_SITE 345.00 [redacted] CANAL_XING 345.00 1	1637
39	[redacted] MISS_SITE 345.00 [redacted] CANAL_XING 345.00 2	1637
40	[redacted] CANAL_XING 345.00 [redacted] FSV345 345.00 1	1637
41	[redacted] CANAL_XING 345.00 [redacted] FSV345 345.00 2	1637
42	[redacted] CANAL_XING 345.00 [redacted] GOOSECRK 345.00 1	1637
43	[redacted] CANAL_XING 345.00 [redacted] GOOSECRK 345.00 2	1637

3.4 Results Summary

The results of all scenarios simulated are summarized in Table 4 through Table 8. The cable under consideration is highlighted if any overloading condition is observed i.e., the cable is listed in the results only if the loading is more than 100%. Five load flow scenarios (base case and four mitigation options) were considered in the study:

1. No Upgrade – Base case
2. The cable between Leetsdale and Elati is upgraded
3. A reactor is connected in series with Leetsdale – Elati cable
4. A phase shifting transformer is connected in series with Leetsdale – Elati cable
5. A BESS is introduced at the Leetsdale bus

Table 4 Branch Overload Conditions: No Upgrade

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
BASE CASE	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	604.16	503.00	120.11
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	604.39	484.00	124.87
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	493.35	484.00	101.93

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
SGL_230_071	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	640.38	503.00	127.31
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	640.62	484.00	132.36
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	354.23	307.00	115.38
	[redacted]	**ELATI1**	**230**	[redacted]	**MONROEPS**	**230**	**1**	**433.04**	**398.00**	**108.80**
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	529.20	484.00	109.34
	[redacted]	LEETSDALE	230	[redacted]	SULLIVN2	230	1	540.23	503.00	107.40
	[redacted]	**MONROEPS**	**230**	[redacted]	**LEETSDALE_T**	**230**	**1**	**503.62**	**398.00**	**126.54**
SGL_230_006	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	637.41	503.00	126.72
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	637.64	484.00	131.74
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	526.43	484.00	108.77
	[redacted]	**MONROEPS**	**230**	[redacted]	**LEETSDALE_T**	**230**	**1**	**439.30**	**398.00**	**110.38**
SGL_230_049	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	657.30	503.00	130.68
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	657.54	484.00	135.85
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	480.48	478.00	100.52
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	545.91	484.00	112.79
	[redacted]	**MONROEPS**	**230**	[redacted]	**LEETSDALE_T**	**230**	**1**	**436.29**	**398.00**	**109.62**
SGL_230_004	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	623.31	503.00	123.92
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	623.54	484.00	128.83
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	512.58	484.00	105.91
	[redacted]	**MONROEPS**	**230**	[redacted]	**LEETSDALE_T**	**230**	**1**	**412.43**	**398.00**	**103.62**
SGL_230_027	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	626.67	503.00	124.59
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	626.90	484.00	129.53
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	515.71	484.00	106.55
	[redacted]	**MONROEPS**	**230**	[redacted]	**LEETSDALE_T**	**230**	**1**	**398.09**	**398.00**	**100.02**
SGL_230_010	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	634.90	503.00	126.22
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	635.14	484.00	131.23
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	524.20	484.00	108.31
	[redacted]	MEADOWHL	230	[redacted]	SMOKY_HILL	230	1	566.15	564.00	100.38
SGL_115_036	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	599.52	503.00	119.19
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	599.76	484.00	123.92
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	488.59	484.00	100.95
SGL_230_043	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	617.65	503.00	122.79
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	617.88	484.00	127.66
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	506.71	484.00	104.69
SGL_115_041	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	594.59	503.00	118.21
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	594.84	484.00	122.90

