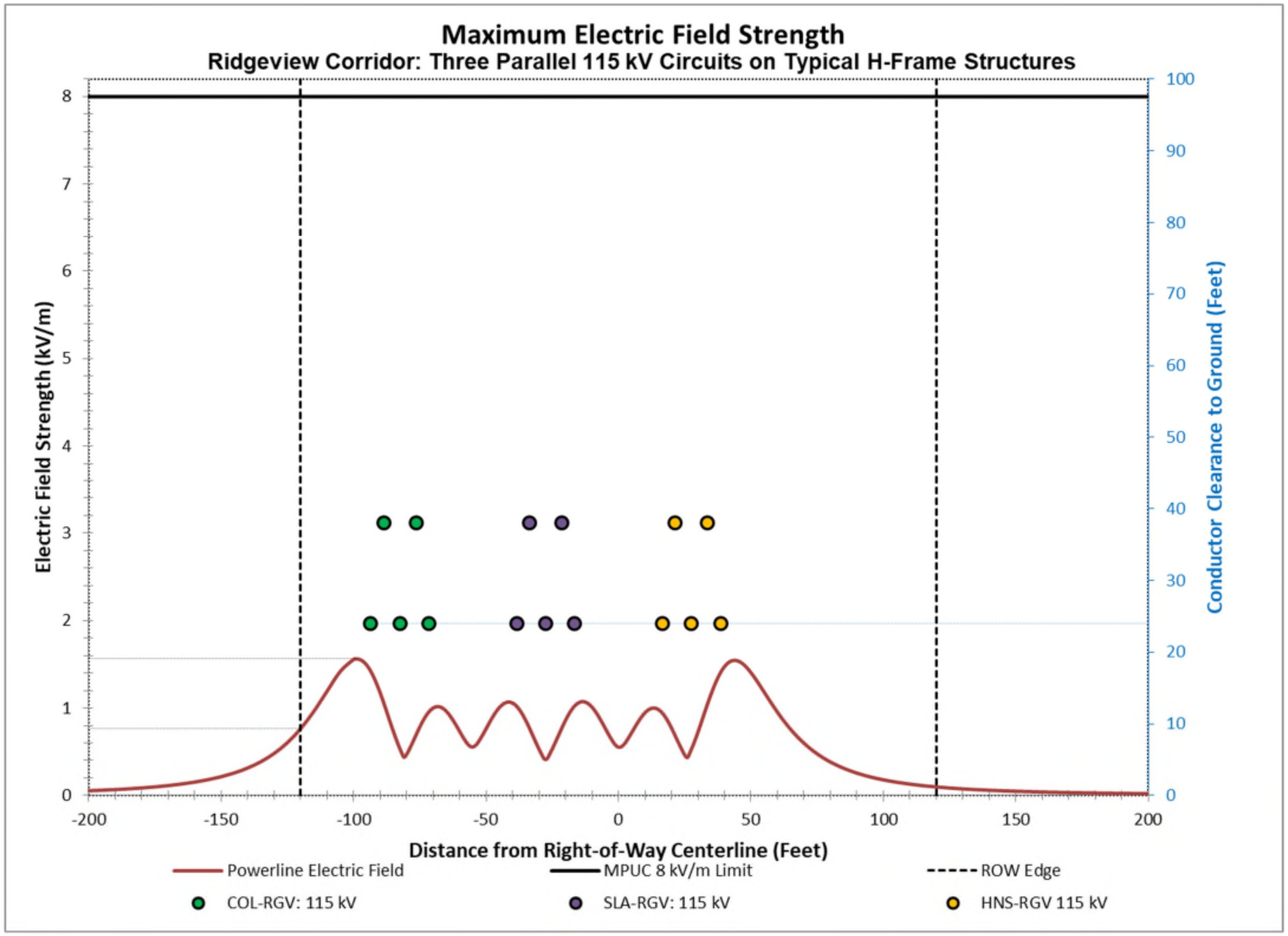
APPENDIX H

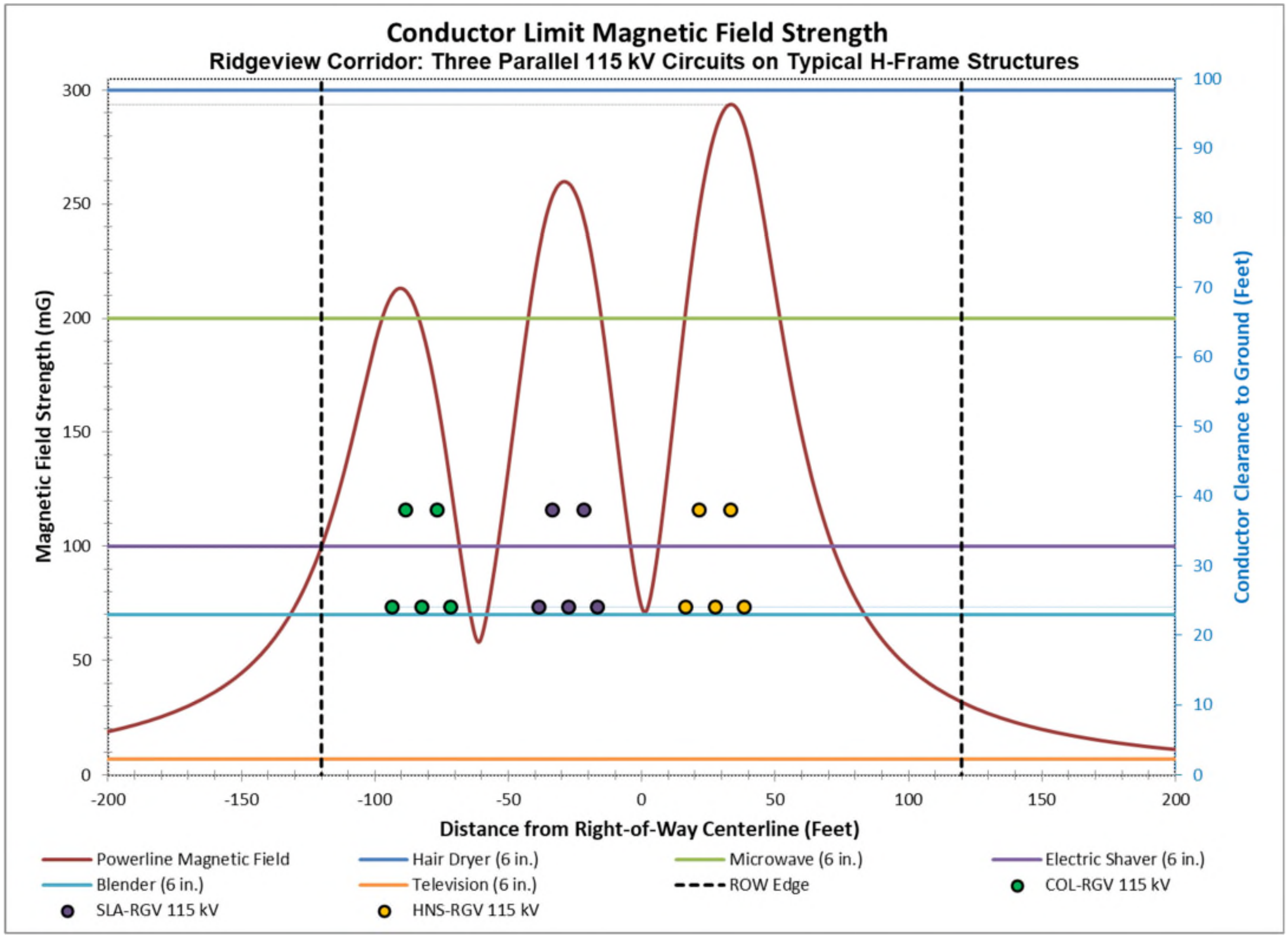
ELECTRIC AND MAGNETIC FIELDS CALCULATIONS AND NOISE CALCULATIONS

Figure 1A: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV H-Frame



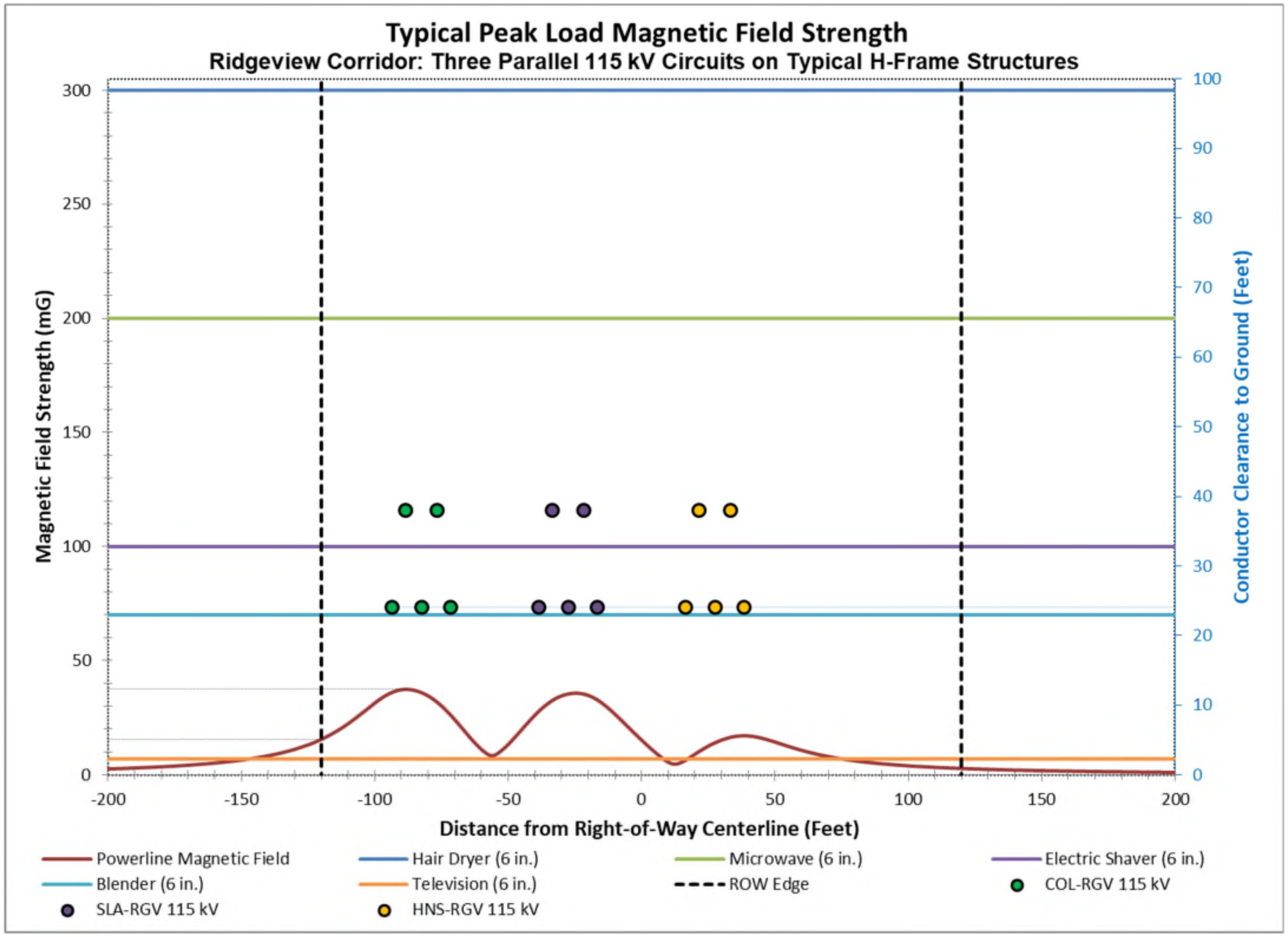
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	-99.0	-120.0	120.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	1.56	0.76	0.10	0.01	0.05	0.21	1.56	0.78	0.76	0.53	0.55	0.46	1.41	0.48	0.18	0.05	0.02	0.01

Figure 1B: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV H-Frame



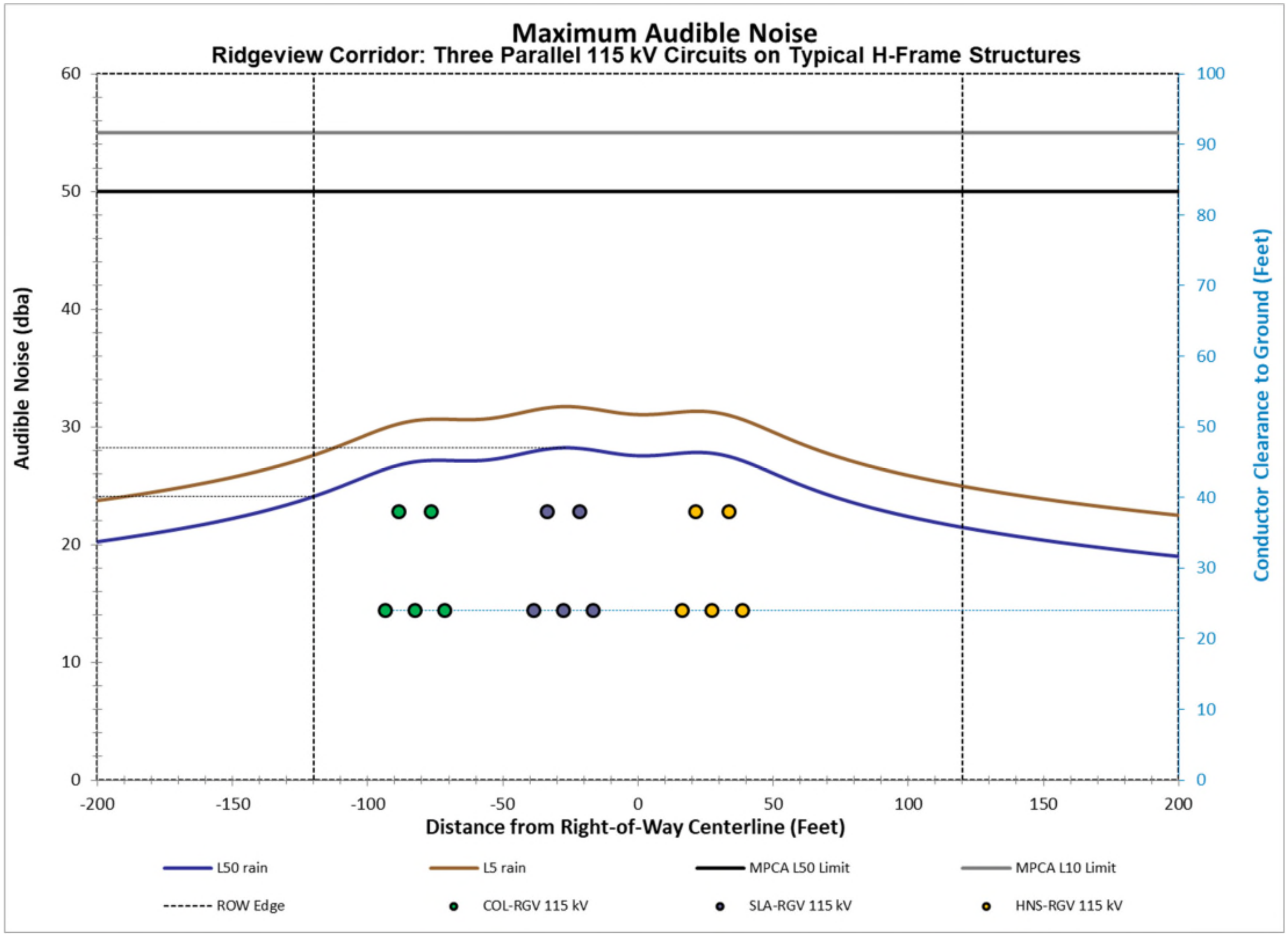
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	33.0	-120.0	120.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	293.70	99.93	31.65	6.91	18.92	44.45	188.89	152.91	134.00	255.02	73.22	270.09	212.71	89.64	46.90	19.88	11.13	5.01

Figure 1C: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV H-Frame



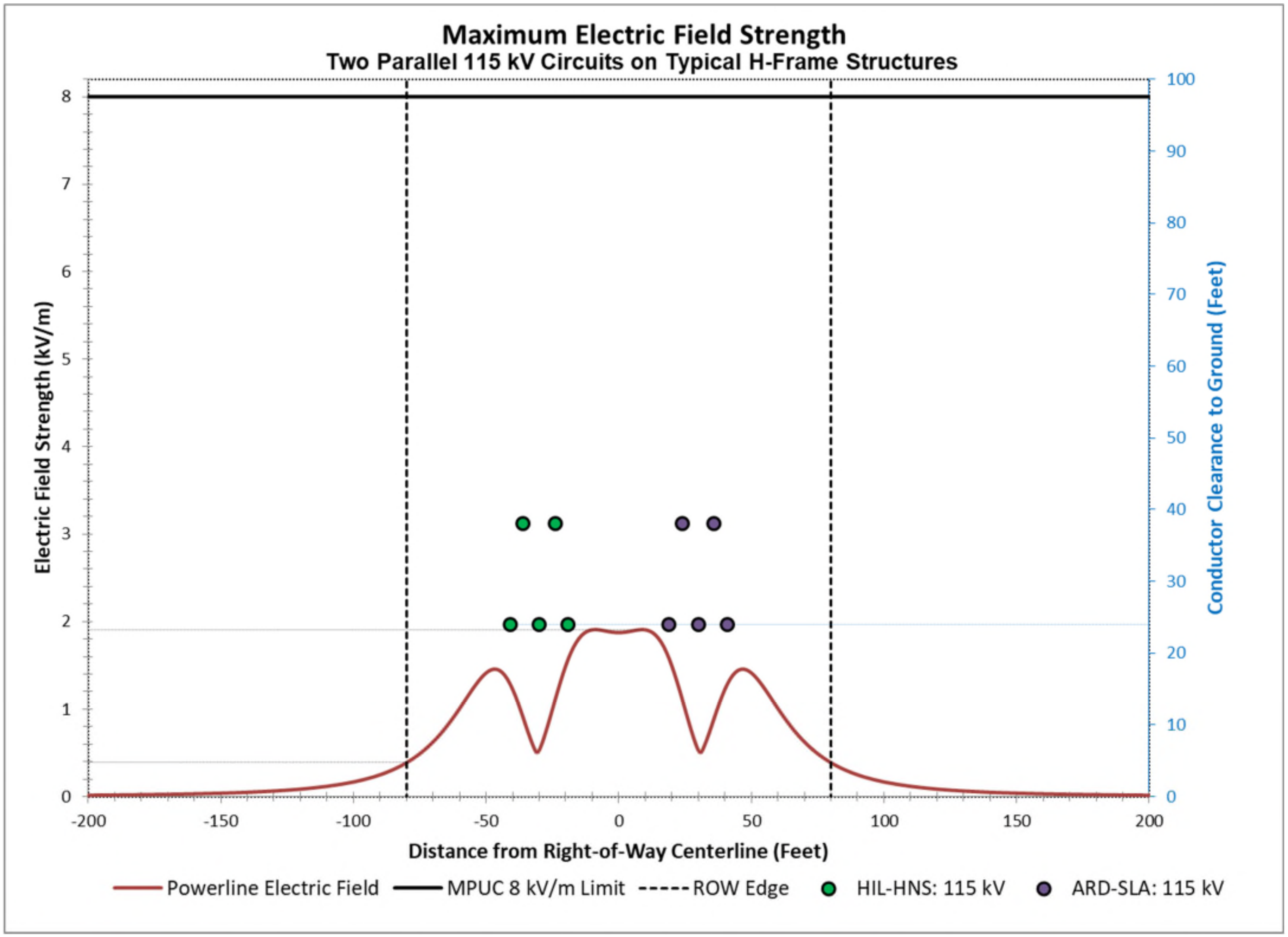
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	-88.0	-120.0	120.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	37.32	15.54	2.81	0.89	2.60	6.49	31.39	30.12	13.34	35.63	15.21	12.56	14.35	6.99	3.98	1.85	1.09	0.52

Figure 1D: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV H-Frame



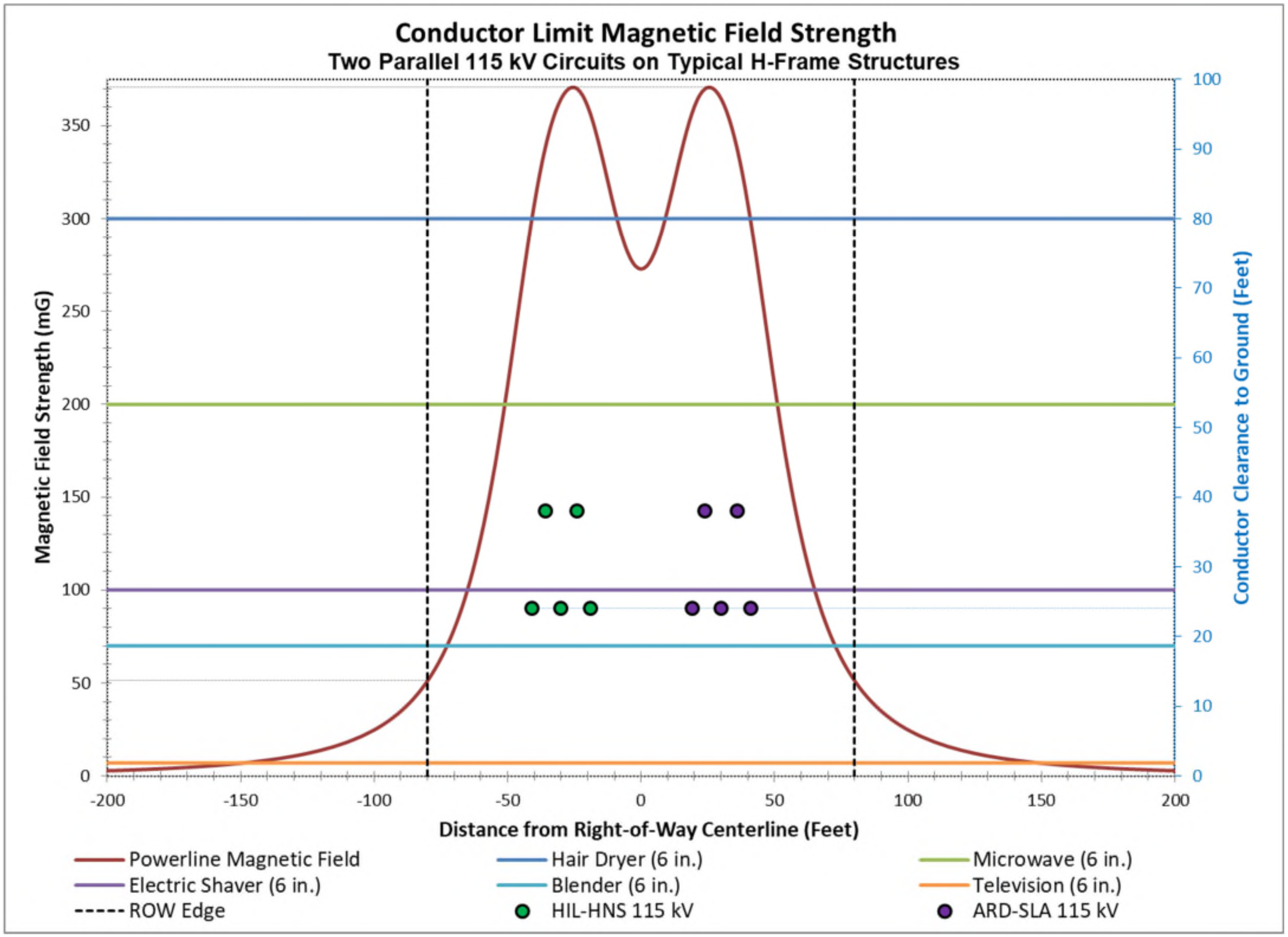
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	-27.0	-120.0	120.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	28.22	24.09	21.47	17.84	20.25	22.22	25.85	27.16	27.38	28.22	27.55	27.81	26.06	23.88	22.38	20.37	18.99	17.06

Figure 2A: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame



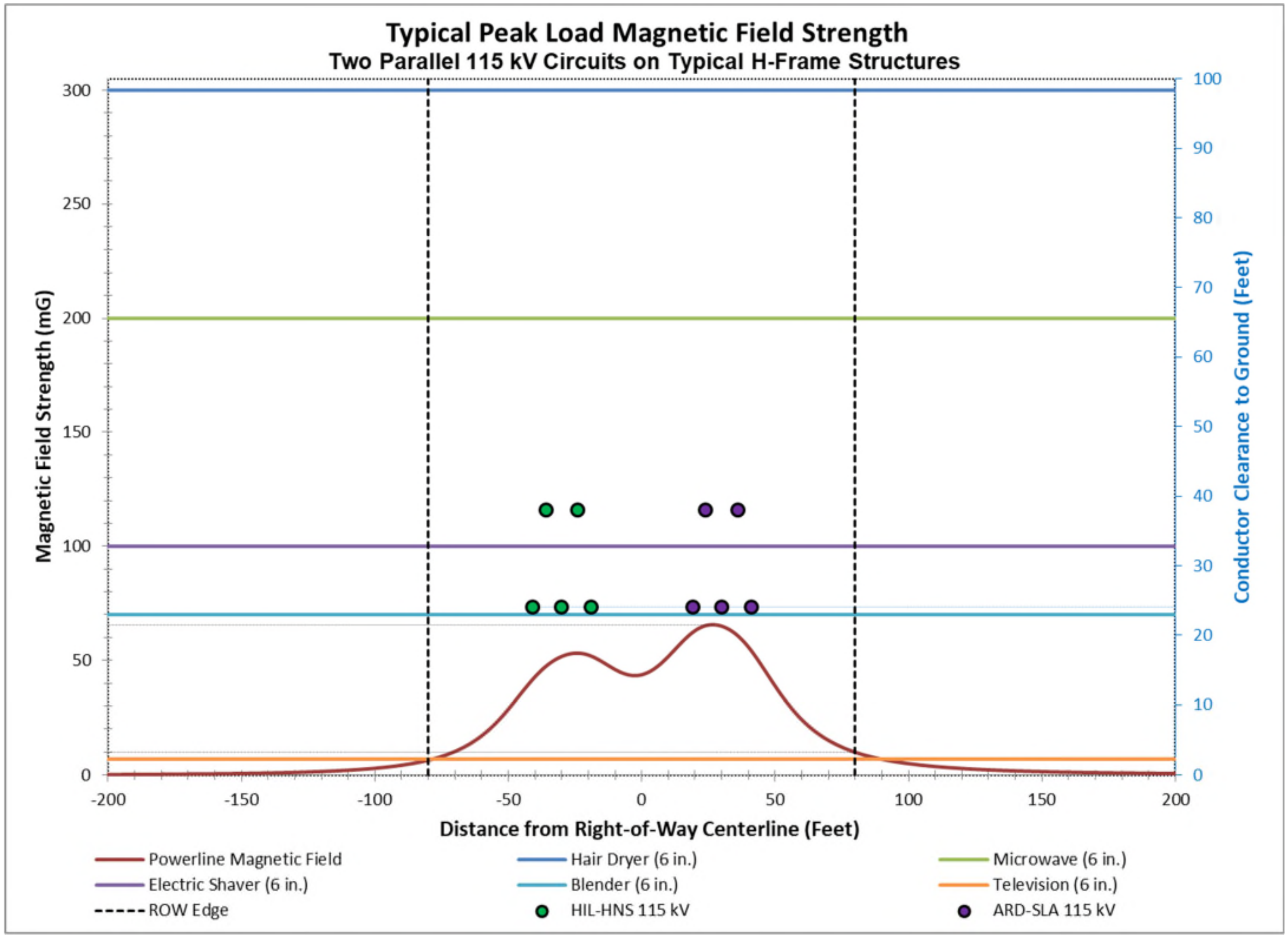
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	9.0	-80.0	80.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	1.91	0.39	0.39	0.01	0.02	0.04	0.17	0.49	1.41	1.00	1.87	1.00	1.41	0.49	0.17	0.04	0.02	0.01

Figure 2B: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame



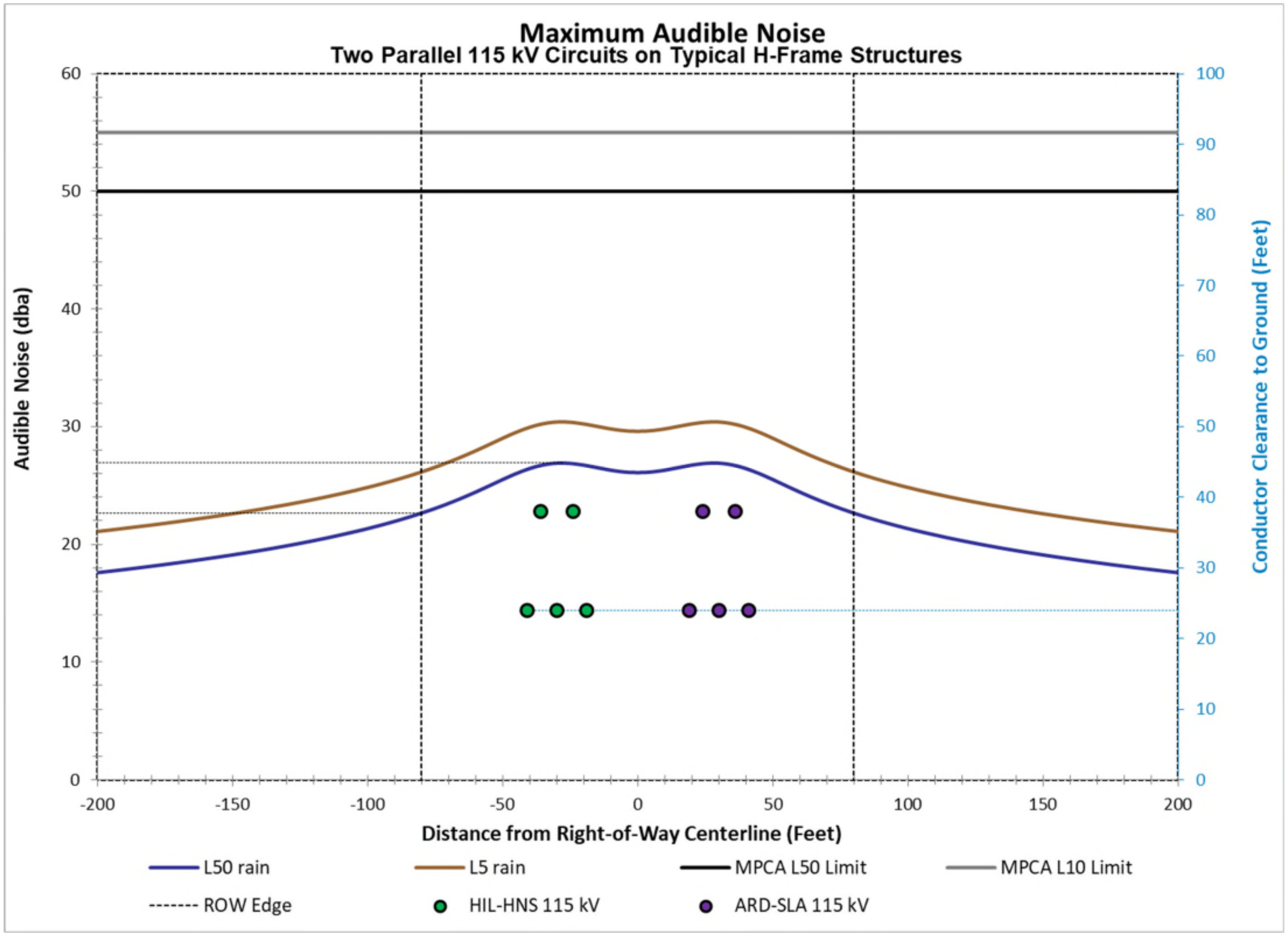
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	26.0	-80.0	80.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	370.60	51.25	51.25	0.82	2.82	6.86	24.80	63.27	210.28	370.58	272.78	370.58	210.28	63.27	24.80	6.86	2.82	0.82

Figure 2C: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame



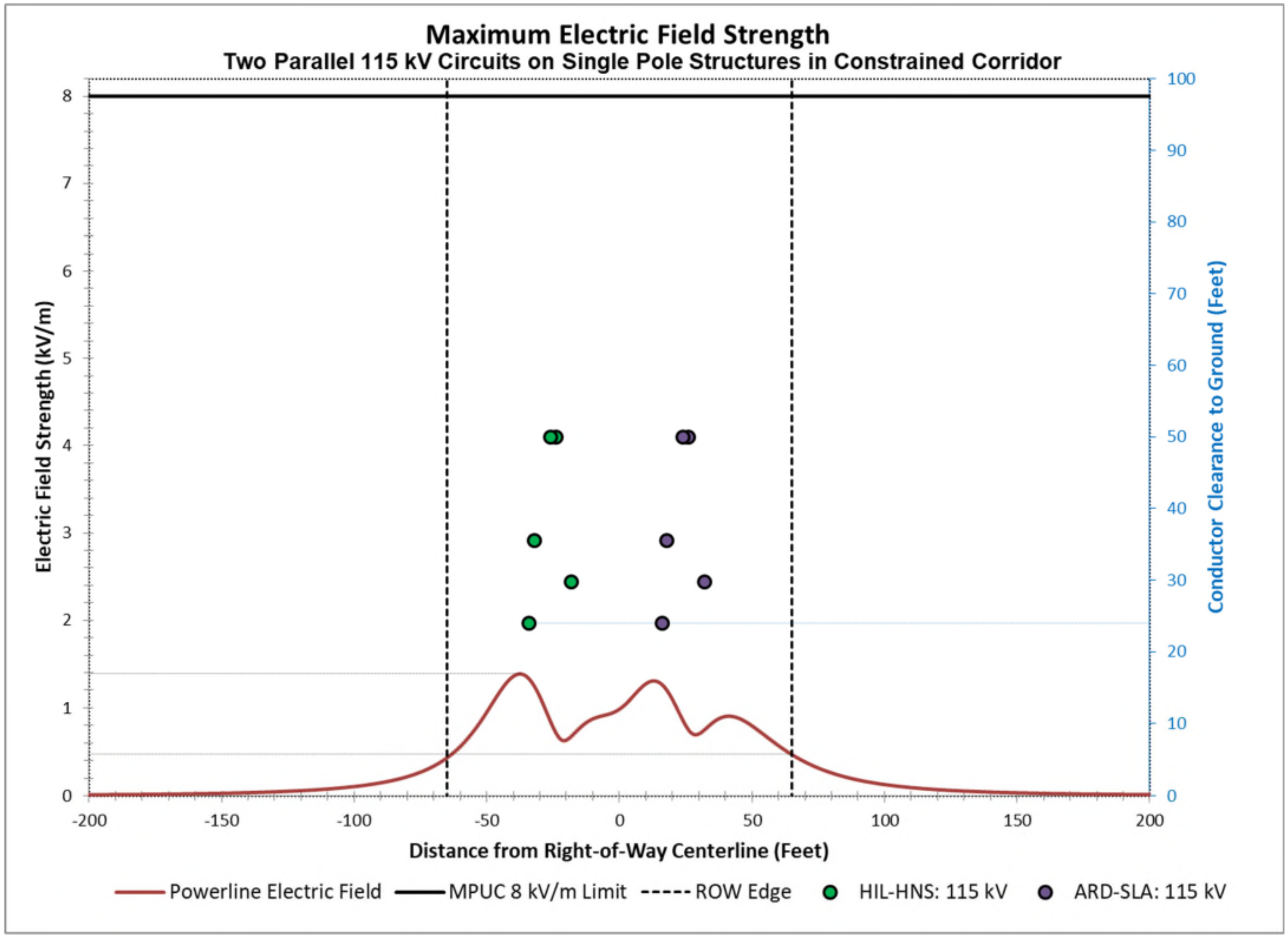
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	27.0	-80.0	80.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	65.62	6.49	9.94	0.04	0.24	0.70	2.97	8.11	28.63	53.14	43.69	65.49	38.72	12.16	4.98	1.50	0.67	0.23

Figure 2D: Corridor Configuration – Project 115 kV H-Frame, Existing 115 kV H-Frame



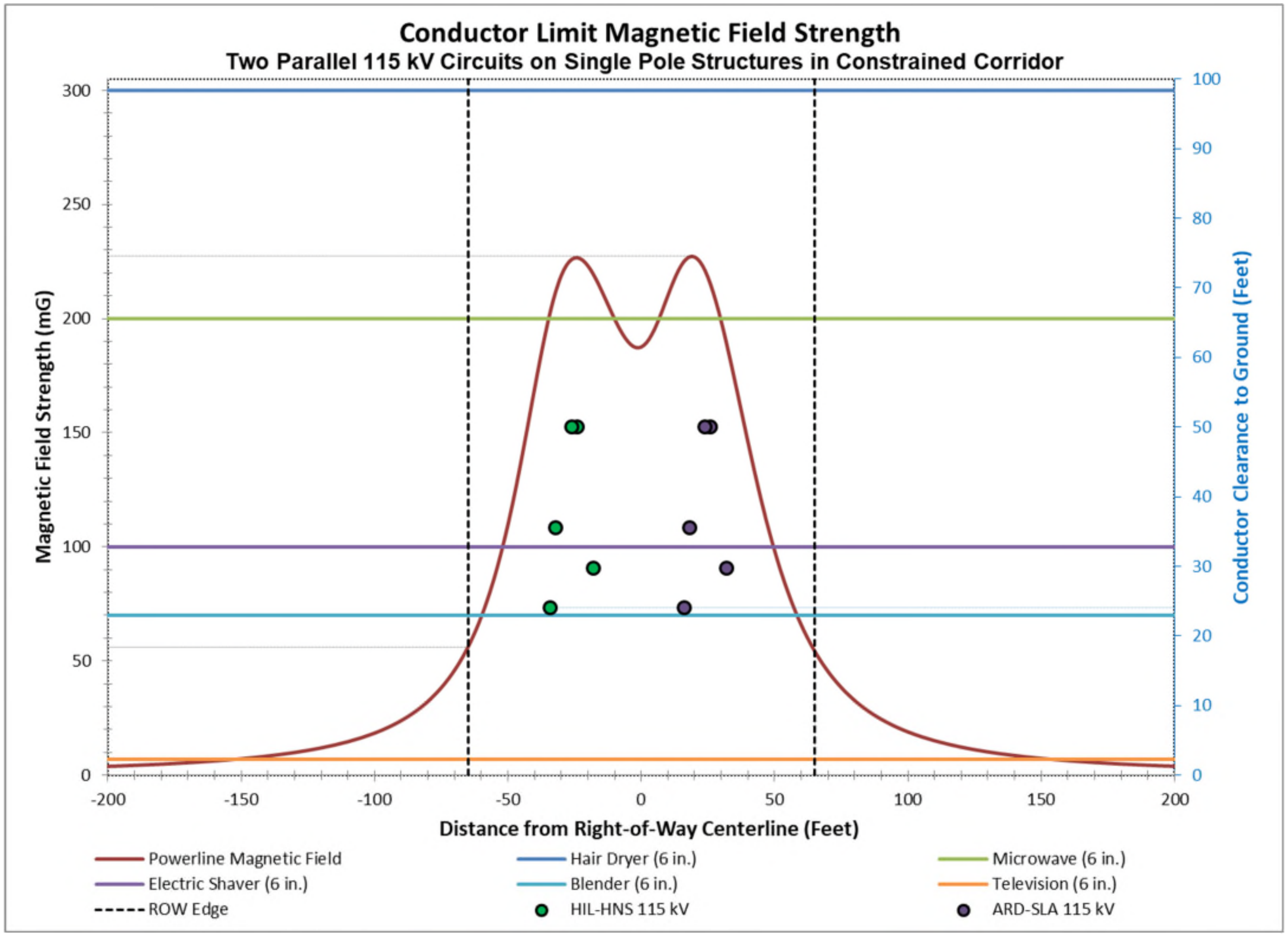
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	-28.0	-80.0	80.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	26.90	22.66	22.66	15.53	17.60	19.10	21.34	23.05	25.51	26.87	26.10	26.87	25.51	23.05	21.34	19.10	17.60	15.53

Figure 3A: Corridor Configuration – Project 115 kV Monopole, Existing 115 kV Monopole



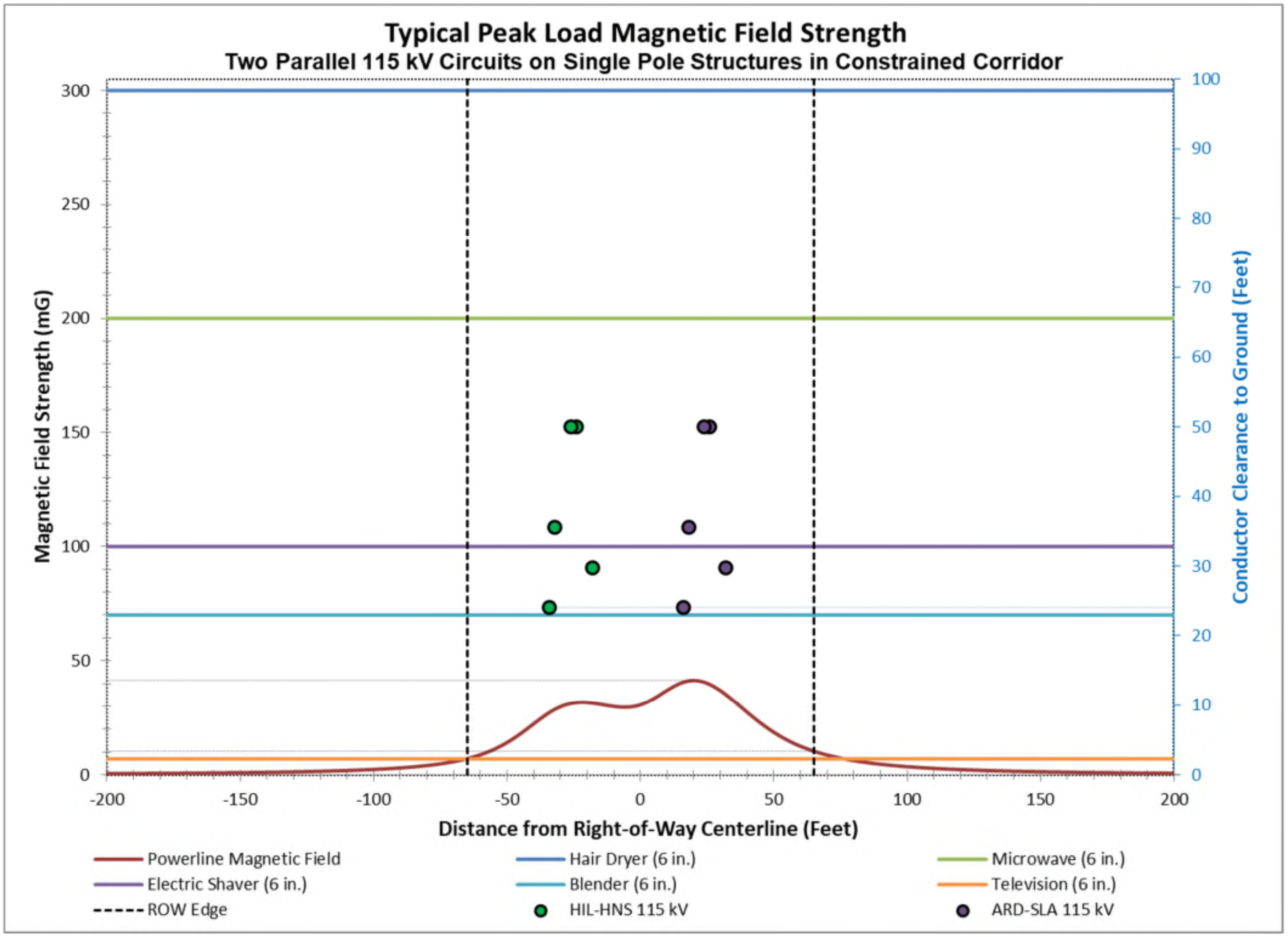
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	-37.0	-65.0	65.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	1.38	0.43	0.47	0.00	0.01	0.03	0.11	0.27	0.95	0.78	0.98	0.80	0.80	0.32	0.13	0.03	0.01	0.00

Figure 3B: Corridor Configuration – Project 115 kV Monopole, Existing 115 kV Monopole



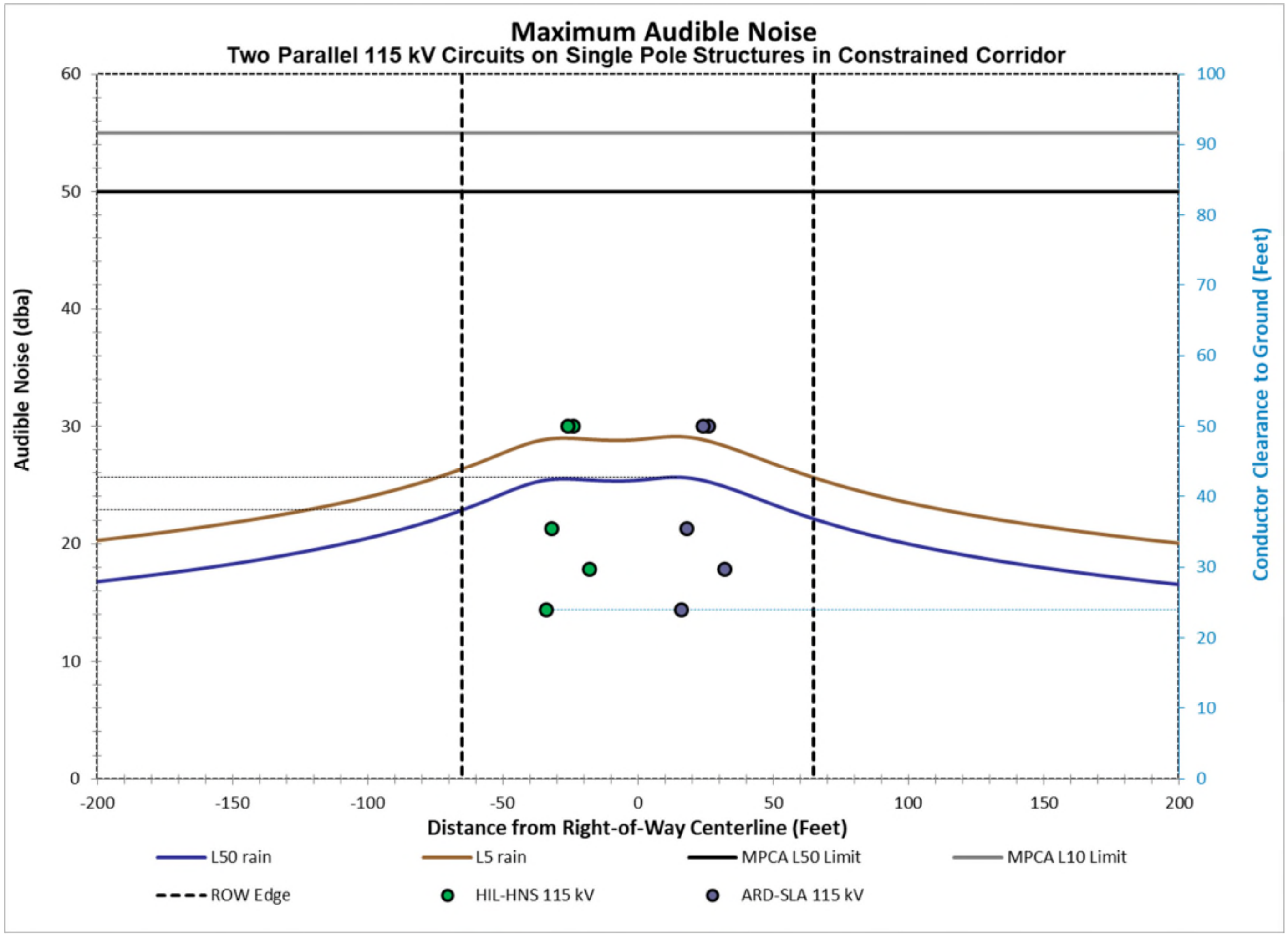
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	19.0	-65.0	65.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	227.31	56.07	54.39	1.65	3.86	7.22	18.46	38.31	109.77	226.62	187.59	218.13	98.30	38.38	18.98	7.37	3.91	1.66

Figure 3C: Corridor Configuration – Project 115 kV Monopole, Existing 115 kV Monopole



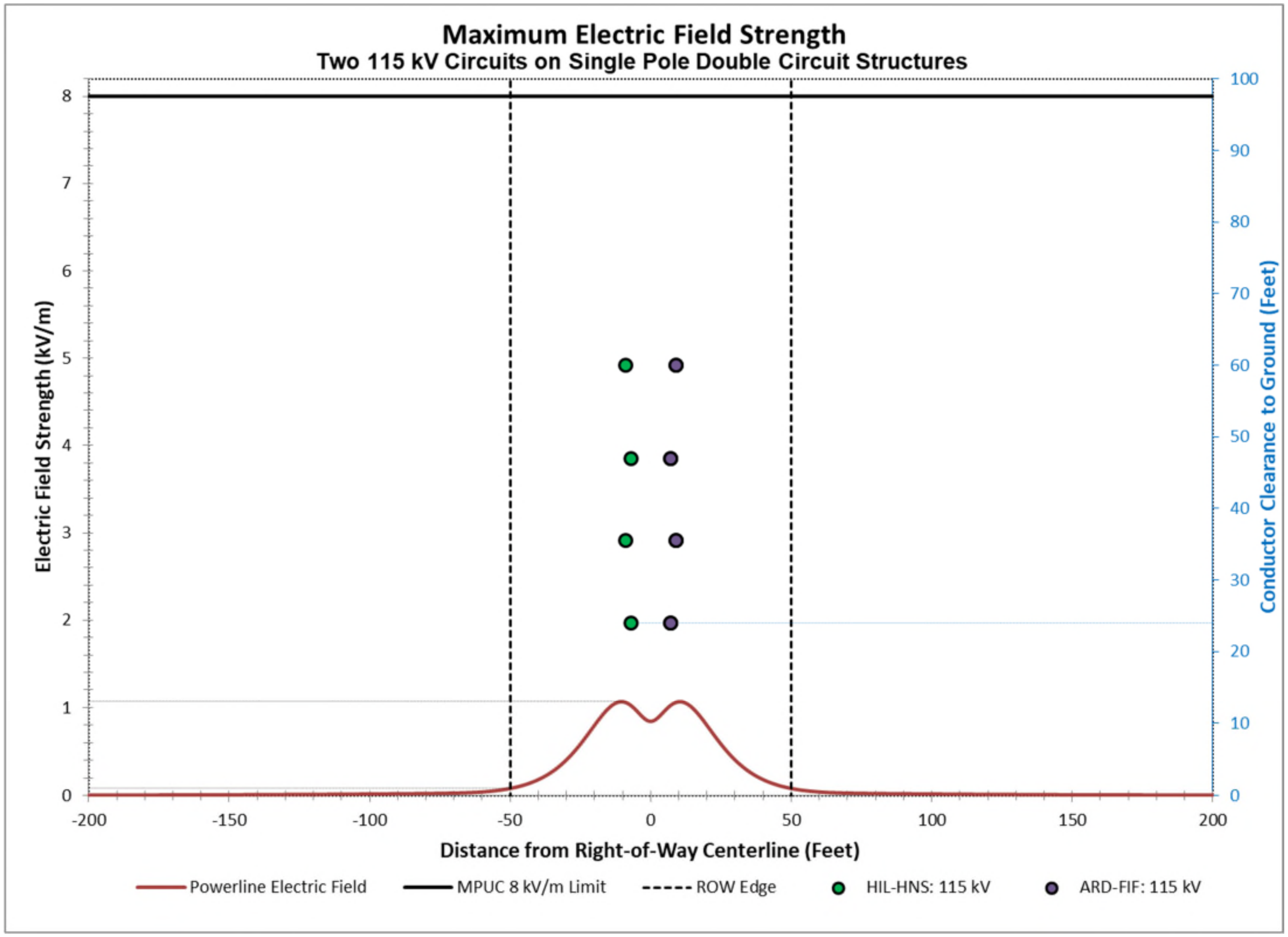
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	20.0	-65.0	65.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	41.37	7.11	10.38	0.25	0.55	1.00	2.40	4.86	14.16	31.46	30.68	40.15	18.63	7.33	3.61	1.38	0.72	0.30

Figure 3D: Corridor Configuration – Project 115 kV Monopole, Existing 115 kV Monopole