Table 5 Branch Overload Conditions: Leetsdale - Elati Cable Upgrade

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
BASE CASE	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	619.51	503.00	123.16
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	619.74	484.00	128.05
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	508.54	484.00	105.07
SGL_230_071	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	659.84	503.00	131.18
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	660.08	484.00	136.38
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	431.85	307.00	140.67
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	482.99	478.00	101.04
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	548.44	484.00	113.31
	[redacted]	LEETSDALE	230	[redacted]	SULLIVN2	230	1	568.78	503.00	113.08
SGL_230_006	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	655.47	503.00	130.31
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	655.71	484.00	135.48
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	370.42	307.00	120.66
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	479.07	478.00	100.22
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	544.33	484.00	112.46
SGL_230_049	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	675.75	503.00	134.34
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	675.99	484.00	139.67
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	367.37	307.00	119.66
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	498.61	478.00	104.31
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	564.17	484.00	116.56
SGL_230_004	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	640.52	503.00	127.34
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	640.75	484.00	132.39
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	344.16	307.00	112.10
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	529.66	484.00	109.43
SGL_230_027	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	643.60	503.00	127.95
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	643.83	484.00	133.02
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	328.25	307.00	106.92
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	532.47	484.00	110.01
SGL_230_010	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	651.14	503.00	129.45
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	651.37	484.00	134.58
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	313.67	307.00	102.17
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	540.27	484.00	111.63
	[redacted]	MEADOWHL	230	[redacted]	SMOKY_HILL	230	1	567.37	564.00	100.60
SGL_230_041	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	310.15	307.00	101.03
SGL_115_036	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	616.54	503.00	122.57
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	616.79	484.00	127.44
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	505.35	484.00	104.41

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
SGL_230_043	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	633.84	503.00	126.01
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	634.08	484.00	131.01
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	308.32	307.00	100.43
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	522.74	484.00	108.00
SGL_115_041	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	605.60	503.00	120.40
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	605.82	484.00	125.17
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	311.66	307.00	101.52
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	495.23	484.00	102.32

Table 6 Branch Overload Conditions: Series Reactor Addition

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
BASE CASE	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	593.16	503.00	117.92
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	593.41	484.00	122.61
SGL_230_071	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	625.68	503.00	124.39
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	625.94	484.00	129.33
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	514.12	484.00	106.22
	[redacted]	LEETSDALE	230	[redacted]	SULLIVN2	230	1	517.93	503.00	102.97
	[redacted]	**MONROEPS**	**230**	[redacted]	**LEETSDALE_T**	**230**	**1**	**434.57**	**398.00**	**109.19**
SGL_230_006	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	624.17	503.00	124.09
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	624.42	484.00	129.01
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	512.81	484.00	105.95
SGL_230_049	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	643.90	503.00	128.01
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	644.15	484.00	133.09
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	532.15	484.00	109.95
SGL_230_004	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	610.79	503.00	121.43
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	611.03	484.00	126.25
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	499.66	484.00	103.24
SGL_230_027	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	614.47	503.00	122.16
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	614.72	484.00	127.01
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	503.13	484.00	103.95
SGL_230_010	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	623.25	503.00	123.91
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	623.50	484.00	128.82
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	512.18	484.00	105.82
	[redacted]	MEADOWHL	230	[redacted]	SMOKY_HILL	230	1	566.27	564.00	100.40
SGL_115_036	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	586.77	503.00	116.65
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	587.02	484.00	121.29

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
SGL_230_043	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	606.00	503.00	120.48
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	606.26	484.00	125.26
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	494.70	484.00	102.21
SGL_115_041	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	583.01	503.00	115.91
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	583.28	484.00	120.51

Table 7 Branch Overload Conditions: Phase Shifting Transformer Addition

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
BASE CASE	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	434.44	307.00	141.51
SGL_230_071	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	489.24	484.00	101.08
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	343.80	307.00	111.99
SGL_230_006	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	494.22	484.00	102.11
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	396.05	307.00	129.01
SGL_230_049	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	513.76	503.00	102.14
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	514.15	484.00	106.23
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	400.27	307.00	130.38
SGL_230_004	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	411.44	307.00	134.02
SGL_230_027	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	486.75	484.00	100.57
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	418.38	307.00	136.28
SGL_230_010	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	497.06	484.00	102.70
	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	425.46	307.00	138.59
	[redacted]	MEADOWHL	230	[redacted]	SMOKY_HILL	230	1	567.96	564.00	100.70
SGL_230_041	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	414.58	307.00	135.04
SGL_115_036	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	417.12	307.00	135.87
SGL_230_043	[redacted]	DENVER_TERM	230	[redacted]	ELATI1	230	1	426.16	307.00	138.81