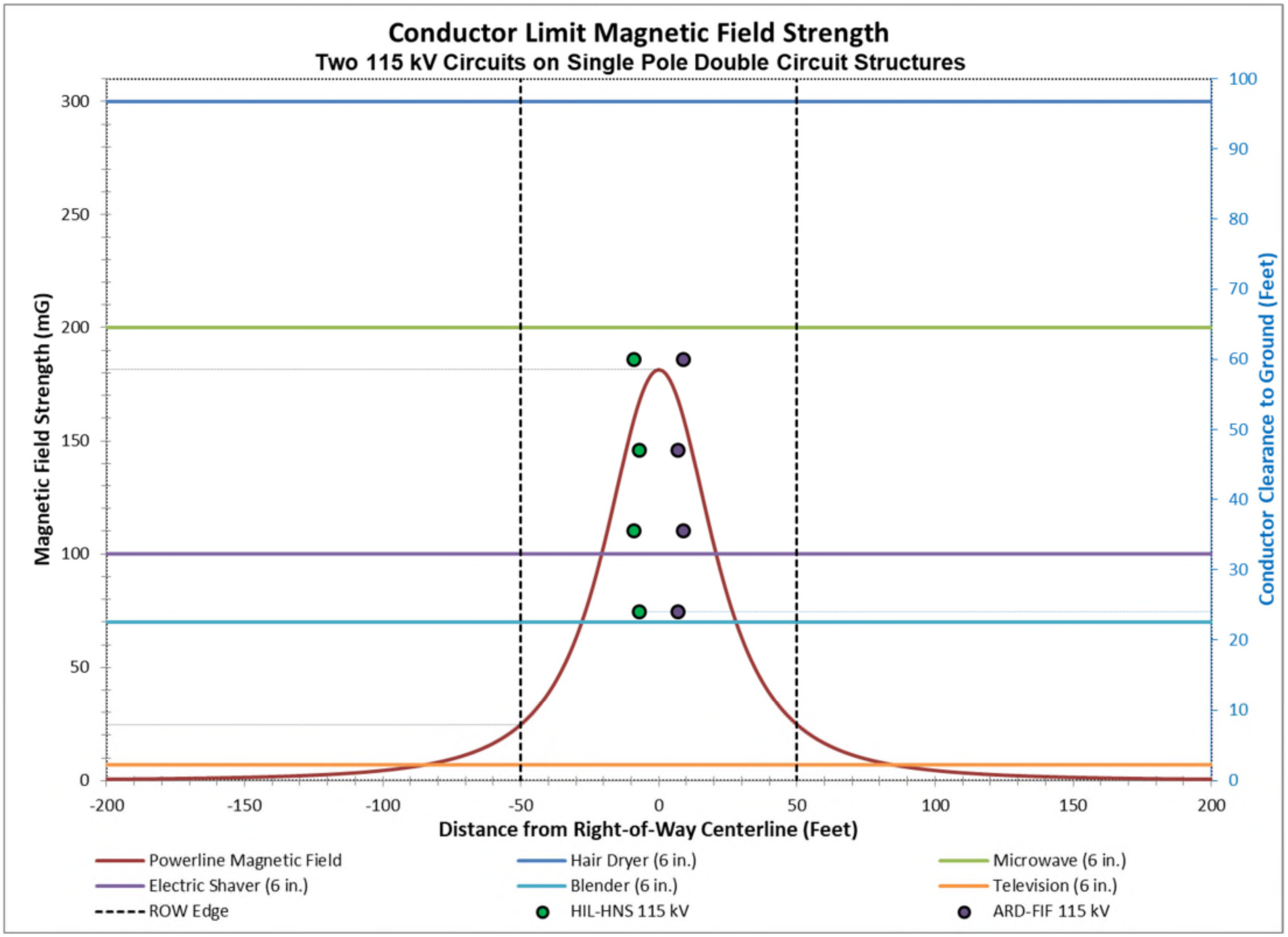
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	14.0	-65.0	65.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	25.64	22.86	22.11	14.70	16.78	18.28	20.46	22.06	24.23	25.49	25.38	25.31	23.33	21.41	19.97	17.96	16.54	14.54

Figure 4A: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole



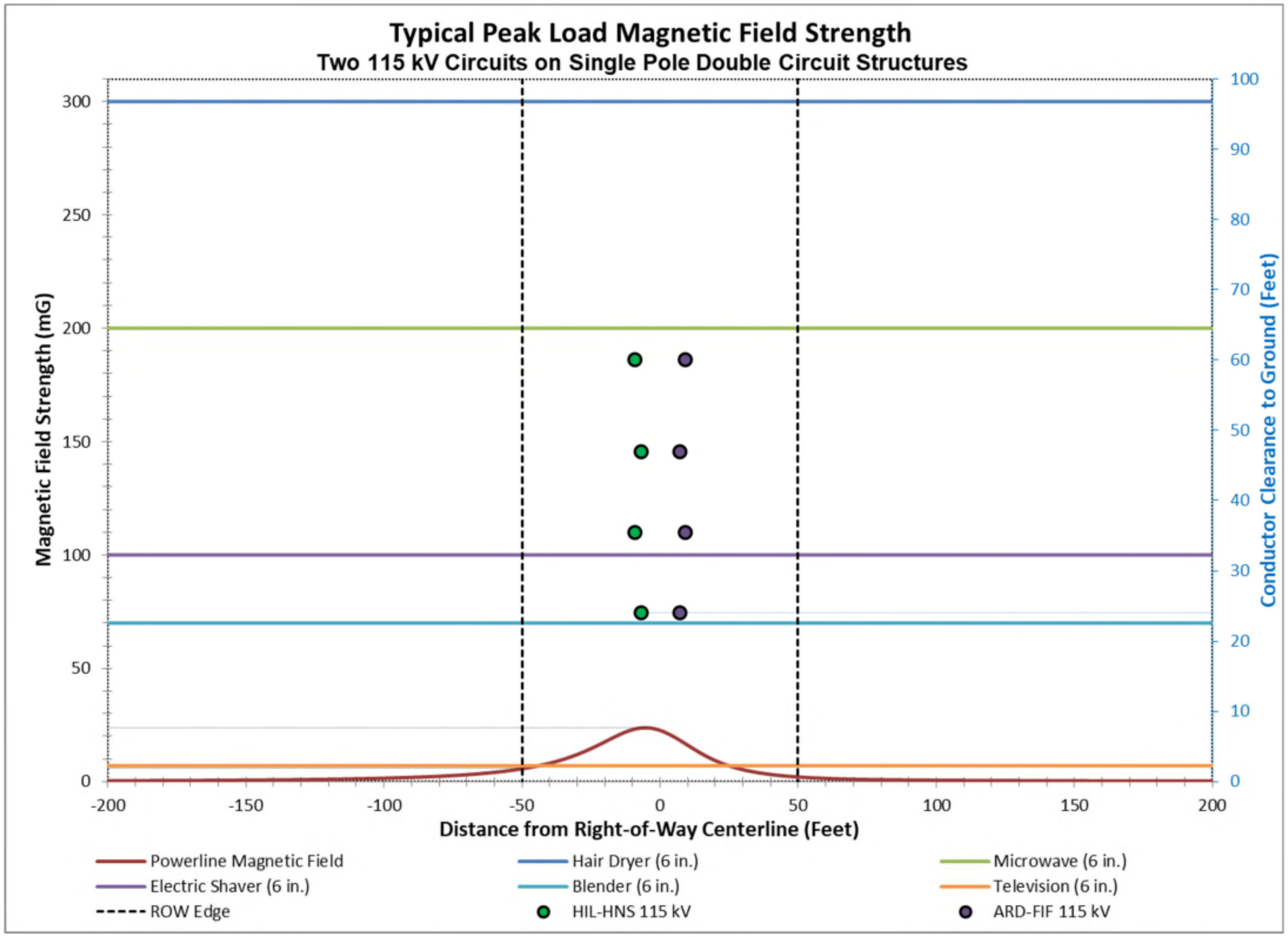
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	-10.0	-50.0	50.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	1.07	0.08	0.08	0.00	0.00	0.01	0.02	0.02	0.08	0.58	0.84	0.58	0.08	0.02	0.02	0.01	0.00	0.00

Figure 4B: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole



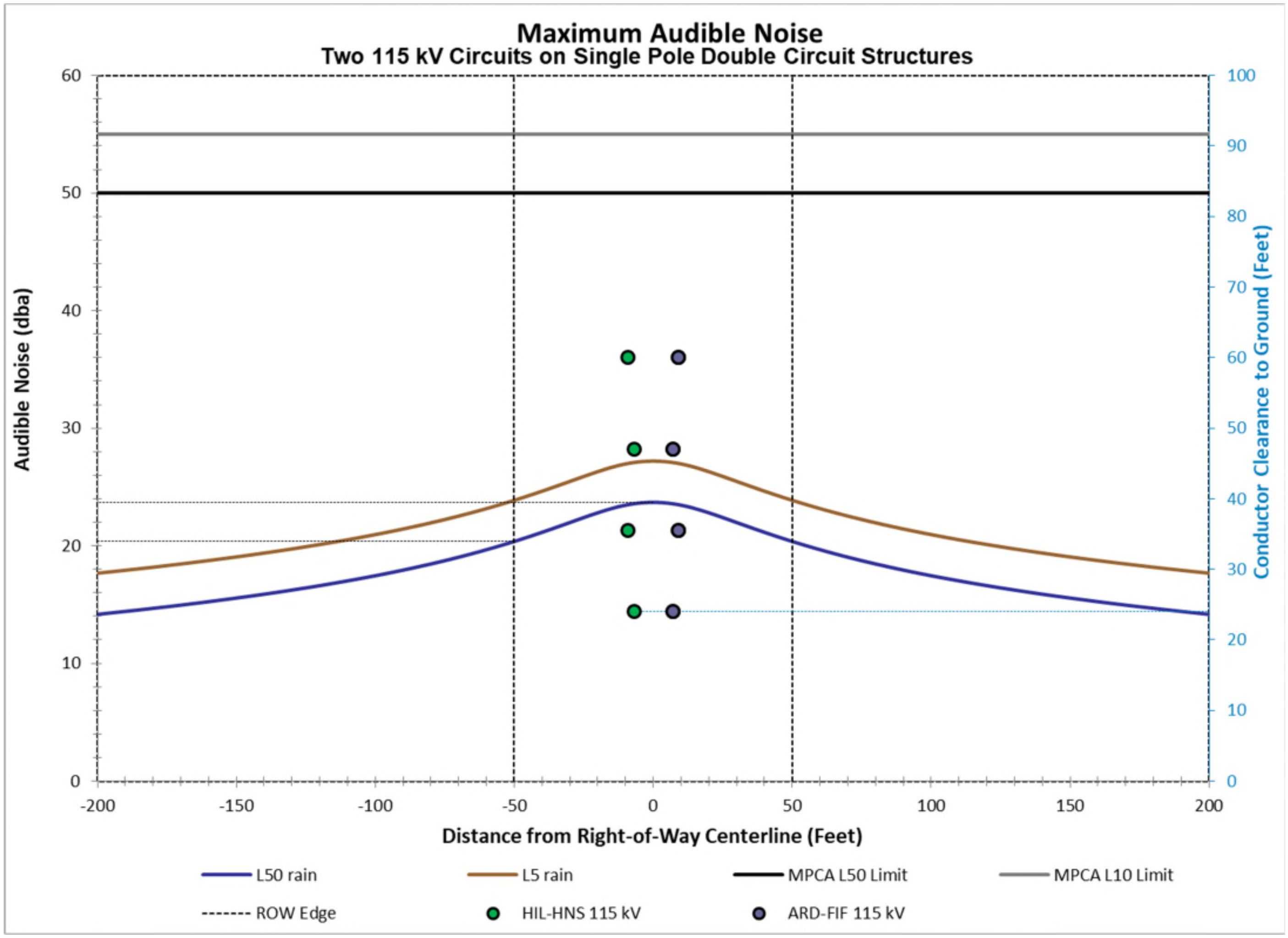
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	0.0	-50.0	50.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	181.40	24.67	24.67	0.19	0.63	1.45	4.50	9.54	24.67	80.99	181.40	80.99	24.67	9.54	4.50	1.45	0.63	0.19

Figure 4C: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole



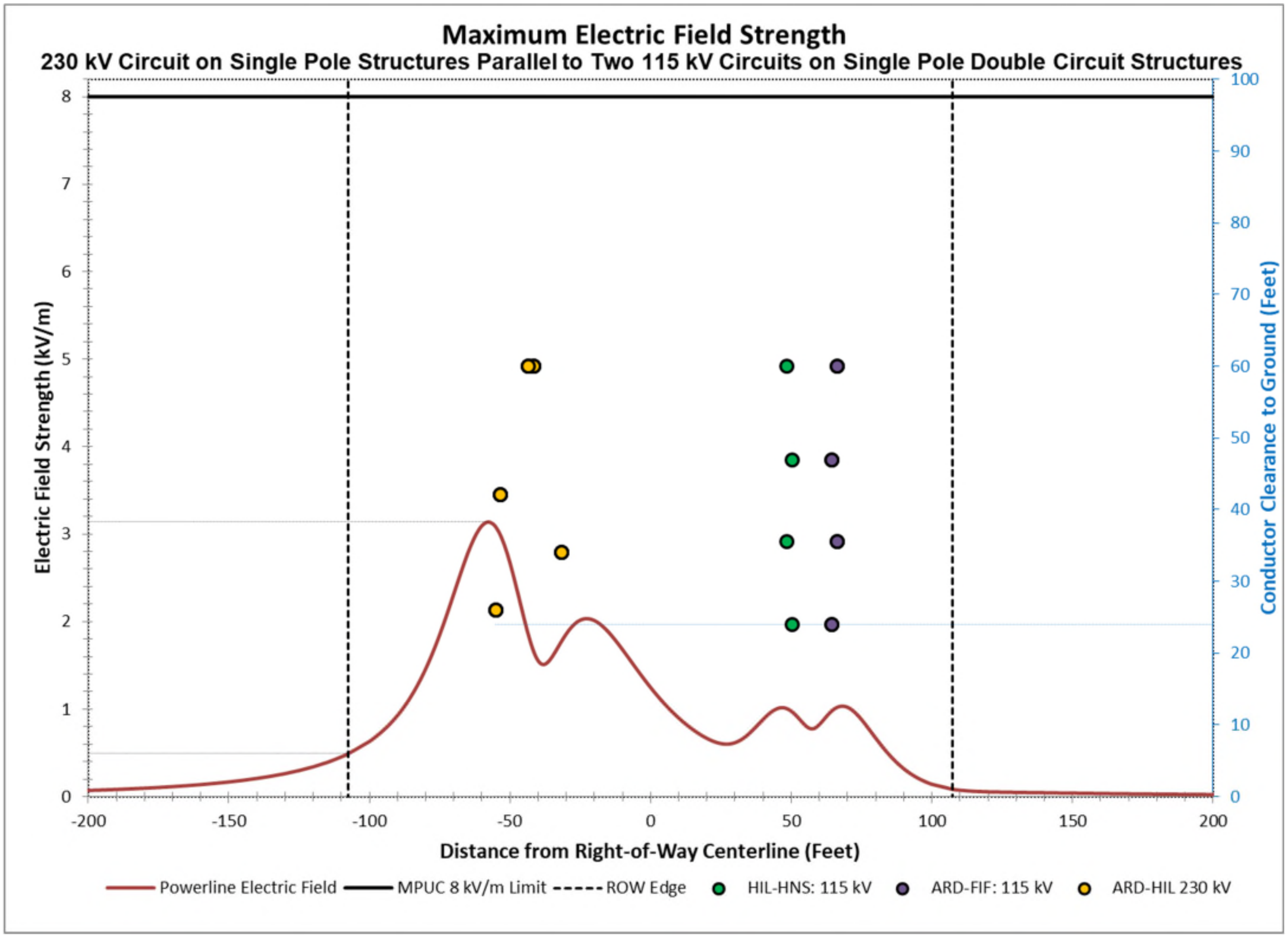
RESULTS	Max	Edge of ROW Left	Edge of ROW Right	Value at Distance from Centerline													
Distance from Centerline (feet)	-5.0	-50.0	50.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	23.72	5.65	2.02	0.14	0.34	0.63	1.48	2.66	5.65	14.55	22.58	6.92	2.02	0.90	0.57	0.32	0.20	0.10

Figure 4D: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole



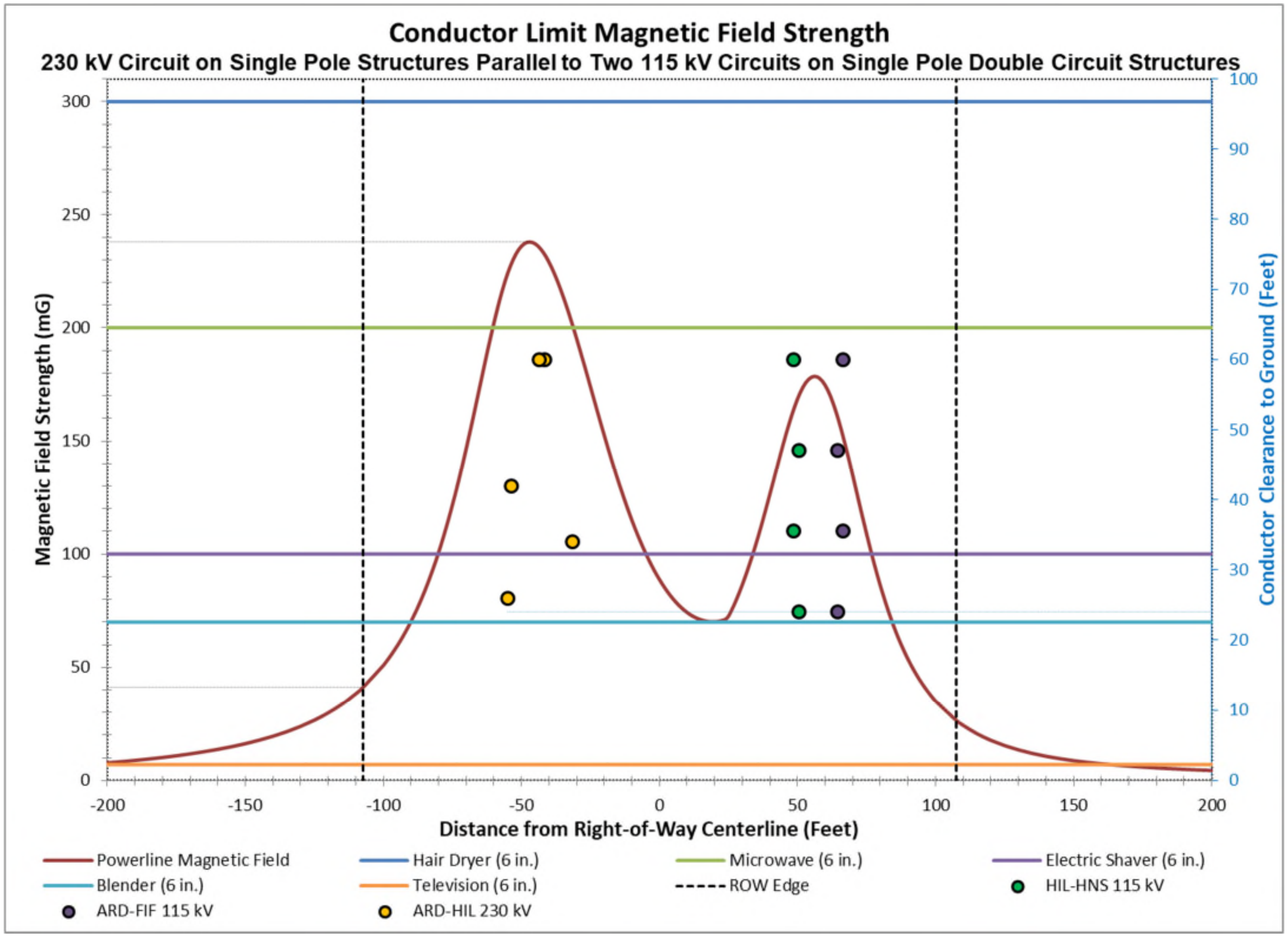
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	0.0	-50.0	50.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	23.70	20.37	20.37	12.19	14.17	15.55	17.46	18.74	20.37	22.40	23.70	22.40	20.37	18.74	17.46	15.55	14.17	12.19

Figure 5A: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole, Existing 230 kV Monopole



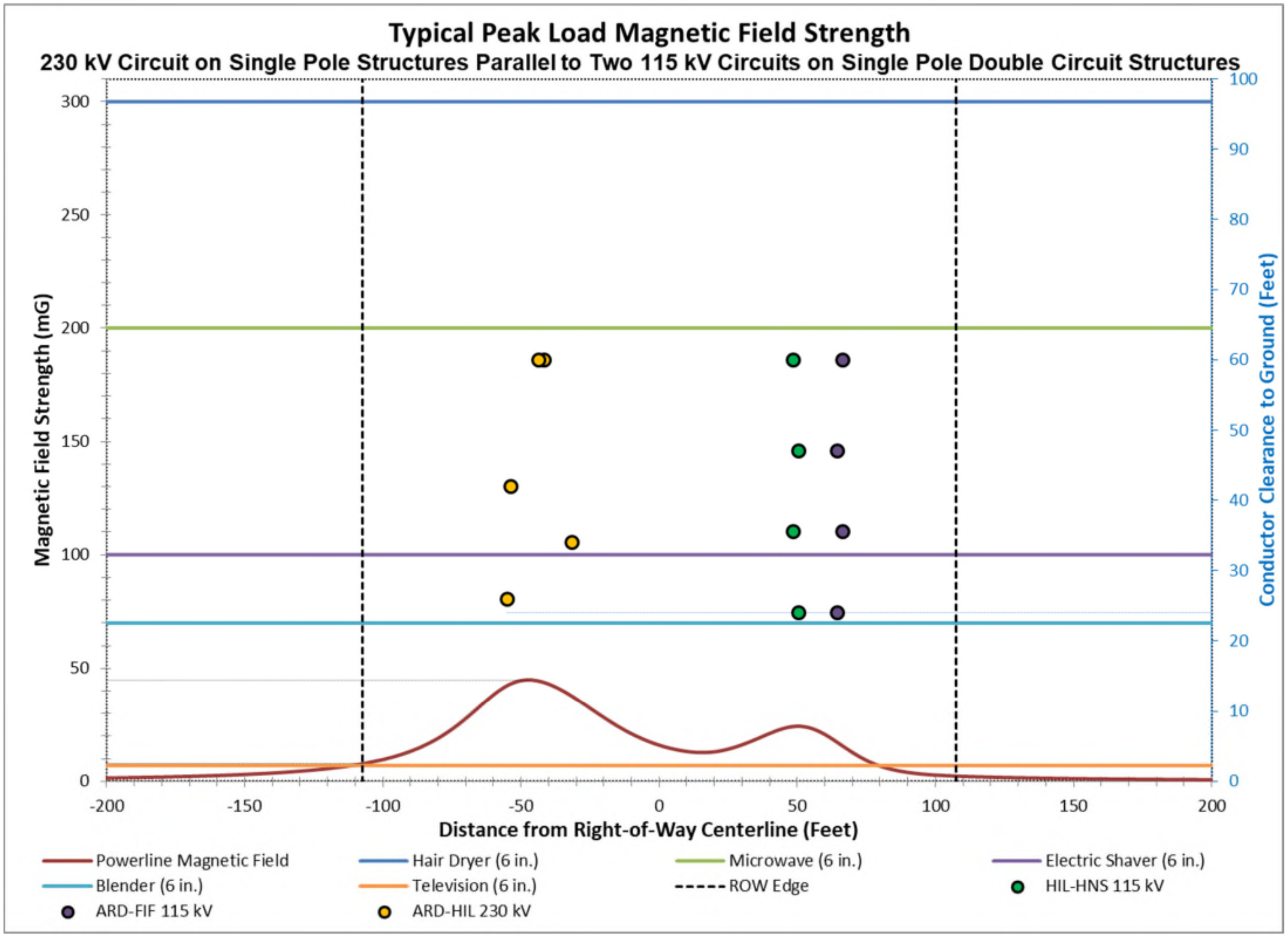
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	-58.0	-107.5	107.5	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	3.14	0.49	0.08	0.02	0.07	0.17	0.63	1.85	2.67	2.02	1.25	0.61	0.98	0.88	0.14	0.04	0.02	0.01

Figure 5B: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole, Existing 230 kV Monopole



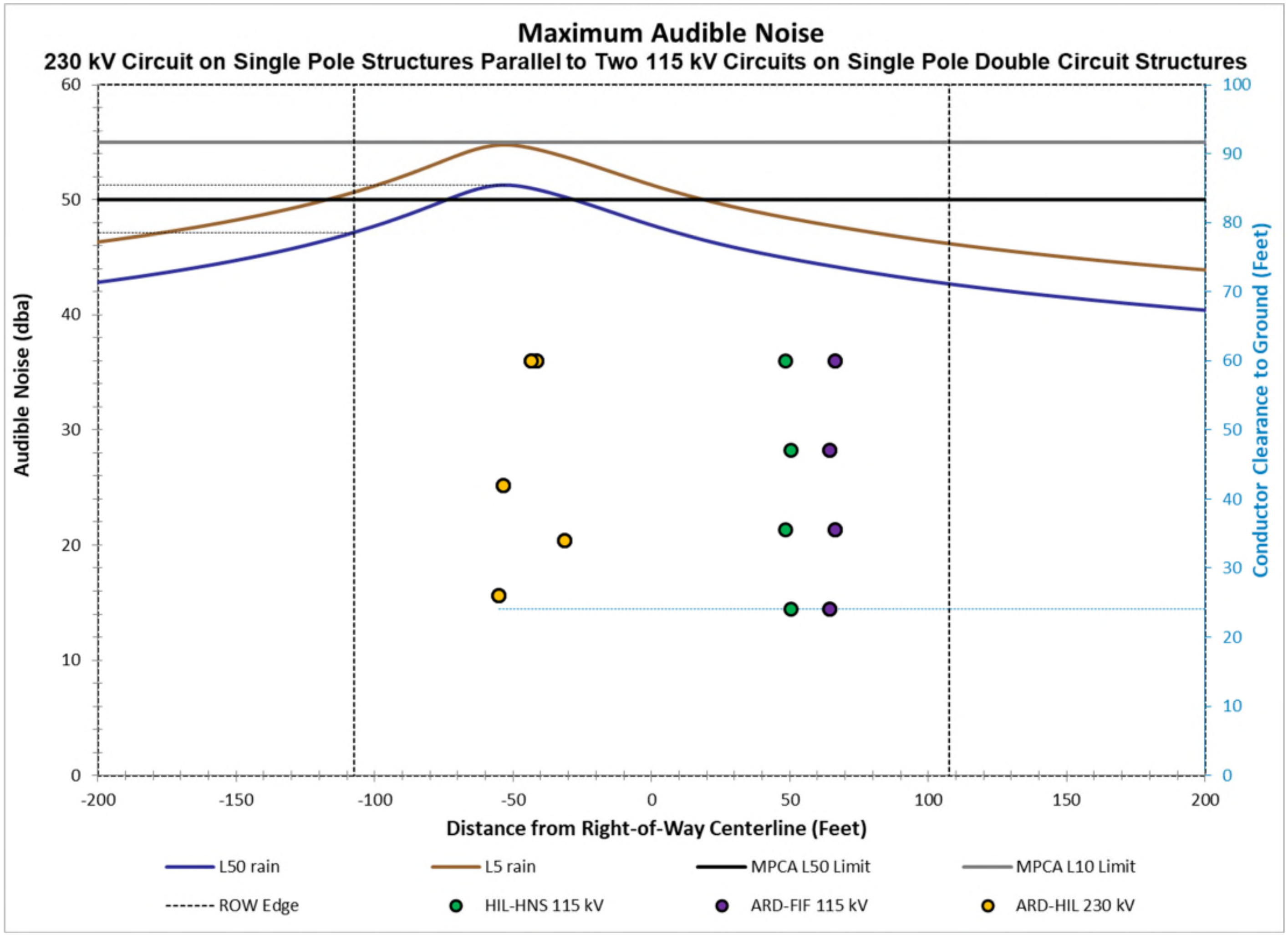
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	-47.0	-107.5	107.5	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	237.89	41.01	26.49	3.00	7.82	16.23	50.91	121.71	236.03	173.92	88.73	72.62	168.65	108.94	35.06	8.75	4.43	1.97

Figure 5C: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole, Existing 230 kV Monopole



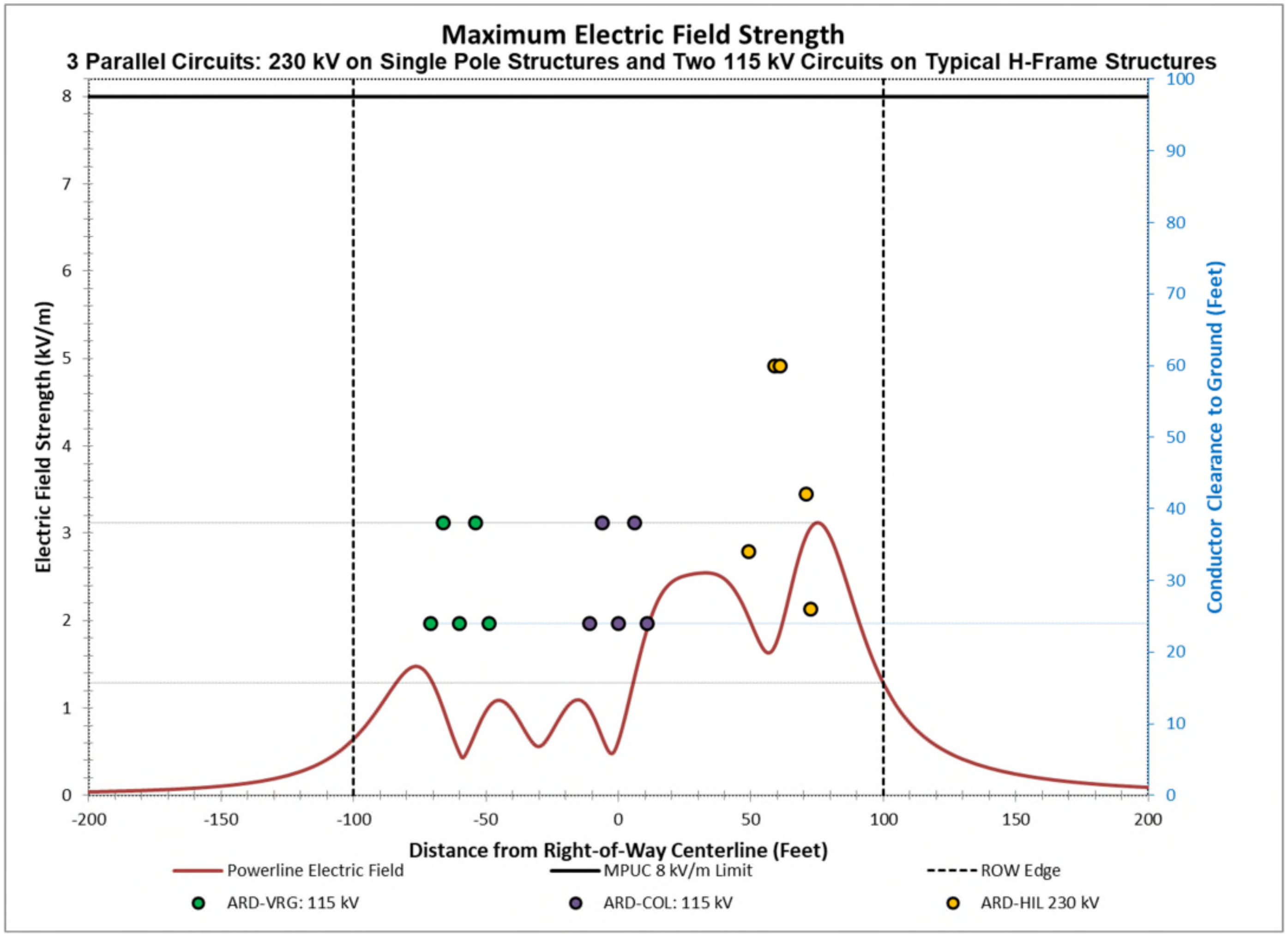
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	-47.0	-107.5	107.5	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	44.91	7.73	2.32	0.56	1.47	3.05	9.61	23.05	44.62	32.38	16.01	14.25	24.35	9.29	2.78	1.21	0.70	0.33

Figure 5D: Corridor Configuration – Project + Existing 115 kV Double Circuit Monopole, Existing 230 kV Monopole



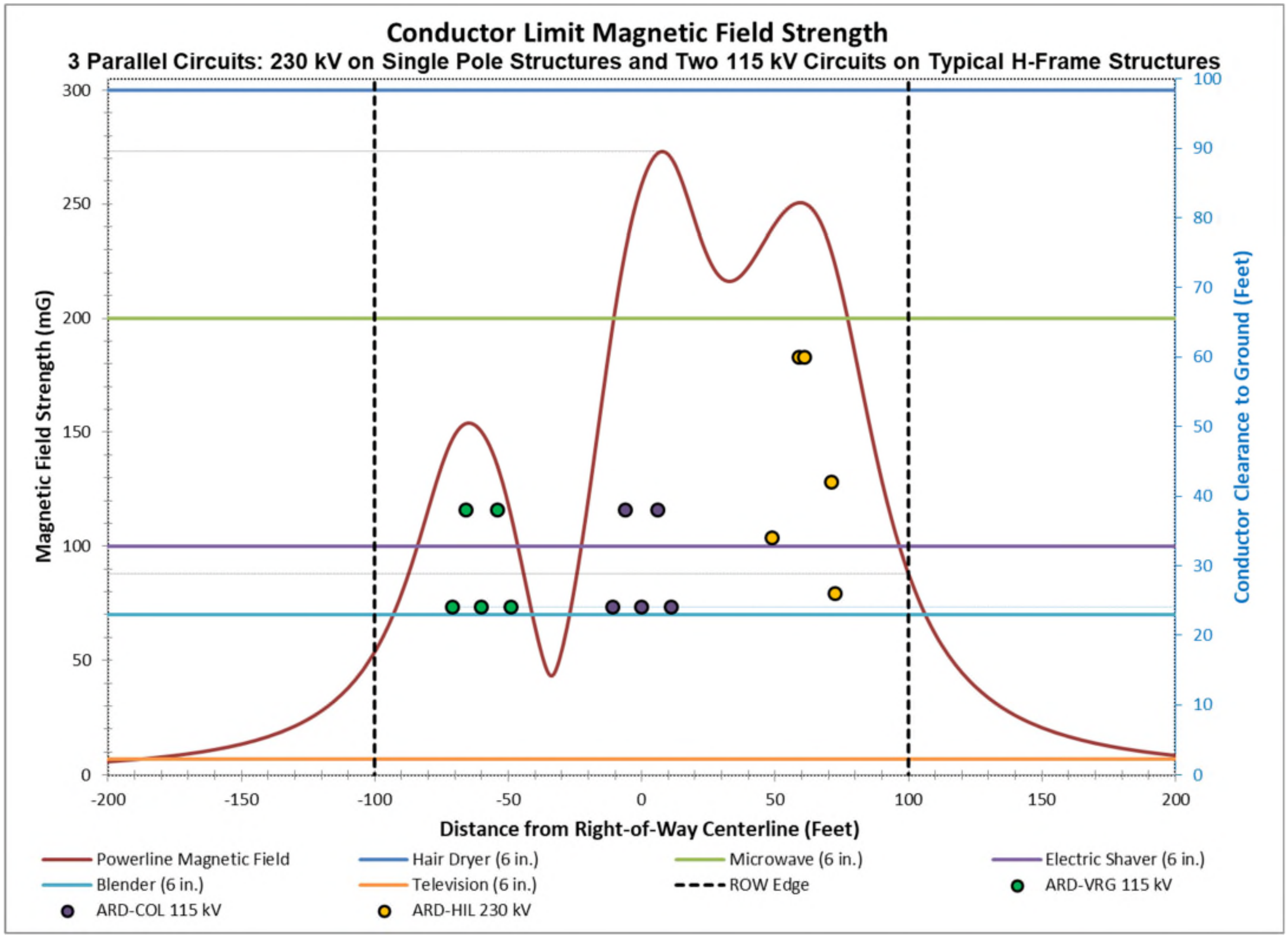
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	-53.0	-107.5	107.5	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	51.27	47.15	42.69	40.35	42.82	44.73	47.70	49.89	51.24	49.76	47.79	46.13	44.87	43.83	42.93	41.51	40.40	38.74

Figure 6A: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame



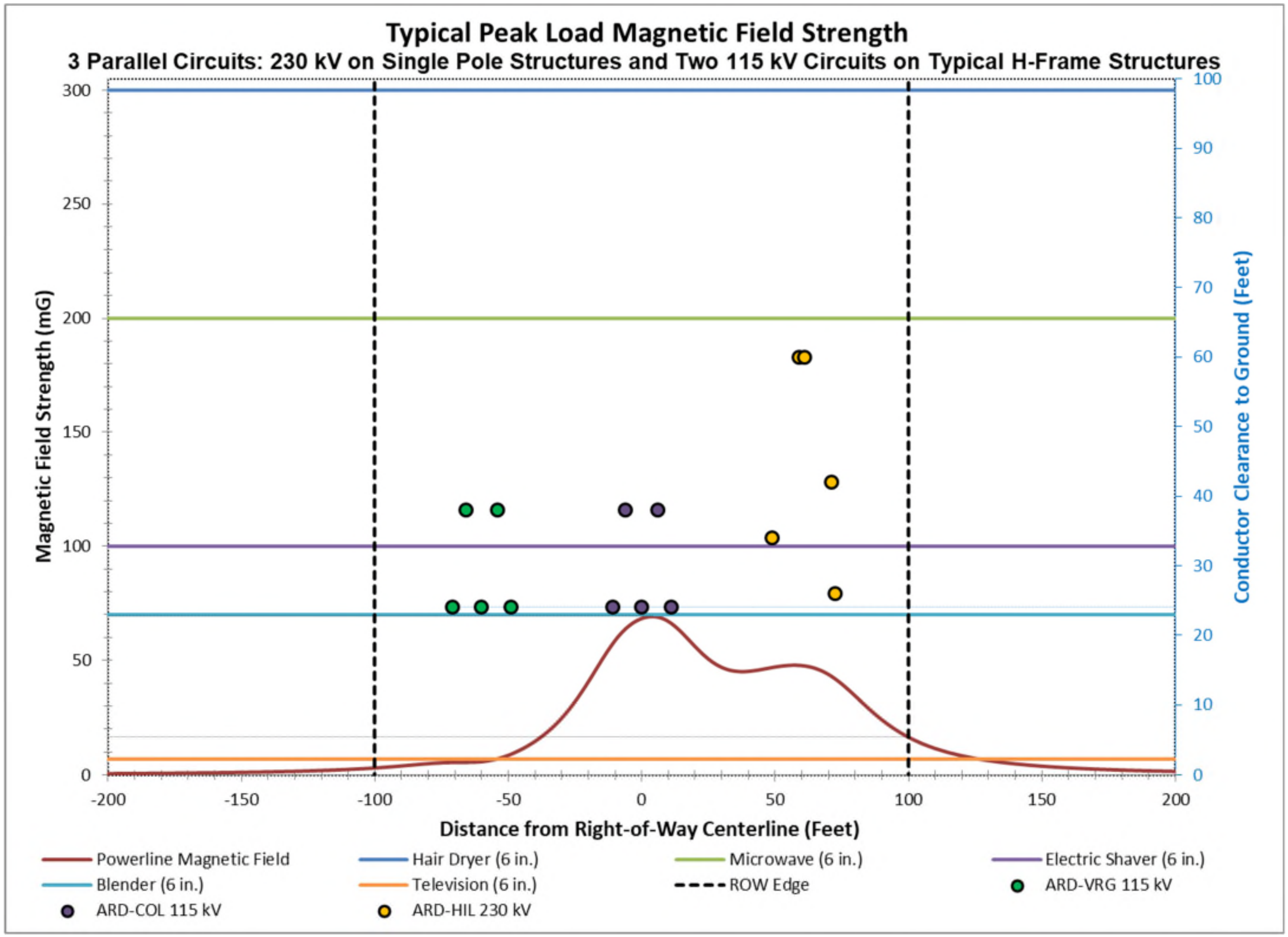
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	75.0	-100.0	100.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	3.12	0.65	1.28	0.01	0.04	0.11	0.65	1.47	0.97	0.74	0.62	2.51	1.97	3.12	1.28	0.24	0.09	0.03

Figure 6B: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame



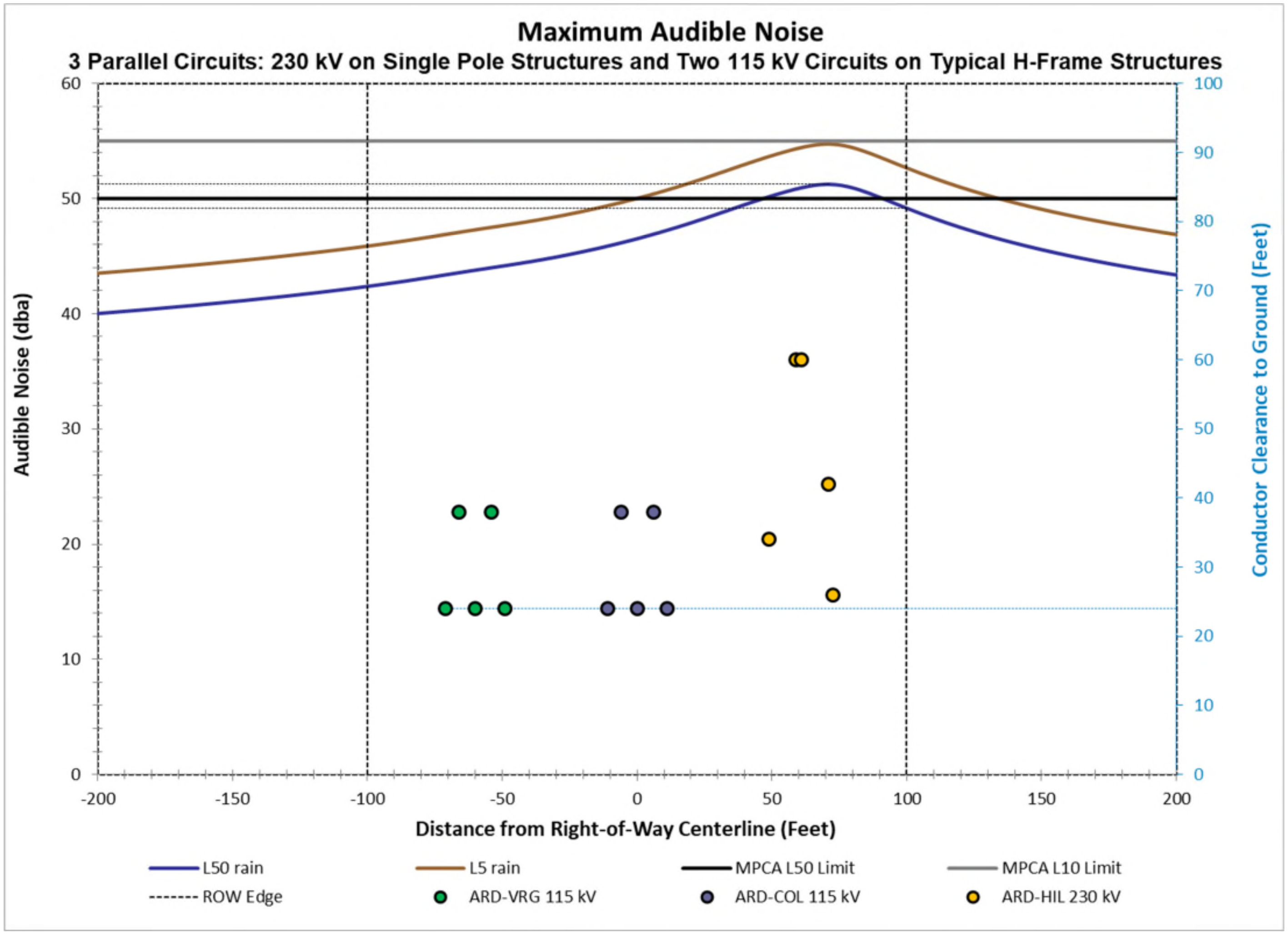
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	8.0	-100.0	100.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	273.07	53.83	87.81	2.09	5.84	13.46	53.83	135.20	118.34	83.15	258.79	226.37	241.41	211.47	87.81	20.59	8.52	2.89

Figure 6C: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame



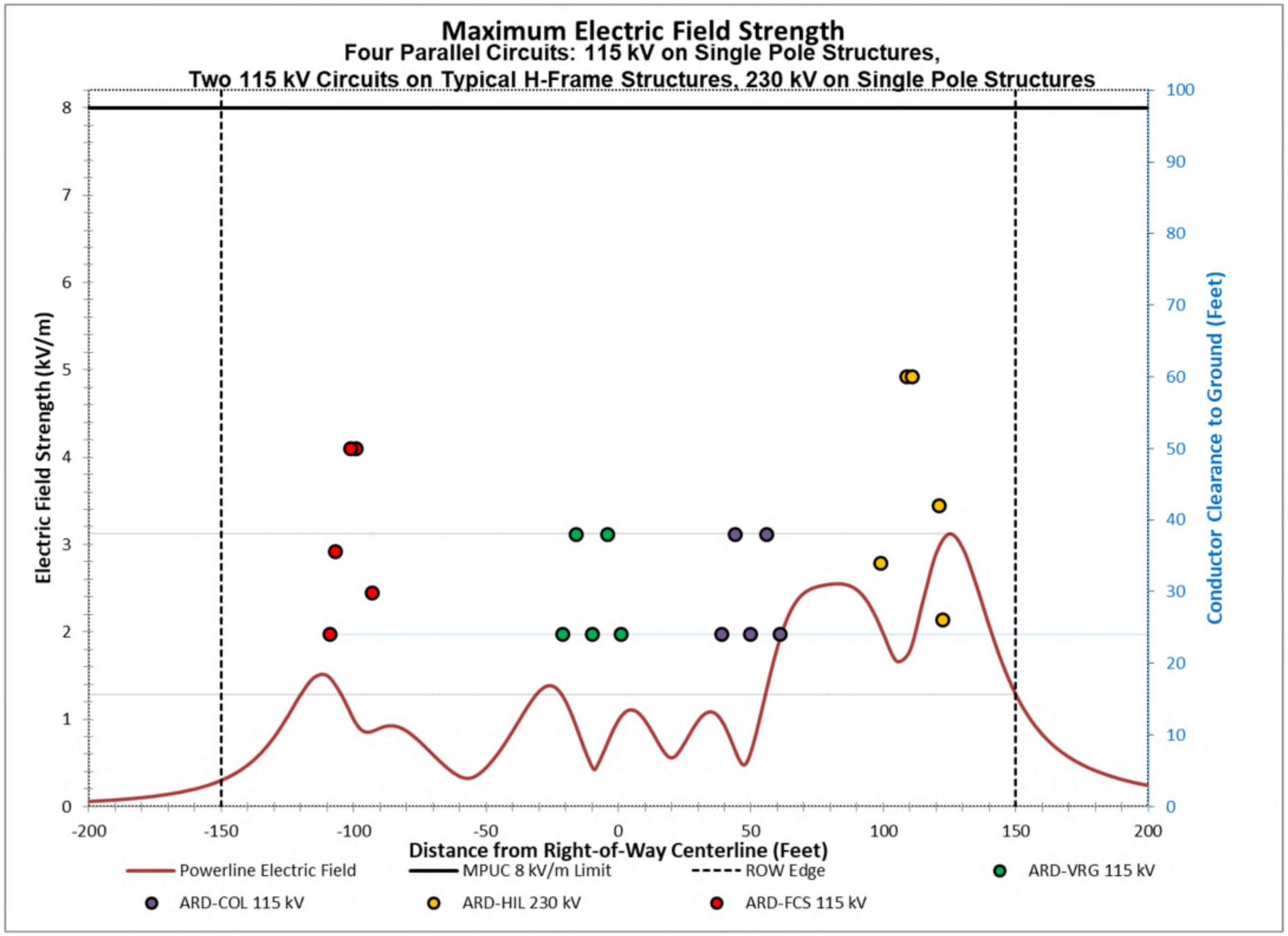
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	4.0	-100.0	100.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	69.21	3.11	16.44	0.28	0.63	1.18	3.11	5.34	8.62	31.95	68.35	50.55	47.06	39.58	16.44	3.87	1.60	0.54

Figure 6D: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame



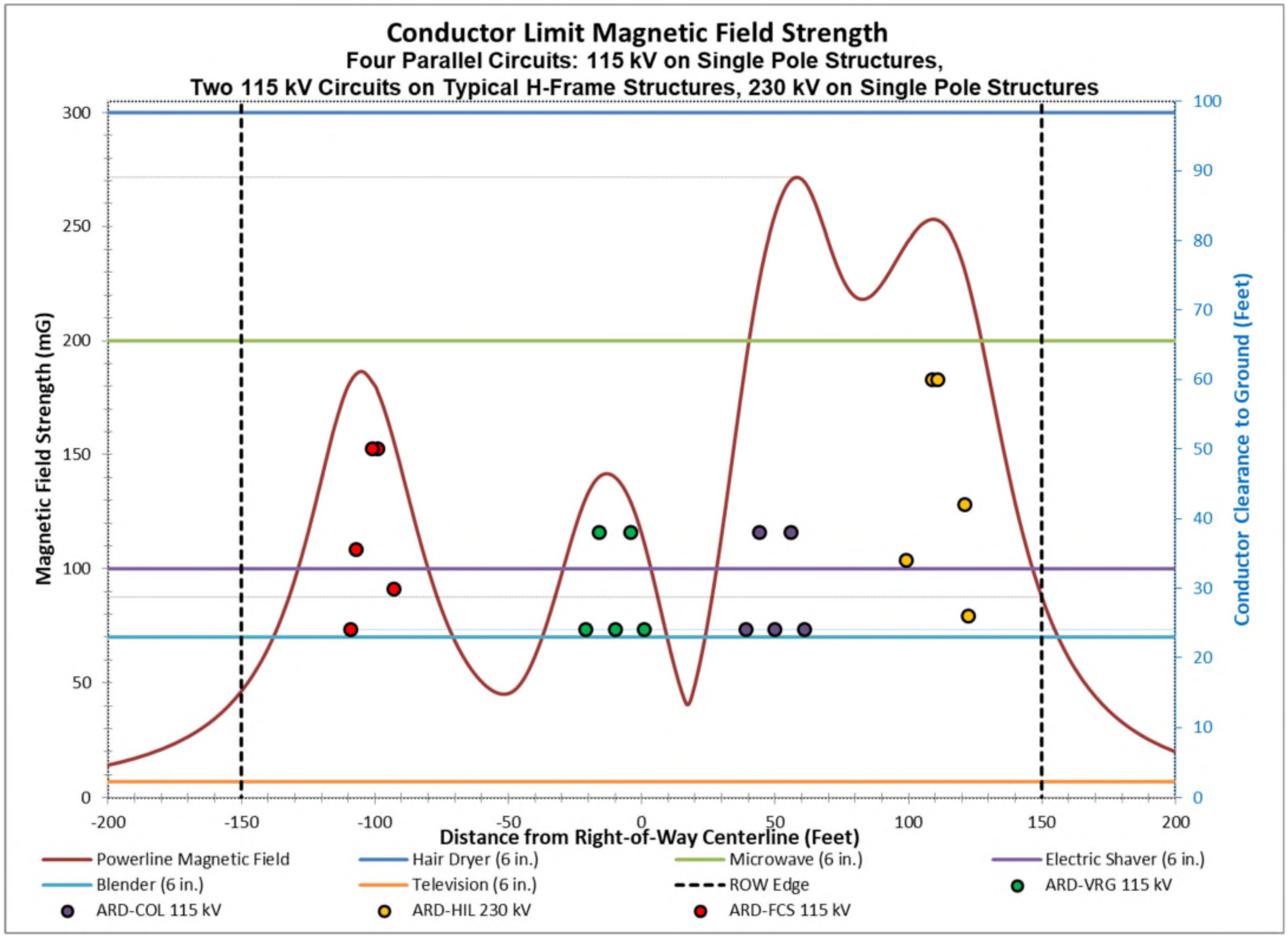
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	71.0	-100.0	100.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	51.23	42.38	49.16	38.45	40.02	41.05	42.38	43.23	44.14	45.15	46.51	48.27	50.23	51.17	49.16	45.57	43.37	40.66