Table 8 Branch Overload Conditions: BESS Addition

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
BASE CASE	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	640.14	503.00	127.26
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	640.34	484.00	132.30
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	530.19	484.00	109.54

Contingency	Branch							Flow (A)	Rate (A)	Flow (%)
SGL_230_071	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	677.56	503.00	134.70
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	677.76	484.00	140.03
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	502.50	478.00	105.13
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	567.15	484.00	117.18
	[redacted]	LEETSDALE	230	[redacted]	SULLIVN2	230	1	589.94	503.00	117.28
	[redacted]	**MONROEPS**	**230**	[redacted]	**LEETSDALE_T**	**230**	**1**	**421.50**	**398.00**	**105.91**
SGL_230_006	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	674.84	503.00	134.16
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	675.04	484.00	139.47
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	500.26	478.00	104.66
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	564.70	484.00	116.67
	[redacted]	LEETSDALE	230	[redacted]	SULLIVN2	230	1	510.46	503.00	101.48
SGL_230_049	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	694.81	503.00	138.13
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	695.01	484.00	143.60
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	519.37	478.00	108.66
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	584.17	484.00	120.70
	[redacted]	MEADOWHL	230	[redacted]	SMOKY_HILL	230	1	576.27	564.00	102.17
SGL_230_004	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	659.83	503.00	131.18
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	660.03	484.00	136.37
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	485.71	478.00	101.61
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	549.96	484.00	113.63
SGL_230_027	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	664.00	503.00	132.01
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	664.19	484.00	137.23
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	489.43	478.00	102.39
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	553.86	484.00	114.43
SGL_230_010	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	671.06	503.00	133.41
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	671.26	484.00	138.69
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	496.87	478.00	103.95
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	561.17	484.00	115.94
	[redacted]	MEADOWHL	230	[redacted]	SMOKY_HILL	230	1	581.47	564.00	103.10
SGL_115_036	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	636.08	503.00	126.46
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	636.28	484.00	131.46
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	525.99	484.00	108.67
SGL_230_043	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	654.45	503.00	130.11
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	654.65	484.00	135.26
	[redacted]	JEWELL2	230	[redacted]	LEETSDALE	230	1	479.91	478.00	100.40
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	544.33	484.00	112.46
SGL_115_041	[redacted]	BUCKLEY2	230	[redacted]	SMOKY_HILL	230	1	630.55	503.00	125.36
	[redacted]	BUCKLEY2	230	[redacted]	TOLLGATE	230	1	630.76	484.00	130.32
	[redacted]	JEWELL2	230	[redacted]	TOLLGATE	230	1	520.19	484.00	107.48

3.5 Summary

Overall results show that the cable upgrade option and the phase shifting transformer option mitigated all overload conditions of the original Leetsdale-Elati cable for all selected contingencies. There would be overloads in other circuits with the addition of a phase shifting transformer.

A summary of each scenario is shown in Table 9 below.

Table 9 Summary

Option	Study Result	Budgetary Cost	Comments
Upgrade Cable	Relieves the cable overload in all contingencies.	$200M	replacing the cable seems the most reasonable option
Series Reactor	Relieves most cable overloads. Still one contingency that results in a cable overload.	$10M	Not feasible since there would still be a cable overload. Significant permitting, design, and construction challenges.
Phase Shifting Transformer	Relieves overloads on the cable circuit but not on adjacent circuits.	$33M	More than a five-year lead time to obtain a phase shifting transformer. Significant permitting, design, and construction challenges.
BESS	Relieves overload cases, but only for the duration the BESS is operating	N/A	Not feasible due to lack of space.

Replacing the cable seems the most reasonable option based on the options studied.

4 References

[1] Greenwood to Denver Terminal 230 Kv Transmission Project System Impact Study Report for the Colorado Energy Plan Portfolio.