Figure 7A: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV Single Pole



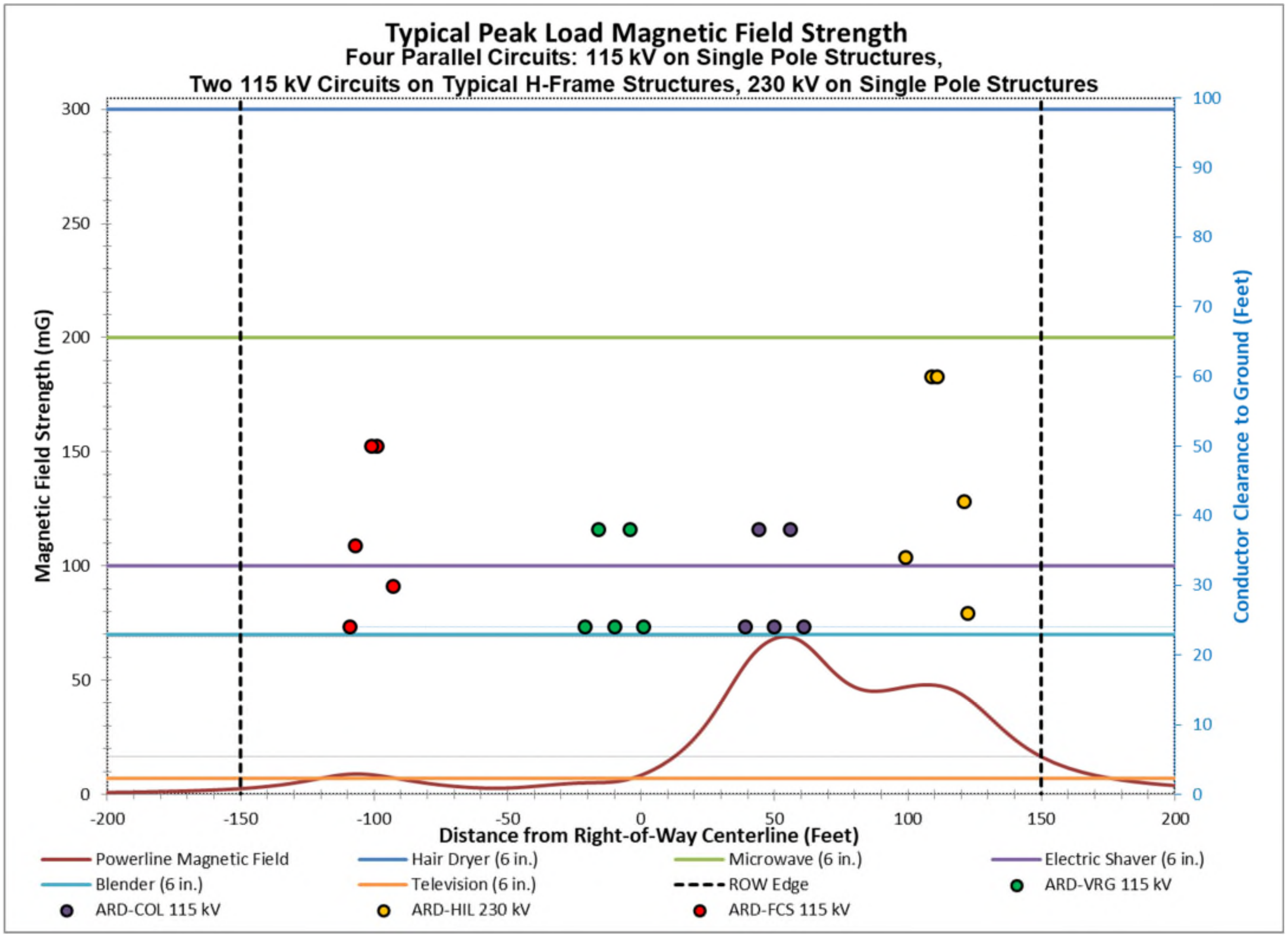
RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	125.0	-150.0	150.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	3.12	0.30	1.28	0.01	0.06	0.30	1.00	0.74	0.44	1.38	0.99	0.73	0.63	2.52	1.98	1.28	0.24	0.04

Figure 7B: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV Single Pole



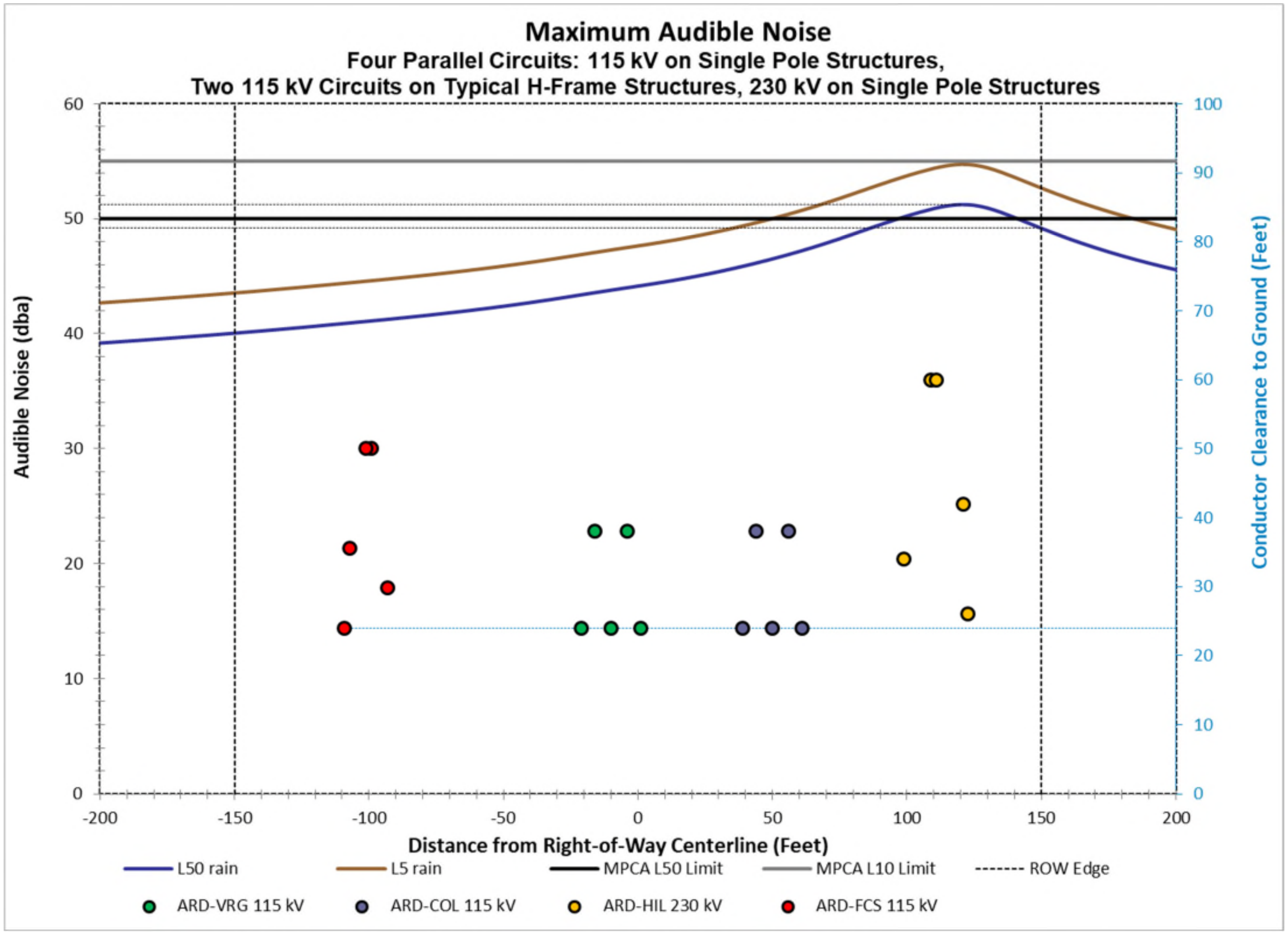
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	58.0	-150.0	150.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	271.60	46.39	87.39	3.98	14.20	46.39	180.29	82.15	45.25	117.74	115.23	78.17	255.47	227.84	244.03	87.39	19.97	4.22

Figure 7C: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV Single Pole



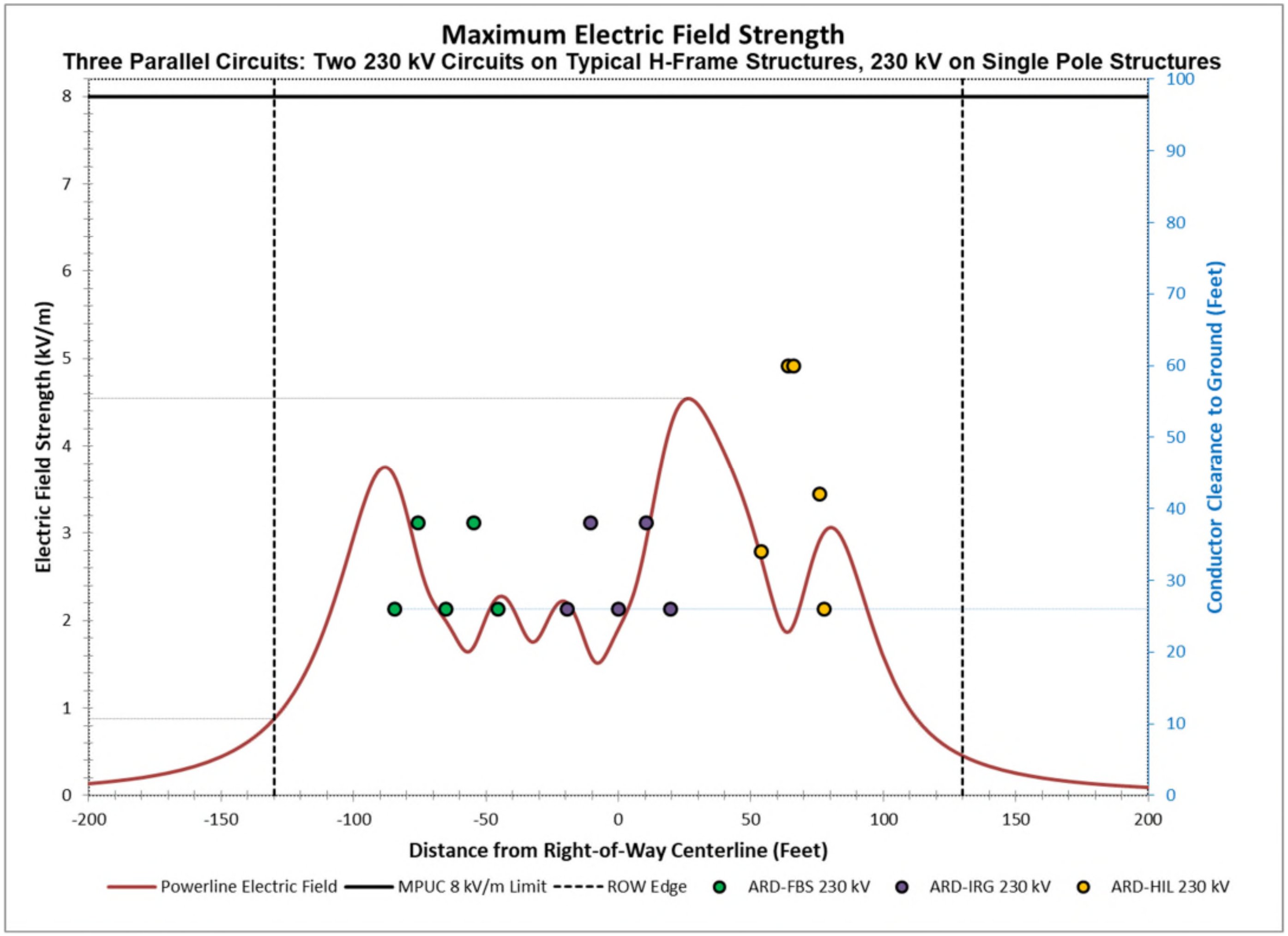
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	54.0	-150.0	150.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	69.08	2.50	16.42	0.26	0.82	2.50	8.47	4.10	2.76	4.86	8.39	31.69	68.17	50.62	47.19	16.42	3.84	0.84

Figure 7D: Corridor Configuration – Project 230 kV Monopole, Existing 115 kV H-Frame, Existing 115 kV H-Frame, Existing 115 kV Single Pole



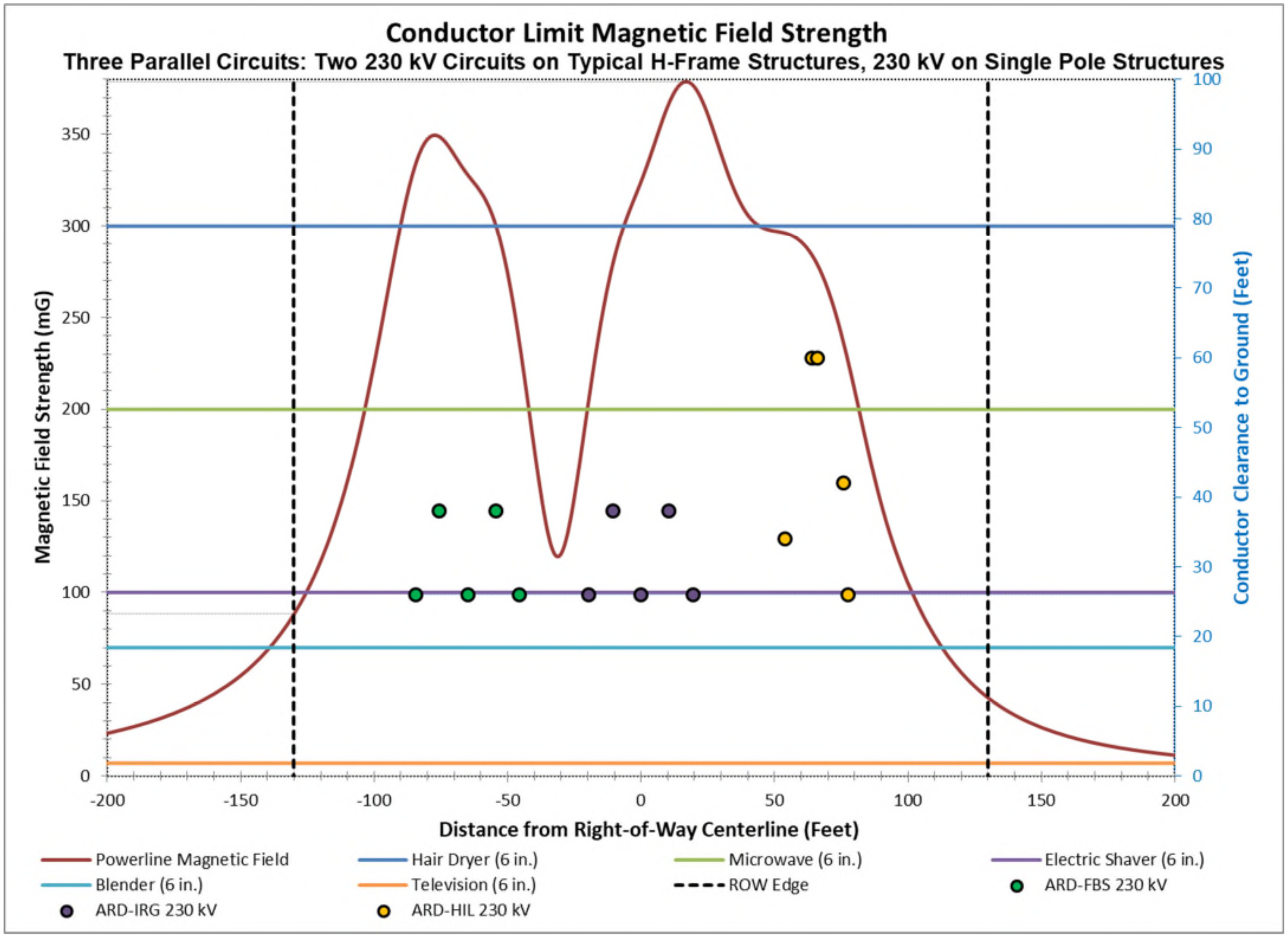
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	120.0	-150.0	150.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	51.23	40.05	49.16	37.82	39.19	40.05	41.10	41.69	42.39	43.24	44.14	45.16	46.51	48.27	50.23	49.16	45.57	41.84

Figure 8A: Corridor Configuration – Project 230 kV Monopole, Existing 230 kV H-Frame, Existing 230 kV H-Frame



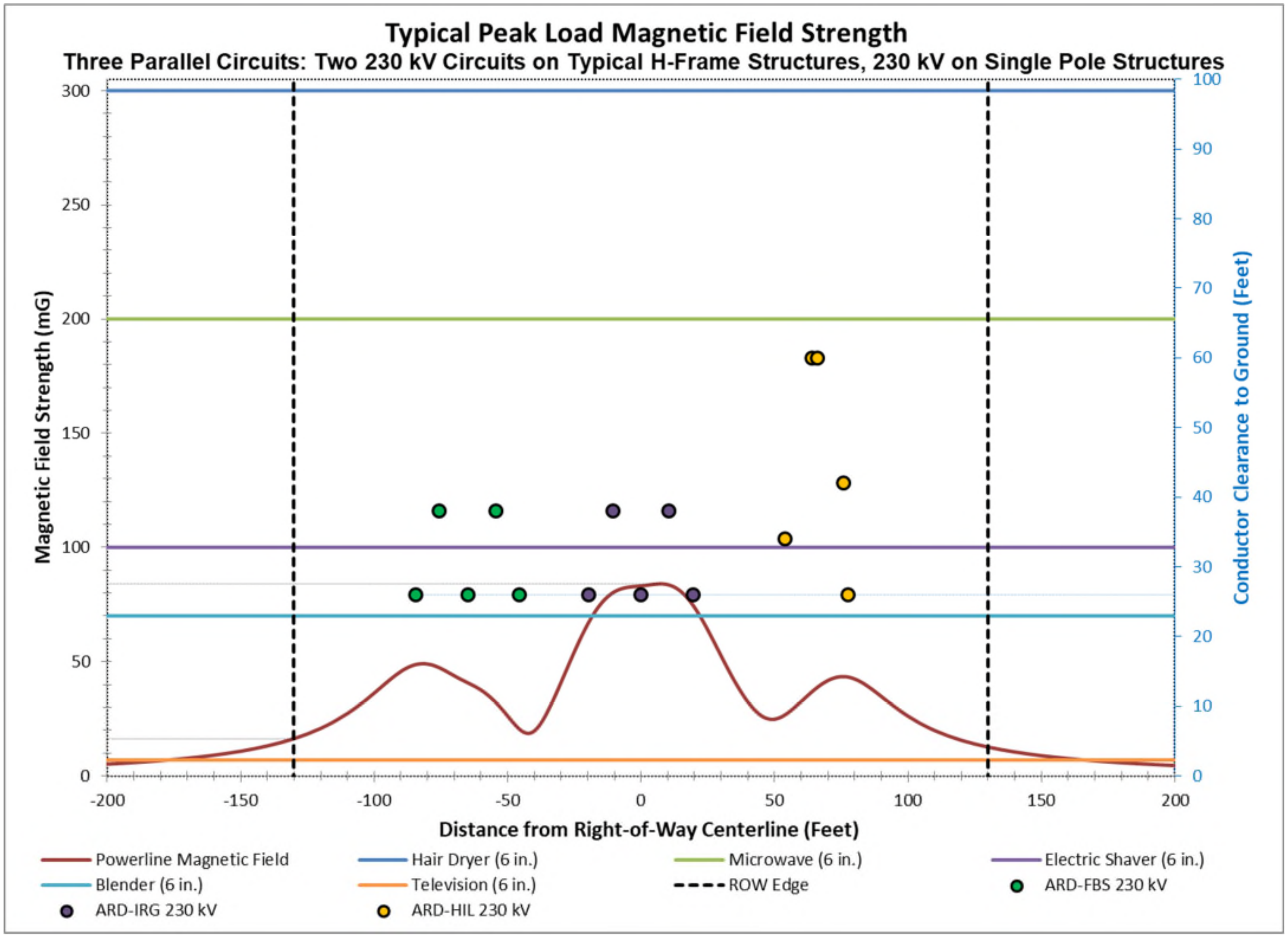
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	26.0	-130.0	130.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (kV/m)	4.54	0.88	0.45	0.04	0.13	0.44	2.96	2.63	2.04	2.10	1.91	4.53	3.12	2.85	1.59	0.25	0.09	0.03

Figure 8B: Corridor Configuration – Project 230 kV Monopole, Existing 230 kV H-Frame, Existing 230 kV H-Frame



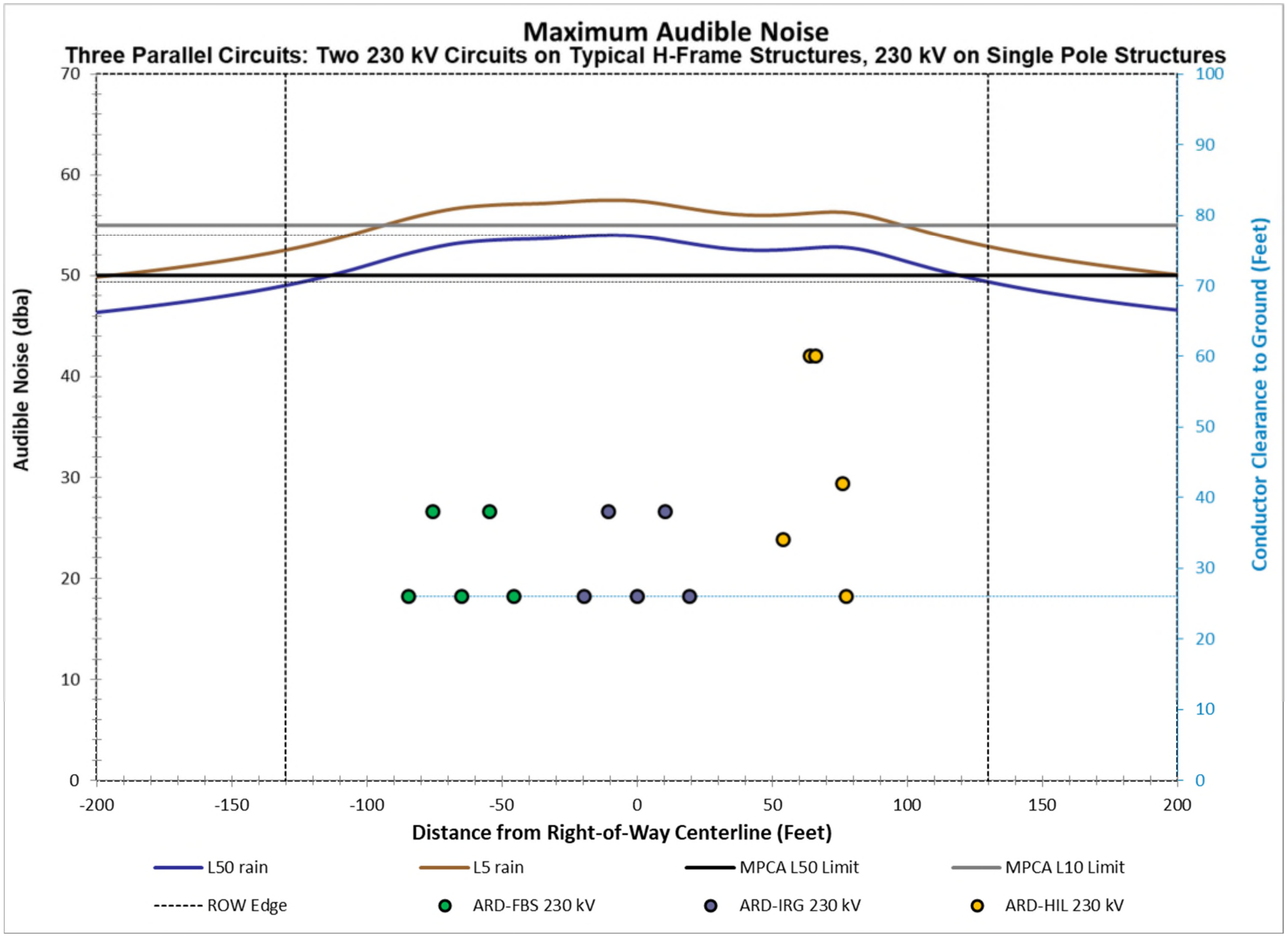
RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	17.0	-130.0	130.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	378.70	88.26	42.63	8.13	23.31	54.77	224.80	348.17	274.05	151.98	324.30	360.68	297.24	240.99	104.99	26.46	11.37	4.37

Figure 8C: Corridor Configuration – Project 230 kV Monopole, Existing 230 kV H-Frame, Existing 230 kV H-Frame



RESULTS	Max	Edge of ROW		Value at Distance from Centerline														
		Left	Right															
Distance from Centerline (feet)	7.0	-130.0	130.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (mG)	84.04	16.36	12.67	2.07	5.20	10.85	36.30	47.06	26.24	54.38	83.13	63.84	24.87	43.49	26.20	8.89	4.59	1.93

Figure 8D: Corridor Configuration – Project 230 kV Monopole, Existing 230 kV H-Frame, Existing 230 kV H-Frame



RESULTS	Max	Edge of ROW		Value at Distance from Centerline													
		Left	Right														
Distance from Centerline (feet)	-9.0	-130.0	130.0	-300	-200	-150	-100	-75	-50	-25	0	25	50	75	100	150	200	300
Value (dba)	53.99	49.02	49.37	44.16	46.35	48.07	51.00	52.79	53.55	53.83	53.92	52.95	52.50	52.81	51.37	48.38	46.57	44.30

APPENDIX I

DULUTH TRANSMISSION STUDY

Minnesota Power

Duluth Transmission Study

Study Report

Kurt Blomquist
September 29, 2021

Revision History

Date	Rev	Description
September 29, 2021	0	Initial Release

Table of Contents

Executive Summary

Background

The "North Shore Loop" is a unique area of the northeastern Minnesota transmission system consisting of 115 kV lines that form a single continuous 140-mile transmission path between northeast Duluth, the North Shore of Lake Superior, and Hoyt Lakes with no connections to the networked transmission system between the two endpoints. The "Duluth Loop" is a network of 115 kV transmission lines between the Arrowhead, Haines Road, Swan Lake Road, and Colbyville substations which create two 115 kV transmission paths from the regional Arrowhead Substation to the North Shore Loop connection at Colbyville. The following transmission lines make up the Duluth Loop:

- Arrowhead – Colbyville 115 kV (57 Line)
- Arrowhead – Haines Road 115 kV (58 Line)
- Haines Road – Swan Lake Road 115 kV (52 Line)
- Swan Lake Road – Ridgeview 115 kV (19 Line)
- Ridgeview – Colbyville 115 kV (56 Line)

A geographical representation of the transmission system which includes the North Shore Loop and the Duluth Loop is shown in Figure E.1.

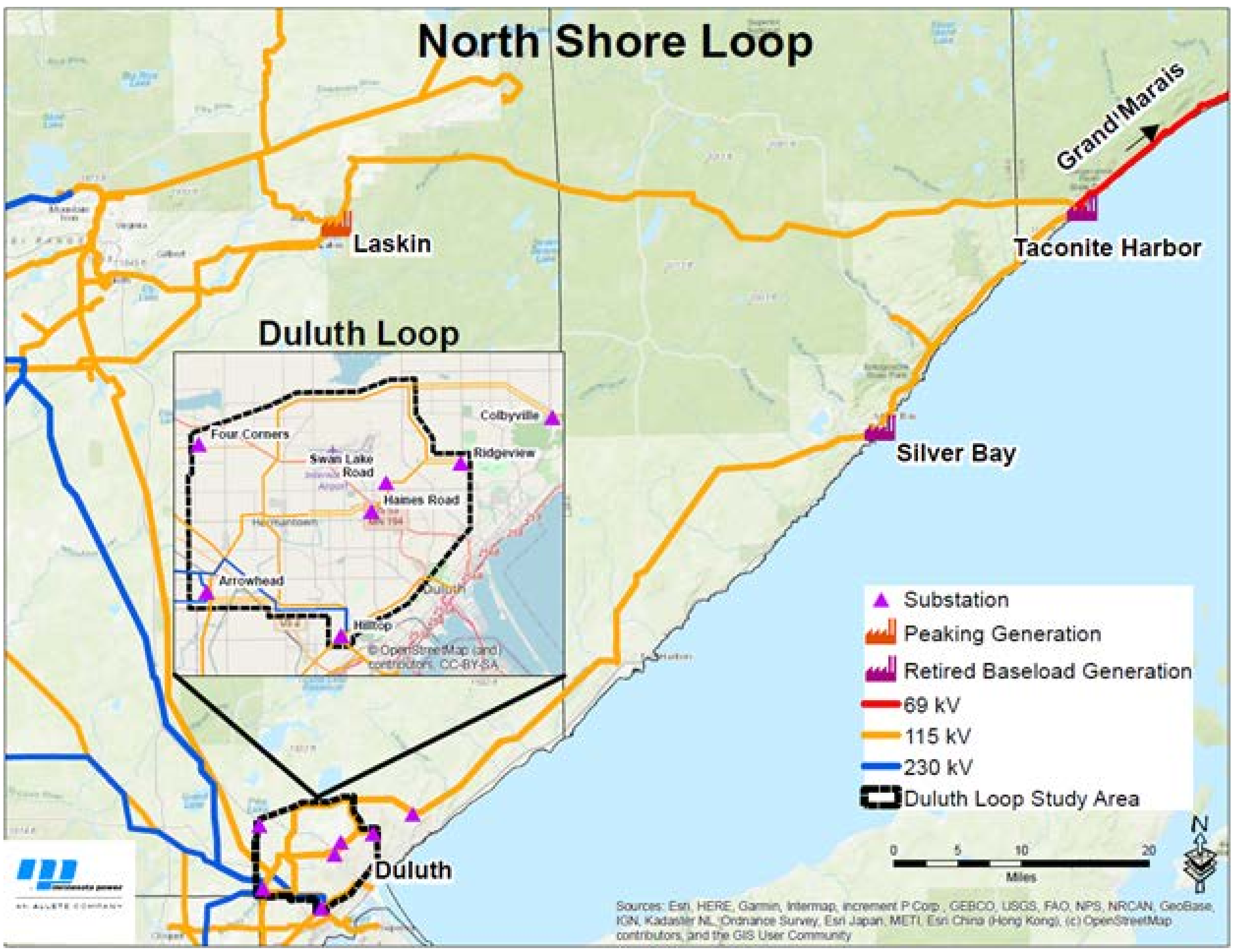


Figure E.1: North Shore Loop and Duluth Loop Transmission System Geographical Representation

Since March 2015, the North Shore Loop has undergone a rapid transition, with all seven of the existing generators in the area remissioned, idled, or retired from baseload coal generation due to regulatory, environmental, and economic concerns. The impact of this transition from an excess of local generation to a scarcity of local generation in the area has driven the need to transform the North Shore Loop transmission system so that it may operate reliably and with sufficient load-serving capacity without relying on the coal-fired generators that have been at the heart of the system for over 60 years. Many transmission projects have been implemented in coordination with the North Shore Loop generator transitions to resolve urgent issues. However, the following outstanding issues remain unresolved.

Duluth Loop Voltage Stability

Voltage collapse scenarios involving loss of Arrowhead – Colbyville 115 kV (57 Line) in conjunction with either:

- Arrowhead – Haines Road 115 kV (58 Line) – Haines Road, Swan Lake Road, Ridgeview, and Colbyville substations served radially from Silver Bay
- Haines Road – Swan Lake Road 115 kV (52 Line) – Swan Lake Road, Ridgeview, and Colbyville substations served radially from Silver Bay
- Swan Lake Road – Ridgeview 115 kV (19 Line) – Ridgeview, and Colbyville substations served radially from Silver Bay
- Colbyville – Ridgeview 115 kV (56 Line) – Colbyville Substation served radially from Silver Bay
    - This voltage collapse scenario can be managed by running Laskin peaking generation during an outage of either 56 Line or 57 Line

Reliability of Duluth-Area Transmission Sources

Two 230/115 kV transformers at Arrowhead Substation and one at Hilltop Substation deliver power to 115 kV transmission lines in the Duluth area from the regional 230 kV transmission network. The Iron Range – Arrowhead – Hilltop 230 kV (98 Line) is the sole 230 kV source into the Hilltop Substation and is 72 miles in length. At the Arrowhead Substation, this line shares a breaker with each Arrowhead 230/115 kV transformer. For a failure of either breaker, one Arrowhead 230/115 kV transformer, 98 Line, and the Hilltop 230/115 kV transformer are disconnected. This leaves a single Arrowhead 230/115 kV transformer delivering power to 115 kV lines in the Duluth area. For historical load levels, this results in overloads on either Arrowhead 230/115 kV transformer. For an outage of one Arrowhead 230/115 kV transformer, the loss of the remaining Arrowhead 230/115 kV transformer causes severe overloads on the Hilltop 230/115 kV transformer for historical load levels.

115 kV Transmission Line Overloads

The risk of severe thermal overloads on North Shore – Taconite Harbor 115 kV (128 Line) and 115 kV transmission lines in the Duluth Loop is a significant issue. When there is not a voltage collapse scenario for loss of both Duluth Loop transmission paths between the Arrowhead and Colbyville substations, severe thermal overloads can occur on 128 Line. For the loss of a Duluth Loop transmission line and loss of North Shore Loop continuity at the Taconite Harbor Substation, severe overloads can occur on the remaining Duluth Loop transmission path between the Arrowhead and Colbyville substations.

North Shore Loop Voltage Stability

A voltage collapse scenario exists involving loss of Big Rock – Colbyville 115 kV (145 Line) in conjunction with loss of one of the two double circuited Taconite Harbor – Dunka Road 115 kV lines (1 Line or 2 Line).

The existing Duluth Area transmission system is illustrated in Figure E.2 below.

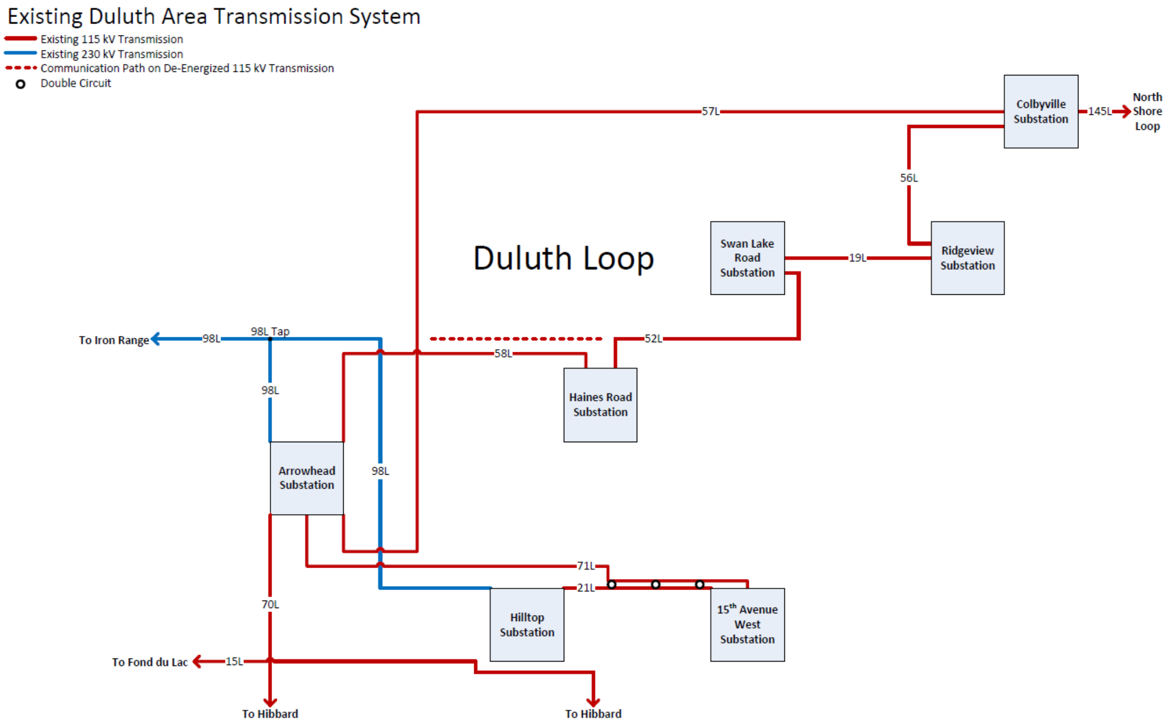


Figure E.2: Existing Duluth Area Transmission System

Recommended Near-Term Solution

The recommended Near-Term solution with the following major components should be completed as soon as reasonably possible:

- Uncross existing Arrowhead – Haines Road 115 kV (58 Line) and existing Arrowhead – Colbyville 115 kV (57 Line), creating Arrowhead – Colbyville 115 kV (new 58 Line)
- Upgrade existing Haines Road – Swan Lake Road 115 kV (52 Line) to 100C operating temperature and connect to the reconfigured Arrowhead – Haines Road 115 kV outside the Haines Road Substation, creating Arrowhead – Swan Lake 115 kV (new 57 Line)
- Construct new Haines Road – Ridgeview 115 kV (new 52 Line) following existing transmission corridor
- Construct new Hilltop – Haines Road 115 kV (new 176 Line) as double circuit with existing Arrowhead – 15th Ave West 115 kV (71 Line) for a portion and then mostly following existing transmission corridor
- Upgrade the existing Hilltop 230 kV Tap to 100C operating temperature, disconnect this tap from existing Iron Range – Arrowhead 230 kV (98 Line), and extend this to a new 230 kV line entrance at the Arrowhead Substation, creating Arrowhead – Hilltop 230 kV (new 108 Line)
- Expand the existing 115 kV bus at the Ridgeview Substation to a 5-position ring bus
- At the Hilltop Substation, expand the existing 115 kV bus to include a new 115 kV line entrance, add a 230 kV breaker on the high side of the 230/115 kV transformer, replace the existing 187 MVA 230/115 kV transformer with a 373 MVA transformer, and replace switches, jumpers, and a 115 kV breaker which would otherwise limit the rating of the new transformer.
- Construct a new 230 kV line entrance for Arrowhead – Hilltop 230 kV (new 108 Line)

The Near-Term solution resolves or improves the aforementioned outstanding issues listed below:

- Voltage collapse scenarios are resolved involving loss of Arrowhead – Colbyville 115 kV (57 Line) in conjunction with either:
    - Arrowhead – Haines Road 115 kV (58 Line)
    - Haines Road – Swan Lake Road 115 kV (52 Line)
    - Swan Lake Road – Ridgeview 115 kV (19 Line)
- Overloads on Taconite Harbor – North Shore 115 kV (128 Line), 19 Line, 52 Line, 57 Line, and 58 Line are resolved
- Severe overloads on the Hilltop 230/115 kV transformer are resolved
- Overloads on one of the Arrowhead 230/115 kV transformers due to a 230 kV circuit breaker failure at the Arrowhead Substation are resolved
- Reliability of the sole 230 kV source into the Hilltop Substation is greatly improved

A preliminary engineering estimate for the Near-Term solution is $50 - $70 Million in 2021 dollars which includes some additional asset renewal components and existing route adjustments. The Near-Term solution is illustrated in Figure E.3 below.

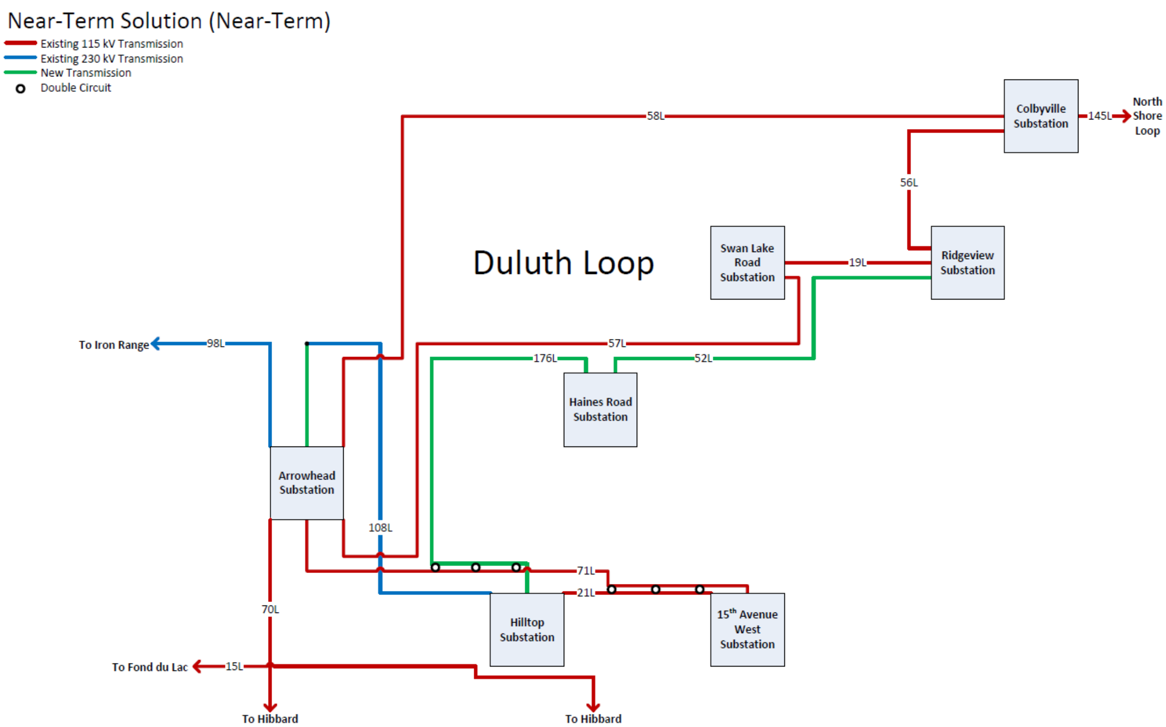


Figure E.3: Near-Term Solution for the Duluth Area Transmission System

Recommended Long-Term Solutions

Two recommended Long-Term solutions with the following major components should be completed when the stated need drivers are realized:

- At the Hilltop Substation, convert the existing 230 kV bus to a 4-position ring bus, install a parallel 230/115 kV 373 MVA transformer, and add a 115 kV tie breaker between both transformer connections on the 115 kV bus. Uncross existing Arrowhead – Hibbard 115 kV (70 Line) from existing Fond du Lac – Hibbard 115 kV (15 Line). Convert Arrowhead – Hibbard 115 kV to 230 kV from the Arrowhead Substation to where it crosses over the Hilltop Substation, creating Arrowhead – Hilltop #2 230 kV (107 Line).

- Minnesota Power will continue to monitor Duluth area 230/115 kV transformer loading along with operation plans for Hibbard generation and the Arrowhead HVDC terminal. If this loading is expected to exceed the emergency rating of a 230/115 kV transformer at the Arrowhead or Hilltop substation, this second 230/115 kV transformer and 230 kV transmission line will become necessary.
- For a conceptual 0.5% - 1.0% annual load growth range and Hibbard generation online, a need for this Long-Term solution is anticipated between 2035 and 2050 with a preliminary planning level estimate of $13.8 Million in 2021 dollars.

- Disconnect existing Big Rock – Colbyville 115 kV (145 Line) from the Colbyville Substation and extend this line to the Ridgeview Substation on new double circuit structures with existing Ridgeview – Colbyville 115 kV (56 Line).
    - Minnesota Power will continue to monitor loading from the Colbyville Substation to Silver Bay along with operation plans for Laskin generation. If this loading begins to exceed the stability threshold with Laskin generation online or if utilizing this generation is no longer an option, this line extension to the Ridgeview Substation will become necessary.
    - For a conceptual 0.5% - 1.0% annual load growth range and Laskin generation online, a need for this Long-Term solution is anticipated between 2033 and 2047 with a preliminary planning level estimate of $24.1 Million in 2021 dollars.

The Long-Term solutions resolve or improve the aforementioned outstanding issues listed below:

- Voltage collapse scenario is resolved involving loss of Arrowhead – Colbyville 115 kV (57 Line) in conjunction with Ridgeview – Colbyville 115 kV (56 Line)
- Overloads on 56 Line are resolved
- Overloads on Duluth area 230/115 kV transformers are resolved
- Redundant 230/115 kV transformer and 230 kV source is established at the Hilltop Substation

The Near-Term and Long-Term solutions are illustrated in Figure E.4 below.

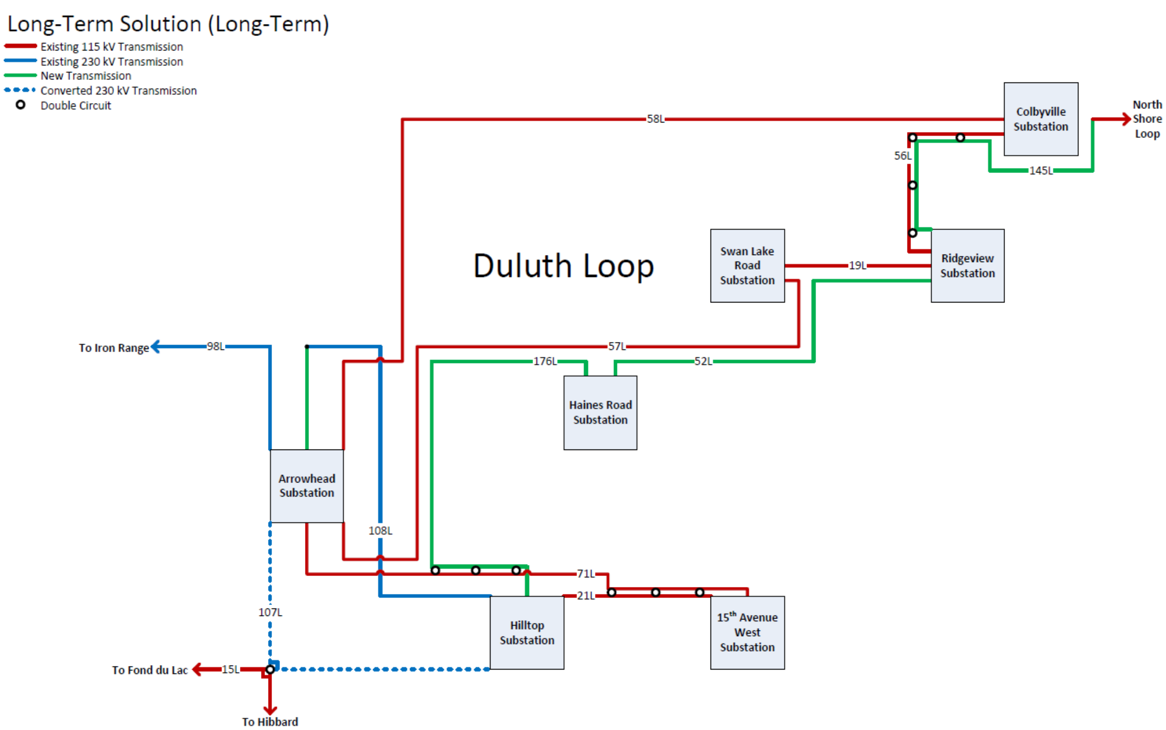


Figure E.4: Long-Term Solution for the Duluth Area Transmission System

Unresolved Outstanding Issue

Significant impacts and investment are anticipated for a solution to resolve the existing North Shore Loop voltage stability issue. For these reasons a solution will not be proposed at this time. This issue will continue to be monitored and when appropriate, a solution may be proposed.

As an interim solution to manage the risk of voltage collapse in real-time operations, Minnesota Power should:

- Develop and enable a transfer trip scheme for use during an outage along 145 Line. For a fault along either 1 Line or 2 Line, this scheme could disconnect at Taconite Harbor either North Shore – Taconite Harbor 115 kV (128 Line) or the remaining in-service Taconite Harbor – Dunka Road 115 kV line (1 Line or 2 Line).
- Open the Big Rock – North Shore 115 kV (42 Line) connection at the Big Rock Substation, separating the North Shore Loop at Big Rock, during an outage on either of the two double circuited Taconite Harbor – Dunka Road 115 kV lines (1 Line or 2 Line). This would cause load at Big Rock and along 145 Line to be served through a single transmission line from the Colbyville substation and load North of Big Rock along the North Shore to be served through a single transmission line from the Hoyt Lakes area.

These operational solutions serve to avoid a larger system blackout but would still result in loss of power for many residential, commercial, and industrial customers. Some large power customers may not be able to return to normal operation until either line outage has been restored.

Section 1: Background

The "North Shore Loop" is a unique area of the northeastern Minnesota transmission system consisting of 115 kV lines that form a single continuous 140-mile transmission path between northeast Duluth, the North Shore of Lake Superior, and Hoyt Lakes with no connections to the networked transmission system between the two endpoints. The "Duluth Loop" is a network of 115 kV transmission lines between the Arrowhead, Haines Road, Swan Lake Road, and Colbyville substations which create two 115 kV transmission paths from the regional Arrowhead Substation to the North Shore Loop connection at Colbyville. A geographical representation of the transmission system which includes the North Shore Loop and the Duluth Loop is shown in Figure 1.1.

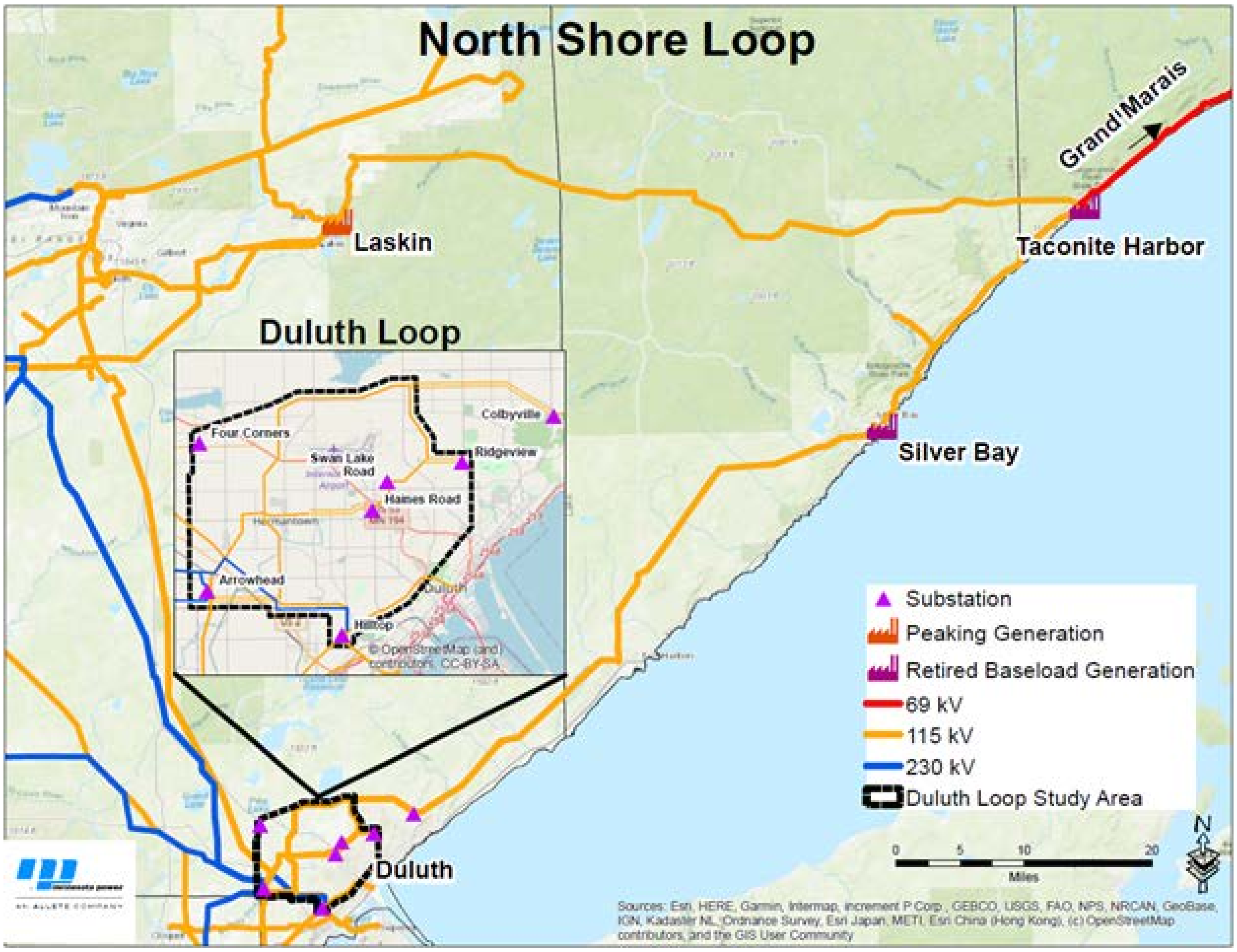


Figure 1.1: North Shore Loop and Duluth Loop Transmission System Geographical Representation

Since March 2015, the North Shore Loop has undergone a rapid transition, with all seven of the existing generators in the area remissioned, idled, or retired from baseload coal generation due to regulatory, environmental, and economic concerns. The impact of this transition from an excess of local generation to a scarcity of local generation in the area has driven the need to transform the North Shore Loop transmission system so that it may operate reliably and with sufficient load-serving capacity without relying on the coal-fired generators that have been at the heart of the system for over 60 years.

Many transmission projects have been implemented in coordination with these generator transitions to resolve urgent issues. However, the following outstanding issues remain unresolved:

Duluth Loop Voltage Stability

For most transmission outages in the Duluth Loop, the loss of a second Duluth Loop transmission line during the outage would leave all or part of the Duluth Loop and the North Shore on a single 140-mile transmission path originating in the Hoyt Lakes area. Without the support previously provided by the local baseload generators in the North Shore Loop, the transmission system is no longer able to support historical Duluth Loop load levels over such a long distance and the expected result would be a post-contingent voltage collapse in the Duluth Loop and extending up the North Shore toward Two Harbors. To manage the risk of voltage collapse in real-time operations, the Regional Transmission Operator (MISO) directs Minnesota Power to open the North Shore transmission connection at the Colbyville substation, separating Duluth from the North Shore during outages in the Duluth Loop. This causes Duluth Loop load to be served through a single transmission path from the Arrowhead substation and load along the North Shore to be served through a single transmission path from the Hoyt Lakes area. This operational solution serves mostly to contain the problem rather than resolve it, as the loss of a second Duluth Loop or North Shore transmission line would still result in loss of power for many residential, commercial, and industrial customers.

The following contingency definitions will be referenced throughout the study which capture the voltage stability issues described above:

- **P61:115-115:MP:ARD-COL:ARD-HNS** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Arrowhead – Haines Road 115 kV (58 Line)*
- **P61:115-115:MP:ARD-COL:SLA-HNS** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Swan Lake Road – Haines Road 115 kV (52 Line)*
- **P61:115-115:MP:ARD-COL:SLA-RGV** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Swan Lake Road – Ridgeview 115 kV (19 Line)*
- **P61:115-115:MP:ARD-COL:COL-RGV** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Colbyville – Ridgeview 115 kV (56 Line)*

North Shore Loop Voltage Stability

During an outage along Big Rock – Colbyville 115 kV (145 Line), which includes 3 taps, the loss of one of the two double circuited Taconite Harbor – Dunka Road 115 kV lines (1 Line or 2 Line) would leave the Taconite Harbor Substation, North Shore Switching Station, and Big Rock Substation served through the remaining Taconite Harbor – Dunka Road 115 kV Line. Both 1 Line and 2 Line are over 60 miles long and have 477 ACSR conductor. Without the support previously provided by the local baseload generators in the North Shore Loop, the transmission system is no longer able to support historical North Shore load levels over such a long distance. At these load levels, the expected result would be a post-contingent voltage collapse at the Taconite Harbor Substation and extending down the North Shore to the Big Rock Substation. To manage the risk of voltage collapse in real-time operations, Minnesota Power could develop and enable a transfer trip scheme during an outage along 145 Line. For a fault along either 1 Line or 2 Line, this scheme could disconnect at Taconite Harbor either North Shore – Taconite Harbor 115 kV (128 Line) or the remaining in-service Taconite Harbor – Dunka Road 115 kV line (1 Line or 2 Line). This operational solution serves to avoid a larger system blackout but would still result in loss of power for many residential, commercial, and industrial customers. Some large power customers may not be able to return to normal operation until either line outage has been restored.

During an outage on either of the two double circuited Taconite Harbor – Dunka Road 115 kV lines (1 Line or 2 Line), the loss of 145 Line would result in the same scenario as described above for historical North Shore load levels. To manage the risk of voltage collapse in real-time operations, Minnesota Power could open the Big Rock – North Shore 115 kV (42 Line) connection at the Big Rock substation, separating the North Shore Loop at Big Rock. This would cause load at Big Rock and along 145 Line to be served through a single transmission line from the Colbyville substation and load North of Big Rock along the North Shore to be served through a single transmission line from the Hoyt Lakes area. This operational solution serves mostly to contain the problem rather than resolve it, as the loss of 145 Line, 128 Line, or the remaining Taconite Harbor – Dunka Road 115 kV line (1 Line or 2 Line) would still result in loss of power for many residential, commercial, and industrial customers.

The following contingency definition will be referenced throughout the study which capture the voltage stability issue described above:

- **P61:115-115:MP:BGR-COL:TCH-DKA** – *Loss of Big Rock – Colbyville 115 kV (145 Line) and Taconite Harbor – Dunka Road 115 kV (1 Line or 2 Line)*

Reliability of Duluth-Area Transmission Sources

Two 230/115 kV transformers at Arrowhead Substation and one at Hilltop Substation deliver power to 115 kV transmission lines in the Duluth area from the regional 230 kV transmission network. The reliance of the Duluth Loop and the North Shore on these transformers has greatly increased without the support previously provided by the local baseload generators in the North Shore Loop. Iron Range – Arrowhead – Hilltop 230 kV (98 Line) is the sole 230 kV source into the Hilltop Substation and is 72 miles in length. At the Arrowhead Substation, this line shares a breaker with each Arrowhead 230/115 kV transformer. For a failure of either breaker, one Arrowhead 230/115 kV transformer, 98 Line, and the Hilltop 230/115 kV transformer are disconnected. This leaves a single Arrowhead 230/115 kV transformer delivering power to 115 kV lines in the Duluth area. For historical load levels, this results in overloads on either Arrowhead 230/115 kV transformer.

For an outage of one Arrowhead 230/115 kV transformer, the loss of the remaining Arrowhead 230/115 kV transformer causes severe overloads on the Hilltop 230/115 kV transformer for historical load levels.

The following contingency definitions will be referenced throughout the study which capture the transmission source reliability issues described above:

- Each 373 MVA Arrowhead 230/115 kV Transformer overloads for a breaker failure contingency which disconnects the other Arrowhead 230/115 kV Transformer, Iron Range – Arrowhead – Hilltop 230 kV (98 Line), and the Hilltop 230/115 kV:
  - **P24:230:MP:ARD:98L**
  - **P24:230:MP:ARD:98-99LW**
- Hilltop 230/115 kV Transformer overloads for loss of both Arrowhead 230/115 kV Transformers ("6TR" & "7TR")
  - **P62:230-230:MP:ARD:6TR:ARD:7TR**

115 kV Transmission Line Overloads

The risk of severe thermal overloads on North Shore – Taconite Harbor 115 kV (128 Line) and 115 kV transmission lines in the Duluth Loop is a significant issue. When there is not a voltage collapse scenario for loss of both Duluth Loop transmission paths between the Arrowhead and Colbyville substations, severe thermal overloads can occur on 128 Line. For the loss of a Duluth Loop transmission line and loss of North Shore Loop continuity at the Taconite Harbor Substation, severe overloads can occur on the remaining Duluth Loop transmission path between the Arrowhead and Colbyville substations.

For a transmission outage in the Duluth Loop, the Regional Transmission Operator (MISO) directs Minnesota Power to open the North Shore transmission connection at the Colbyville substation, separating Duluth from the North Shore during outages in the Duluth Loop. This causes Duluth Loop load to be served through a single transmission path from the Arrowhead substation and load along the North Shore to be served through a single transmission path from the Hoyt Lakes area. For Duluth Loop line overloads, this operational solution serves prevents these overloads but does not than resolve them, as the loss of a second Duluth Loop or North Shore transmission line would still result in loss of power for many residential, commercial, and industrial customers.

For transmission outages affecting North Shore Loop continuity at the Taconite Harbor Substation, Minnesota Power could open the Ridgeview – Colbyville 115 kV (56 Line) connection at the Colbyville Substation. This would cause load at substations from Colbyville to Finland to be served through a single transmission line from the Arrowhead Substation, the remaining Duluth Loop load to be served through a separate single transmission line from the Arrowhead Substation, and load at Taconite Harbor Substation to be served through a single transmission line from either the Hoyt Lakes area or from the Arrowhead Substation. This operational solution serves mostly to contain the problem rather than resolve it, as the loss of a remaining Duluth Loop or North Shore transmission line would still result in loss of power for many residential, commercial, and industrial customers.

The following contingency definitions will be referenced throughout the study which capture these transmission line overloads described above:

- **P61:115-115:MP:ARD-COL:ARD-HNS** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Arrowhead – Haines Road 115 kV (58 Line)*
- **P61:115-115:MP:ARD-COL:SLA-HNS** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Swan Lake Road – Haines Road 115 kV (52 Line)*
- **P61:115-115:MP:ARD-COL:SLA-RGV** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Swan Lake Road – Ridgeview 115 kV (19 Line)*
- **P61:115-115:MP:ARD-COL:COL-RGV** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Colbyville – Ridgeview 115 kV (56 Line)*
- **P61:115-115:MP:ARD-COL:NTS-TCH** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and North Shore – Taconite Harbor 115 kV (128 Line)*
- **P61:115-115:MP:ARD-COL:TCH TR4** – *Loss of Arrowhead – Colbyville 115 kV (57 Line) and Taconite Harbor 138/115 kV transformer*
- **P61:115-115:MP:ARD-HNS:NTS-TCH** – *Loss of Arrowhead – Haines Road 115 kV (58 Line) and North Shore – Taconite Harbor 115 kV (128 Line)*
- **P61:115-115:MP:ARD-HNS:TCH TR4** – *Loss of Arrowhead – Haines Road 115 kV (58 Line) and Taconite Harbor 138/115 kV transformer*
- **P61:115-115:MP:SLA-HNS:NTS-TCH** – *Loss of Swan Lake Road – Haines Road 115 kV (52 Line) and North Shore – Taconite Harbor 115 kV (128 Line)*
- **P61:115-115:MP:SLA-HNS:TCH TR4** – *Loss of Swan Lake Road – Haines Road 115 kV (52 Line) and Taconite Harbor 138/115 kV transformer*

The Duluth Transmission Study will analyze these outstanding issues in detail in order to better understand the severity of these issues and to evaluate various solutions to resolve them.

Section 2: Model Development

Study models were derived from 2019 MTEP model series and updated as described in **Error! Reference source not found.**. Topology updates were made to the 2019 MTEP models to reflect Minnesota Power's long-range transmission plan. The benchmark cases are listed below along with key interface flow levels:

Summer Peak Model

Filename: MISO19_2024_SUM___TA_Final.sav
Interface Flows: [MHEX = 1819.27; MWEX = 744.60; NDEX = 640.54]

Shoulder Peak Model

Filename MISO19_2024_SLL90_TA_Final.sav
Interface Flows: [MHEX = 1429.06; MWEX = 549.18; NDEX = 1562.17]

Winter Peak Model

Filename MISO19_2024_WIN___TA_Final.sav
Interface Flows: [MHEX = -912.55; MWEX = 460.72; NDEX = 147.47]

Updates were made to the benchmark cases to thoroughly evaluate the issues described in Section 1. Those having a significant impact on these issues are listed below:

- Mesaba Junction and Voltage Conversion Project:
    - Modeled the Mesaba Junction Switching Station near the Hoyt Lakes Substation with 2x28 MVAR capacitor banks
    - Reconductored and extended existing Forbes – Laskin 115 kV (38 Line) from Laskin to Mesaba Junction Switching Station with 666 ACSS conductor
    - Converted the existing 138 kV system between Laskin and Taconite Harbor to 115 kV
- Changed operations of the Stinson PST to normally operate around 0 MW
- Updated and corrected modeled load in the North Shore Loop, Duluth, Superior, and surrounding area to reflect projected 2024 load based on historical coincident peak loading
- Turned off Taconite Harbor generation which was idled in 2016
- Turned off Laskin generation which was converted to natural gas peaking generation in 2015

Section 3: Study Methodology

In general, *PSSE* version 33 was used to perform AC Contingency Analysis (ACCC) on each of the study models. Benchmark contingency input files were developed based on the contingencies listed in Section 3.1. Monitored elements for all study cases are listed in Section 3.2.

3.1 Contingencies

Benchmark Contingencies

The following contingencies were analyzed for the steady state analysis part of the study:

1. All NERC Category P1, P2, and P7 contingencies associated with the following substations and transmission lines connecting these substations: Forbes, ETCO, Virginia, Laskin, Hat Trick, Embarrass, Tower, Babbitt, Hoyt Lakes, Mesaba Junction, Dunka Road, Taconite Harbor, North Shore, Silver Bay, Big Rock, Colbyville, Ridgeview, Swan Lake Road, Haines Road, Arrowhead, Hilltop, Canosia Road, Cloquet, Potlatch, Savanna, Thomson, Fond Du Lac, Hibbard, LSPI, 15th Avenue West, Gary, Winter Street, Stinson, Fairmount Park, Nemadji, Enbridge East, Enbridge North, Enbridge South, and Gordon
2. Targeted combinations of NERC Category P6.1 (multiple transmission circuit) contingencies of transmission lines between the above mentioned substations.

3.2 Monitored Elements

Transmission lines may have a 30 minute emergency rating that is up to 10% above the normal rating. Transformers may have an emergency rating that is up to 25% above the normal rating. The emergency rating may be limited by the ampacity of substation equipment. Thermal overloads listed in tables throughout the study report are color coordinated as follows:

- RED numbers with WHITE cell background indicate the overload is above the normal facility rating but within the emergency facility rating.
- BLACK numbers with RED cell background indicate the overload is above the emergency facility rating but does not exceed 125% of the normal facility rating.
- RED numbers with BLACK cell background indicate the overload is above the emergency facility rating and exceeds 125% of the normal facility rating.

Monitored Transformers

The following transformers were monitored for flow violations based on "Rate A" in the PSSE models:

Frm Bus #	To Bus #	Tert Bus #	Frm Bus Name	Voltage	Ckt
608615	608673	608555	ARROWHD4	230/115	1
608615	608673	608557	ARROWHD4	230/115	2
608616	608672	608577	HILLTOP4	230/115	1
608697	615372	615373	TAC HBR7	115/69	1
699448	699449		AWHD PST	345/230	1

Table 3.1: Monitored Transformers

Monitored Branches

All 230 kV, 138 kV, 115 kV, and 69 kV branches connecting Monitored Buses in the tables below were monitored for flow violations based on "Rate A" in the PSSE models.

Monitored Buses

Planning criteria for all Minnesota Power-owned 100+ kV buses being analyzed for this study require that pre-contingent voltage be within 1.00 – 1.05 per unit while post-contingent voltage be within 0.95 – 1.10

per unit. For Great River Energy-owned buses being analyzed for this study, pre-contingent voltage must be within 0.95 – 1.05 per unit while post-contingent voltage must be within 0.92 – 1.10 per unit.

Voltage was monitored on the following 69 kV buses:

Bus #	Bus Name	kV	Bus #	Bus Name	kV
613090	GRAND MA	69	616202	GRE-MAPLE H8	69
615090	GRE-ARROWHD8	69	616203	GRE-GNDMRTP8	69
615372	GRE-TAC HAR8	69	616204	GRE-COLVILL8	69
616200	GRE-SCHRDER8	69	616205	GRE-MPLHLTP8	69
616201	GRE-LUTSEN 8	69	616206	GRE-CASCADE8	69

Table 3.2: Monitored 69 kV Buses

Voltage was monitored on the following 230 kV and 115 kV buses.

Bus #	Bus Name	kV	Bus #	Bus Name	kV	Bus #	Bus Name	kV
608614	98L TAP4	230	608683	STIN-MN7	115	608747	HATTRICK7	115
608615	ARROWHD4	230	608684	STIN-WI7	115	608883	TOWERMP7	115
608616	HILLTOP4	230	608685	SWAN LK7	115	608914	NTS1BUS7	115
608622	IRONRNG4	230	608686	15TH AV7	115	608915	N_SHORE7	115
608696	TAC HBR6	138	608688	COLBYVL7	115	608916	CANOSIA7	115
608630	STINSON5	115	608689	FRNCHRV7	115	608917	37L TAP7	115
608633	FAIRMPK7	115	608690	SBY2BUS7	115	608930	ENBSTH7	115
608660	BIGROCK7	115	608691	SLVRBYH7	115	608931	ENBEAST7	115
608661	TWOHBRS7	115	608692	SLVRBAY7	115	608932	ENBNTH7	115
608662	SAVANNA7	115	608694	FINLND_7	115	608970	BBT TAP7	115
608663	FLDWDTP7	115	608695	NUGGET 6	115	608971	ARGOTAP7	115
608664	WRENSHL7	115	608697	TAC HBR7	115	608972	ARGOSUB7	115
608665	THOMSON7	115	608698	HOYT LK6	115	608973	NSM1SUB7	115
608666	FONDULC7	115	608699	DUNKARD6	115	608974	NSM2SUB7	115
608667	POTLTCH7	115	608700	43L TAP6	115	615517	GRE-4CORNRS7	115
608668	CLOQUET7	115	608702	LASKIN 7	115	616675	GRE-WALDO 7	115
608669	FLDWOOD7	115	608704	EMBARAS7	115	616676	GRE-FINLAND7	115
608670	MDWLNDS7	115	608705	BABBITT7	115	616677	GRE-CLVRVLY7	115
608671	BURNETT7	115	608708	VIRGNIA7	115	618000	GRE-BERGNLK7	115
608672	HILLTOP7	115	608718	16L TAP7	115	618001	GRE-BERGNTP7	115
608673	ARROWHD7	115	608720	COTTNTP7	115	618004	GRE-LAKELND7	115
608674	HANESRD7	115	608721	ETCO 7	115	618005	GRE-COTTON 7	115
608675	RIDGEVW7	115	608722	FORBES 7	115	618006	GRE-IRON 7	115
608676	HIBBARD7	115	608734	IRON TP7	115	618007	GRE-PEARY 7	115
608678	NEMADJI7	115	608735	TBIRD S7	115	618019	GRE-KNFFLTP7	115
608679	GARY 7	115	608736	T-BIRD 7	115	618020	GRE-KNIFEFL7	115
608680	WNTR ST7	115	608739	BLCKBRY7	115			
608681	LSPI 7	115	608742	TAFT 7	115			

Table 3.3: Monitored 115+ kV Buses

Section 4: Base Case Analysis

The Winter (WTR), Summer (SUM), and Shoulder (SSH) Base Case models were developed utilizing MTEP19 2024 models with a local coincident peak developed from historical data.

4.1 System Intact Voltage Violations

There were no system intact voltage violations.

4.2 Non-Converged Contingencies

A "non-converged" contingency is one that the power flow software program (*PSS/E*) was not able to solve. There could be a number of explanations for why a solution could not be reached, but in general non-converged contingencies are indicative of severe contingencies and in some cases potential voltage or transient stability problems. The following non-converged contingencies result in voltage collapse scenarios which were not able to be resolved with existing infrastructure in the models.

Base Case: Voltage Collapse Scenarios	
Contingency	**Base Case**
P61:115-115:MP:BGR-COL:TCH-DKA	WTR
P61:115-115:MP:ARD-COL:ARD-HNS	WTR, SUM, & SSH
P61:115-115:MP:ARD-COL:SLA-HNS	WTR & SUM
P61:115-115:MP:ARD-COL:SLA-RGV	WTR
P61:115-115:MP:ARD-COL:COL-RGV	WTR

Table 4.1: Base Case Voltage Collapse Scenarios

North Shore Loop Voltage Stability

The first voltage collapse scenario listed in Table 4.1 exists in the Winter Base Case model and involves loss of Big Rock – Colbyville 115 kV (145 Line) in conjunction with the loss of either double circuited Taconite Harbor – Dunka Road 115 kV line (1 Line or 2 Line). It may be acceptable for planned outages on these three lines to occur during times of lighter North Shore Loop loading, such as during favorable Spring or Fall weather or during planned outages for a large industrial customer in Silver Bay. Unplanned outages on these three lines during times of higher North Shore Loop loading would likely result in an operational guide placing additional customers at risk of outage for loss of another line. The **North Shore Loop Voltage Stability** issue is discussed at length in Section 1.

Duluth Loop Voltage Stability

The final four voltage collapse scenarios listed in Table 4.1 involve loss of Arrowhead – Colbyville 115 kV (57 Line) in conjunction with either:

- Arrowhead – Haines Road 115 kV (58 Line) – Haines Road, Swan Lake Road, Ridgeview, and Colbyville substations served radially from Silver Bay
    - Collapse in Winter, Summer, and Shoulder models
- Swan Lake Road – Haines Road 115 kV (52 Line) – Swan Lake Road, Ridgeview, and Colbyville substations served radially from Silver Bay
    - Collapse in Winter and Summer models
- Swan Lake Road – Ridgeview 115 kV (19 Line) – Ridgeview, and Colbyville substations served radially from Silver Bay
    - Collapse in Winter model
- Colbyville – Ridgeview 115 kV (56 Line) – Colbyville Substation served radially from Silver Bay
    - Collapse in Winter model

Targeting lighter North Shore Loop and Duluth Loop loading for planned outages on the five Duluth Loop 115 kV transmission lines and at the Arrowhead, Haines Road, Swan Lake Road, Ridgeview, and Colbyville substations is not a viable solution. A voltage collapse scenario exists in the lightly loaded Shoulder Base Case model and others exist in the Summer Base Case model. Due to voltage stability concerns, a stability margin should be maintained and more Summer and Shoulder Base Case stability concerns may exist than the collapse scenarios listed above. Both planned and unplanned outages in the Duluth Loop would likely result in an operational guide placing additional customers at risk of outage for loss of another line. The **Duluth Loop Voltage Stability** issue is discussed at length in Section 1.

4.3 Post-Contingent Voltage Violations

Many post-contingent voltage violations were mitigated by switching local capacitor banks. Some voltage violations were identified and are discussed below.

Loss of Arrowhead – Haines Road 115 kV Line

Table 4.2 below shows 4 contingencies which disconnect Arrowhead – Haines Road 115 kV (58 Line) causing voltage violations in the Summer Base Case. With 58 Line out of service, system operations has historically been directed by MISO to open the Colbyville 145L breaker as an interim solution to avoid a potential voltage collapse scenario. Instead, the Big Rock – North Shore 115 kV (42 Line) connection at the Big Rock substation should be opened to separate the North Shore Loop. The Big Rock capacitor bank can support voltage in the Duluth Loop and with the 230 kV capacitor bank at Arrowhead, the violations listed below can be mitigated to an acceptable level.

Base Case: Post-Contingent Voltage Violations in Per Unit Voltage (Vpu) Following loss of Arrowhead – Haines Road 115 kV (58 Line) in Summer Case			
Bus	**Criteria Vpu**	**Base Case Vpu**	**Corrective Action**
P12:115:MP:ARD-HNS			
608674 HANESRD7 115.00	0.95	0.9290	Interim: Open 42 Line at BGR
608685 SWAN LK7 115.00	0.95	0.9302	Interim: Open 42 Line at BGR
P22:115:MP:ARD:BUS2			
608674 HANESRD7 115.00	0.95	0.9266	Interim: Open 42 Line at BGR
608685 SWAN LK7 115.00	0.95	0.9278	Interim: Open 42 Line at BGR
P23:115:MP:ARD:129L			
608674 HANESRD7 115.00	0.95	0.9266	Interim: Open 42 Line at BGR
608685 SWAN LK7 115.00	0.95	0.9278	Interim: Open 42 Line at BGR
P23:115:MP:ARD:6T			
608674 HANESRD7 115.00	0.95	0.9266	Interim: Open 42 Line at BGR
608685 SWAN LK7 115.00	0.95	0.9278	Interim: Open 42 Line at BGR

Table 4.2: Post-Contingent Voltage Violations Following Loss of Arrowhead – Haines Road 115 kV (58 Line)

4.4 Transformer Overloads

Three overloaded transformers were identified in the Duluth area and are discussed below.

In Tables 4.3 – 4.4, overloads on the two Arrowhead 230/115 kV transformers remain within their respective emergency rating following a 230 kV breaker fault at Arrowhead. A 98L or 98-99LW breaker failure results in the loss of one Arrowhead 230/115 kV transformer, Iron Range – Arrowhead – Hilltop 230 kV (98 Line), and the Hilltop 230/115 kV transformer. The remaining Arrowhead 230/115 kV transformer becomes the only 230/115 kV source to the Duluth area. The **Reliability of Duluth-Area Transmission Sources** issue is discussed at length in Section 1.

Concerns remain with post-contingent overloads on the Arrowhead 230/115 kV transformers. Post-contingent overloads on the Arrowhead 230/115 kV transformers are approximately 15 – 18 MW below their respective emergency rating. Local generation connected to the 115 kV system is online near the modeled maximum in the Winter Base Case model. If 25 MW of Winter Base Case generation listed below is offline, overloads begin to exceed the emergency rating of the remaining transformer.

- Hibbard generation is online at 62.5 MW, near the modeled maximum of 69 MW
- Thomson hydro generation is online at the modeled maximum of 76 MW
- Fond du Lac hydro generation is online at the modeled maximum of 12 MW

Relieving these transformer overloads will be considered when evaluating a solution to resolve existing issues on the transmission system in the Duluth area.

Base Case: Post-Contingent Loading of Arrowhead 230/115 kV Transformer #6					
Branch Name:	608615 ARROWHD4 230.00 3WNDTR ARD6 WND 1 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P24:230:MP:ARD:98L	**373.0**	**438.0**	**420.63**	Refer to Section 4.3

Table 4.3: Post-Contingent Overloads on Arrowhead 230/115 kV "6TR"

Base Case: Post-Contingent Loading of Arrowhead 230/115 kV Transformer #7					
Branch Name:	608615 ARROWHD4 230.00 3WNDTR ARD7 WND 1 2				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P24:230:MP:ARD:98-99LW	**373.0**	**438.0**	**422.74**	Refer to Section 4.3

Table 4.4: Post-Contingent Overloads on Arrowhead 230/115 kV "7TR"

In Table 4.5, the Hilltop 230/115 kV transformer is overloaded for an outage of one Arrowhead 230/115 kV transformer during a prior outage of the other Arrowhead 230/115 kV transformer. The Hilltop 230/115 kV transformer becomes the only 230/115 kV source to the Duluth area. This transformer is overloaded well above its emergency rating for the Winter, Summer, and Shoulder Base Case models. Replacing the Hilltop transformer with a larger capacity transformer or adding a parallel 230/115 kV transformer at Hilltop will resolve these overloads. The **Reliability of Duluth-Area Transmission Sources** issue is discussed at length in Section 1.

Base Case: Post-Contingent Loading of Hilltop 230/115 kV Transformer #1					
Branch Name:	608616 HILLTOP4 230.00 3WNDTR HIL1 WND 1 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P61:230-230:MP:ARD:6T:ARD:7TR	**187.0**	**234.0**	**320.59**	Additional Hilltop 230/115 kV Transformation
SUM	P61:230-230:MP:ARD:6T:ARD:7TR	**187.0**	**217.0**	**268.56**	Additional Hilltop 230/115 kV Transformation
SSH	P61:230-230:MP:ARD:6T:ARD:7TR	**187.0**	**217.0**	**252.53**	Additional Hilltop 230/115 kV Transformation

Table 4.5: Post-Contingent Overloads on Hilltop 230/115 kV "1TR"

4.5 Transmission Line Overloads

4.5.1 Single contingency overloads

Single contingency overloads are listed below which do not have a readily available system adjustment to mitigate the violation within a reasonable timeframe. For these overloads, there is an interim corrective action which is described but this is not viewed as an acceptable long-term solution.

Overloads listed in Tables 4.6 – 4.8 below are caused by the loss of a transmission line between the Arrowhead Substation and the North Shore Loop connection at the Colbyville Substation. Interim mitigation should involve opening the Big Rock – North Shore 115 kV (42 Line) connection at the Big Rock substation to prevent the thermal overloads listed in Tables 4.6 – 4.8 below.

Base Case: Post-Contingent Loading of Haines Road – Swan Lake Road 115 kV (52 Line)					
Branch Name:	608674 HANESRD7 115.00 608685 SWAN LK7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P12:115:MP:ARD-COL	**185.0**	**204.0**	**195.83**	Interim: Open 42 Line at BGR
SUM	P12:115:MP:ARD-COL	**144.0**	**159.0**	**152.66**	Interim: Open 42 Line at BGR

Table 4.6: Post-Contingent Overloads on Haines Road – Swan Lake Road 115 kV (52 Line)

Base Case: Post-Contingent Loading of Arrowhead – Colbyville 115 kV (57 Line)					
Branch Name:	608673 ARROWHD7 115.00 608688 COLBYVL7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P12:115:MP:ARD-HNS	**214.0**	**232.0**	**225.96**	Interim: Open 42 Line at BGR

Table 4.7: Post-Contingent Overloads on Arrowhead – Colbyville 115 kV (57 Line)

Base Case: Post-Contingent Loading of Arrowhead – Haines Road 115 kV (58 Line)					
Branch Name:	608673 ARROWHD7 115.00 608674 HANESRD7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P12:115:MP:ARD-COL	**214.0**	**235.0**	**228.55**	Interim: Open 42 Line at BGR

Table 4.8: Post-Contingent Overloads on Arrowhead – Haines Road 115 kV (58 Line)

4.5.2 Multiple contingency overloads

Multiple contingency overloads are listed below which do not have a readily available system adjustment to mitigate the violation within a reasonable timeframe. For some overloads, there may be an interim corrective action which is described but this is not viewed as an acceptable long-term solution.

Overloads listed in Tables 4.9 – 4.13 below are caused by the loss one transmission element listed below during a prior outage of another:

- Loss of North Shore Loop continuity at the Taconite Harbor Substation: An outage of Taconite Harbor – North Shore 115 kV (128 Line), Taconite Harbor 4TR 138/115 kV transformer, or double circuit Taconite Harbor – Dunka Road 115 kV (1 and 2 Lines); the most severe of these contingencies is loss of double circuit 1 and 2 Lines which leaves tapped load on 128 Line and load at the Taconite Harbor Substation served through the Duluth Loop; however, this contingency was not studied
- Outage of a transmission line in the Duluth Loop: An outage of Arrowhead – Colbyville 115 kV (57 Line) or Arrowhead – Haines Road 115 kV (58 Line) are more severe than other line outages

The more severe outages studied cause all in-service load in the Duluth Loop and up the North Shore to the GRE-Finland Substation to be served through a single transmission path in the Duluth Loop. Until a project is identified to mitigate these issues, the following interim mitigation should be utilized to avoid overloading Duluth Loop transmission lines:

- For a prior outage on the Taconite Harbor – North Shore 115 kV (128 Line), the 56L breaker at Colbyville should be opened. This causes Haines Road, Swan Lake Road, and Ridgeview substations to be served radially through Arrowhead – Haines Road 115 kV (58 Line) and Colbyville Substation, Big Rock Substation, and North Shore Switching Station to be served radially through Arrowhead – Colbyville 115 kV (57 Line). In this configuration, loss of a transmission line along either radial path leads to a significant loss of load.
- For a prior outage of a Duluth Loop transmission line, the Big Rock – North Shore 115 kV (42 Line) connection at the Big Rock substation should be opened. This causes the Duluth Loop and Big Rock Substation to be served radially through a transmission line originating at the Arrowhead Substation and the remaining North Shore load to be served radially from Taconite Harbor. In this configuration, loss of a transmission line along either radial path leads to a significant loss of load.

For these interim solutions, overloads listed in Tables 4.9 – 4.13 below remain within the respective normal rating of each transmission line. Overloads on the Ridgeview – Colbyville 115 kV (56 Line) can be resolved with a 90C thermal upgrade on this line. The **115 kV Transmission Line Overloads** issue is discussed at length in Section 1.

Base Case: Post-Contingent Loading of Ridgeview – Swan Lake Road 115 kV (19 Line)					
Branch Name:	608675 RIDGEVW7 115.00 608685 SWAN LK7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P61:115-115:MP:ARD-COL:TCH TR4	**185.0**	**204.0**	**204.47**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:TCH TR4	**144.0**	**159.0**	**185.93**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SSH	P61:115-115:MP:ARD-COL:TCH TR4	**144.0**	**159.0**	**160.21**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:NTS-TCH	**144.0**	**159.0**	**179.21**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above

Table 4.9: Post-Contingent Overloads on Ridgeview – Swan Lake 115 kV (19 Line)

Base Case: Post-Contingent Loading of Ridgeview – Colbyville 115 kV (56 Line)					
Branch Name:	608675 RIDGEVW7 115.00 608688 COLBYVL7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P61:115-115:MP:ARD-COL:TCH TR4	**178.0**	**196.0**	**178.05**	**90C Thermal Upgrade** Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:TCH TR4	**135.0**	**148.0**	**161.60**	**90C Thermal Upgrade** Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:NTS-TCH	**135.0**	**148.0**	**155.12**	**90C Thermal Upgrade** Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above

Table 4.10: Post-Contingent Overloads on Ridgeview – Colbyville 115 kV (56 Line)

Base Case: Post-Contingent Loading of Haines Road – Swan Lake Road 115 kV (52 Line)					
Branch Name:	608674 HANESRD7 115.00 608685 SWAN LK7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P61:115-115:MP:ARD-COL:TCH TR4	**185.0**	**204.0**	252.06	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:TCH TR4	**144.0**	**159.0**	235.52	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SSH	P61:115-115:MP:ARD-COL:TCH TR4	**144.0**	**159.0**	188.16	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
WTR	P61:115-115:MP:ARD-COL:NTS-TCH	**185.0**	**204.0**	245.94	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:NTS-TCH	**144.0**	**159.0**	228.63	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SSH	P61:115-115:MP:ARD-COL:NTS-TCH	**144.0**	**159.0**	183.56	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above

Table 4.11: Post-Contingent Overloads on Haines Road – Swan Lake 115 kV (52 Line)

Base Case: Post-Contingent Loading of Arrowhead – Colbyville 115 kV (57 Line)					
Branch Name:	608673 ARROWHD7 115.00 608688 COLBYVL7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P61:115-115:MP:ARD-HNS:TCH TR4	**214.0**	**232.0**	283.28	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-HNS:TCH TR4	**182.0**	**200.0**	265.91	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SSH	P61:115-115:MP:ARD-HNS:TCH TR4	**182.0**	**200.0**	216.44	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
WTR	P61:115-115:MP:ARD-HNS:NTS-TCH	**214.0**	**232.0**	276.30	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-HNS:NTS-TCH	**182.0**	**200.0**	257.37	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SSH	P61:115-115:MP:ARD-HNS:NTS-TCH	**182.0**	**200.0**	211.17	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
WTR	P61:115-115:MP:SLA-HNS:TCH TR4	**214.0**	**232.0**	265.94	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:SLA-HNS:TCH TR4	**182.0**	**200.0**	234.97	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
WTR	P61:115-115:MP:SLA-HNS:NTS-TCH	**214.0**	**232.0**	257.82	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:SLA-HNS:NTS-TCH	**182.0**	**200.0**	241.02	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above

Table 4.12: Post-Contingent Overloads on Arrowhead – Colbyville 115 kV (57 Line)

Base Case: Post-Contingent Loading of Arrowhead – Haines Road 115 kV (58 Line)					
Branch Name:	608673 ARROWHD7 115.00 608674 HANESRD7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
WTR	P61:115-115:MP:ARD-COL:TCH TR4	**214.0**	**235.0**	**281.63**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:TCH TR4	**182.0**	**200.0**	**263.82**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SSH	P61:115-115:MP:ARD-COL:TCH TR4	**182.0**	**200.0**	**206.79**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
WTR	P61:115-115:MP:ARD-COL:NTS-TCH	**214.0**	**235.0**	**275.36**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SUM	P61:115-115:MP:ARD-COL:NTS-TCH	**182.0**	**200.0**	**256.78**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above
SSH	P61:115-115:MP:ARD-COL:NTS-TCH	**182.0**	**200.0**	**202.16**	Interim: Open COL 56L Breaker or 42 Line at BGR As Described Above

Table 4.13: Post-Contingent Overloads on Arrowhead – Haines Road 115 kV (58 Line)

Overloads listed in Table 4.14 below are caused by the loss of a Duluth Loop transmission line during a prior outage of another Duluth Loop transmission line. This causes all or most in-service load between the Taconite Harbor and Arrowhead substations to be served from Taconite Harbor, causing overloads on 128 Line. Until a project is identified to mitigate these issues, the Big Rock – North Shore 115 kV (42 Line) connection at the Big Rock substation should be opened to create a normal open in the North Shore Loop. For this interim solution, overloads listed in Table 4.14 below remain within the normal rating of the transmission line. The **115 kV Transmission Line Overloads** issue is discussed at length in Section 1.

Base Case: Post-Contingent Loading of North Shore – Taconite Harbor 115 kV (128 Line)					
Branch Name:	608694 FINLND_7 115.00 608915 N_SHORE7 115.00 1 608694 FINLND_7 115.00 608697 TAC HBR7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
SUM	P61:115-115:MP:ARD-COL:SLA-RGV	**174.0**	**191.0**	**198.94**	Interim: Open 42 Line at BGR
SSH	P61:115-115:MP:ARD-COL:SLA-HNS	**174.0**	**191.0**	**210.64**	Interim: Open 42 Line at BGR

Table 4.14: Post-Contingent Overloads on North Shore – Taconite Harbor 115 kV (128 Line)

Overloads listed in Table 4.15 below are caused by the loss of Big Rock – Colbyville 115 kV (145 Line) during a prior outage of one of the double circuit Taconite Harbor – Dunka Road 115 kV lines (1 Line or 2 Line). All of the North Shore Loop load from Taconite Harbor to Two Harbors is being served through a single set of 477 ACSR conductor on the remaining Taconite Harbor – Dunka Road 115 kV line. This scenario causes severe overloads in the Summer and Shoulder Cases and a voltage collapse scenario in the Winter Case. It may be acceptable for planned outages on these three lines to occur during times of lighter North Shore Loop loading, such as during favorable Spring or Fall weather or during planned outages for a large industrial customer in Silver Bay. However, these customer outage periods typically occur at most twice a year and are typically short in duration. Unplanned outages on these three lines would likely result in an operational guide placing additional customers at risk of outage for loss of another line. The same interim operational solutions which apply to the **North Shore Loop Voltage Stability** issue is discussed at length in Section 1 would resolve overload listed in Table 4.15 below.

Base Case: Post-Contingent Loading of Taconite Harbor – Dunka Road 115 kV Lines (1 & 2 Line)					
Branch Name:	608697 TAC HBR7 115.00 608699 DUNKARD7 115.00 1 608697 TAC HBR7 115.00 608699 DUNKARD7 115.00 2				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
SUM	P61:115-115:MP:BGR-COL:TCH-DKA	**123.0**	**135.0**	170.58	Interim: Operational Guide as Discussed
SSH	P61:115-115:MP:BGR-COL:TCH-DKA	**123.0**	**135.0**	146.03	Interim: Operational Guide as Discussed

Table 4.15: Post-Contingent Overloads on Taconite Harbor – Dunka Road 115 kV Lines (1 & 2 Line)

The 98L Tap – Hilltop 230 kV (Hilltop 98 Line) is overloaded for an outage of one Arrowhead 230/115 kV transformer during a prior outage of the other Arrowhead 230/115 kV transformer. The Hilltop 230/115 kV transformer becomes the only 230/115 kV source to the Duluth area and Hilltop 98 Line is the only 230 kV line into the Hilltop Substation. The overload listed in Table 4.15 below is within the emergency rating of this line in the Summer Base Case. Overloads on Hilltop 98 Line can be resolved with a 100C thermal upgrade of this line. Increasing the normal rating of this line is necessary to allow additional 230/115 kV transformation capacity at Hilltop to be fully utilized.

Base Case: Post-Contingent Loading of 98L Tap – Hilltop 230 kV (Hilltop 98 Line)					
Branch Name:	608614 98L TAP4 230.00 608616 HILLTOP4 230.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Base Case MVA**	**Corrective Action**
SUM	P61:230-230:MP:ARD:6T:ARD:7TR	**252.0**	**277.0**	**268.56**	**100C Thermal Upgrade**

Table 4.16: Post-Contingent Overloads on 98L Tap – Hilltop 230 kV (Hilltop 98 Line)

4.6 Base Case Outstanding Issues

The Base Case study results illustrate the outstanding voltage stability issues and thermal overloads which remain in the North Shore Loop and the Duluth Loop after generator transitions in the area. Currently, there are interim solutions which can be utilized to manage most of these issues. However, these interim solutions add more operational complexity, planned outage restrictions, and outage risk to customers. The Base Case results also illustrate the severity of some of the outstanding issues discussed in Section 1.

North Shore Loop Voltage Stability

To help manage the voltage collapse scenario and severe thermal overloads for loss of Big Rock – Colbyville 115 kV (145 Line) and either of the Taconite Harbor – Dunka Road 115 kV lines (1 Line or 2 Line), planned outages of 1 Line, 2 Line, or 145 Line, it may be acceptable for planned outages on these three lines to occur during times of lighter North Shore Loop loading, such as during favorable Spring or Fall weather or during planned outages for a large industrial customer in Silver Bay. However, these customer outage periods typically occur at most twice a year and are typically short in duration. These outage constraints severely limit Minnesota Power's ability to perform maintenance on approximately 145 miles of 115 kV transmission lines. Unplanned outages on these three lines would likely result in an operational guide placing additional customers at risk of outage for loss of another line.

Minnesota Power should implement the near-term transfer trip scheme and operational guides described under **North Shore Loop Voltage Stability** in Section 1 to manage these issues. A long-term transmission solution to resolve these issues will not be proposed at this time due to the significant investment likely required. These issues will continue to be monitored and when appropriate, a long-term transmission solution may be proposed. Some conceptual long-term transmission solutions to resolve these voltage stability concerns and thermal overloads listed in Table 4.15 are:

- Construct a parallel Big Rock – Colbyville 115 kV line approximately 23 miles long
- Construct a new Taconite Harbor – Dunka Road 115 kV line approximately 61 miles long
- Rebuild the existing double circuited Taconite Harbor – Dunka Road 115 kV lines with significantly larger conductor

Sufficient dispatchable generation in targeted locations between the Taconite Harbor and Big Rock substations could resolve the identified 1 Line and 2 Line overloads and North Shore Loop voltage collapse scenarios. This generation could potentially be utilized to resolve other Base Case outstanding issues.

Duluth Loop Voltage Stability and 128 Line Overloads

The risk of voltage collapse or North Shore – Taconite Harbor 115 kV (128 Line) overloads remains a significant concern for loss of multiple Duluth Loop transmission lines. Targeting lighter North Shore Loop and Duluth Loop loading for planned outages on the five Duluth Loop 115 kV transmission lines and at the Arrowhead, Haines Road, Swan Lake Road, Ridgeview, and Colbyville substations is not a viable long-term solution. Voltage stability concerns and 128 Line overloads still exist in the lightly loaded Shoulder Base Case model. The existing operational guide places all Duluth Loop and North Shore Loop load on a radial feed from either the Taconite Harbor Substation or the Arrowhead Substation. The **Duluth Loop Voltage Stability** issue is discussed at length in Section 1. New transmission infrastructure, generation infrastructure, or some combination of both is needed to resolve these issues.

A new transmission path into the Ridgeview Substation would resolve the identified 128 Line overloads and voltage collapse scenarios associated with serving Haines Road, Swan Lake Road, and Ridgeview substations from Silver Bay. Extending this transmission path further to the Colbyville Substation would resolve the remaining Winter Case collapse scenario associated with serving Colbyville Substation from Silver Bay. Sufficient dispatchable generation in targeted locations between Silver Bay and the Haines Road Substation could also resolve the identified 128 Line overloads and Duluth Loop voltage collapse scenarios.

Duluth Loop Line Overloads

The risk of severe thermal overloads on 115 kV transmission lines in the Duluth Loop remains a significant concern for loss of a Duluth Loop transmission line and the 115 kV connection between the Taconite Harbor Substation and the North Shore Switching Station. Targeting lighter North Shore Loop and Duluth Loop loading for planned outages on the five Duluth Loop 115 kV transmission lines, Taconite Harbor – North Shore 115 kV (128 Line), and at the Arrowhead, Haines Road, Swan Lake Road, Ridgeview, Colbyville, and Taconite Harbor substations is not a viable solution. Severe Duluth Loop transmission line overloads still exist in the lightly loaded Shoulder Base Case model. The existing Duluth Loop operational guide places all Duluth Loop and North Shore Loop load on a radial feed from either the Taconite Harbor Substation or the Arrowhead Substation. New transmission infrastructure, generation infrastructure, or some combination of both is needed to resolve these issues. The **115 kV Transmission Line Overloads** issue is discussed at length in Section 1. A new transmission path into the Ridgeview Substation along with a 90C thermal upgrade of Ridgeview – Colbyville 115 kV (56 Line) could resolve the identified Duluth Loop overloads associated with serving load between the Haines Road and Finland substations through a single Duluth Loop transmission path. Sufficient dispatchable generation in targeted locations between Silver Bay and the Haines Road Substation could also resolve the identified Duluth Loop line overloads.

Reliability of Duluth-Area Transmission Sources

To manage the risk of significant overloads on either Arrowhead 230/115 kV transformer, planned outages on each of these transformers should be targeted for lighter loading timeframes. However, each Arrowhead 230/115 kV transformer shares a 230 kV circuit breaker with the sole 230 kV transmission line into the Hilltop substation. A failure of either of these breakers would disconnect a 230/115 kV transformer at the Arrowhead Substation and the sole 230/115 kV transformer at the Hilltop Substation. During Winter Peak, this would cause overloads on the remaining Arrowhead 230/115 kV transformer approaching its emergency rating. The **Reliability of Duluth-Area Transmission Sources** issue is discussed at length in Section 1.

Severe overloads remain on the Hilltop 230/115 kV transformer for an outage of both Arrowhead 230/115 kV transformers. These severe overloads occur even during lighter loading timeframes for targeted outages on either Arrowhead 230/115 kV transformer. Replacing the Hilltop transformer with a larger capacity transformer or adding a parallel 230/115 kV transformer at Hilltop will resolve these overloads. Sufficient dispatchable generation connected to the 115 kV transmission system in the Duluth Area could also resolve these overloads.

Iron Range – Arrowhead – Hilltop 230 kV (98 Line) is an existing 3-terminal line approximately 72 Miles in length. The Hilltop 230 kV Tap on this line is approximately 0.7 miles from the Arrowhead Substation. Disconnecting this 230 kV tap from 98 Line and extending this to an open line entrance position at the Arrowhead Substation would greatly reduce line mile exposure to the sole Hilltop 230 kV source from 72 Miles to approximately 8 Miles. The additional breaker at the Arrowhead Substation associated with this 230 kV tap extension would eliminate one of the existing breaker failure scenarios disconnecting a 230/115 kV transformer at both the Arrowhead and Hilltop substations. This would also allow significant relaying improvements to be made on 98 Line and newly created Arrowhead – Hilltop 230 kV (108 Line).

Disconnecting the Hilltop 230 kV Tap from existing 98 Line and extending this tap to the Arrowhead Substation provides significant reliability improvements to the 230/115 kV transformers at the Arrowhead and Hilltop Substations and will be evaluated. Additionally, overloads on the 98L Tap – Hilltop 230 kV can be resolved with a 100C thermal upgrade of this line. Increasing the normal rating of this line is necessary to allow additional 230/115 kV transformation capacity at Hilltop to be fully utilized.

4.7 Duluth Loop Voltage Stability Threshold

Four Duluth Loop voltage collapse scenarios listed in Table 4.1 involve loss of Arrowhead – Colbyville 115 kV (57 Line) in conjunction with an outage along the remaining Duluth Loop transmission path:

- Arrowhead – Haines Road 115 kV (58 Line) – Collapse in Winter, Summer, and Shoulder models
- Swan Lake Road – Haines Road 115 kV (52 Line) – Collapse in Winter and Summer models
- Swan Lake Road – Ridgeview 115 kV (19 Line) – Collapse in Winter model
- Colbyville – Ridgeview 115 kV (56 Line) – Collapse in Winter model

During an outage along one of the five transmission lines listed above, the loss of a second Duluth Loop transmission line during the outage would leave the North Shore and all or part of the Duluth Loop served by a single 140-mile-long transmission line originating in the Hoyt Lakes area. Without the support previously provided by the local baseload generators in the North Shore Loop, the transmission system is no longer able to support the large amount of Duluth Loop load over such a long distance. The expected result would be a post-contingency voltage collapse in the Duluth Loop area that would then extend up the North Shore toward Silver Bay.

More collapse scenarios exist in the Winter Case, which has higher load levels than the Summer Case and Shoulder Case. The STATCOM and 4 capacitor banks at the North Shore Switching Station in Silver Bay provide voltage support to the transmission system. When the STATCOM reaches its maximum MVAR output with all local capacitor banks in-service, a voltage collapse scenario occurs.

For various levels of generation in the North Shore Loop, the maximum modeled load level was identified which could be served radially from Silver Bay toward Duluth prior to a voltage collapse. This load level was found by scaling modeled load between the Silver Bay Hillside and Haines Road substations. To maintain some stability margin, the Duluth Loop stability threshold was defined to be 90% of the maximum modeled load level identified prior to a voltage collapse. With Arrowhead – Colbyville 115 kV (57 Line) and Arrowhead – Haines Road 115 kV (58 Line) disconnected in the Winter Case, power-Voltage (PV) curves were developed and the following thresholds were determined:

- January 2014 Timeframe: All North Shore Loop generators online (459 MW):
  - MISO_2014WIN Model – Winter Case
  - Prior to development of the North Shore Switching Station and STATCOM
  - 108 MW Duluth Loop stability threshold
- January 2020 Timeframe – Only Laskin generation online (118 MW)
  - Winter Base Case Model
  - Includes the North Shore Switching Station and STATCOM in Silver Bay
  - 65.7 MW Duluth Loop stability threshold
- January 2020 Timeframe – No North Shore Loop generators online (0 MW)
  - Winter Base Case Model
  - Includes the North Shore Switching Station and STATCOM in Silver Bay
  - 54 MW Duluth Loop stability threshold

Figure 4.1 below shows PV curves at substations in the Duluth Loop and North Shore Loop for scaled load levels from Haines Road to Silver Bay Hillside substations with all North Shore Loop generation online in the 2014 timeframe. A voltage collapse occurs when this load level exceeds 120 MW. This is an optimistic load level prior to reaching a voltage collapse as capacitor banks were switched on manually as the load was increased. In reality, having these capacitor banks online prior to the second transmission line tripping offline could lead to high voltage violations at some buses.

- Duluth Loop voltage stability threshold with all North Shore Loop generators online:
  90% * 120 MW = 108 MW

The Duluth Loop voltage stability threshold was 108 MW with all North Shore Loop generators online in the 2014 timeframe. Modeled peak load from Ridgeview to Silver Bay Hillside substations is 90.5 MW, within this threshold, but an additional 34.9 MW of modeled peak load at the Swan Lake Road Substation exceeds this threshold.

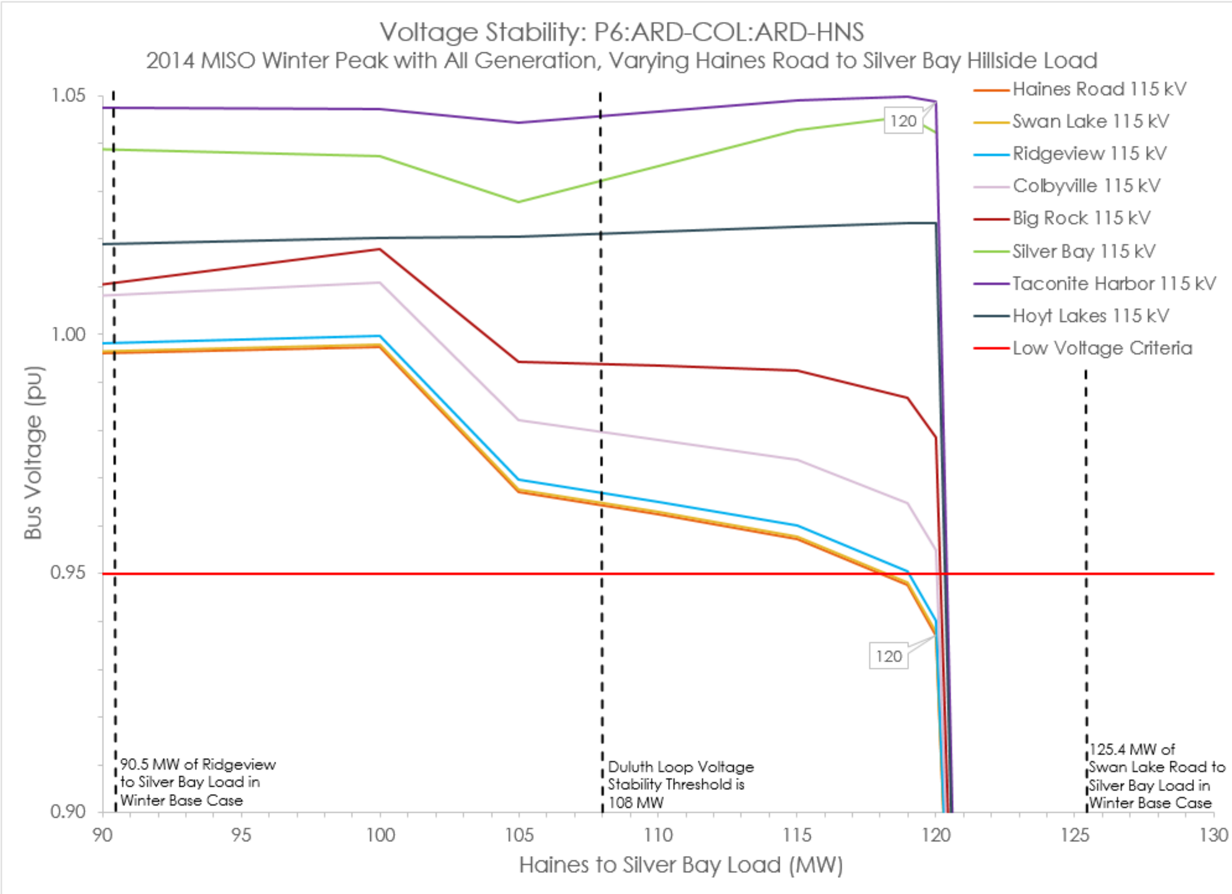


Figure 4.1: PV Curves for Duluth Loop Voltage Stability Threshold with all North Shore Loop Generation Online

Figure 4.2 below shows PV curves at substations in the Duluth Loop and North Shore Loop for scaled load levels from Haines Road to Silver Bay Hillside substations with Laskin Generation online. A voltage collapse occurs when this load level exceeds 73 MW. This is an optimistic load level prior to reaching a voltage collapse as capacitor banks were switched on manually as the load was increased. In reality, having these capacitor banks online prior to the second transmission line tripping offline could lead to high voltage violations at some buses.

- Duluth Loop voltage stability threshold with Laskin generation online: 90% * 73 MW = 65.7 MW

The Duluth Loop voltage stability threshold is 65.7 MW with Laskin Generation online. Modeled peak load from Colbyville to Silver Bay Hillside substations is 63.1 MW, within this threshold, but an additional 27.4 MW of modeled peak load at the Ridgeview Substation exceeds this threshold.

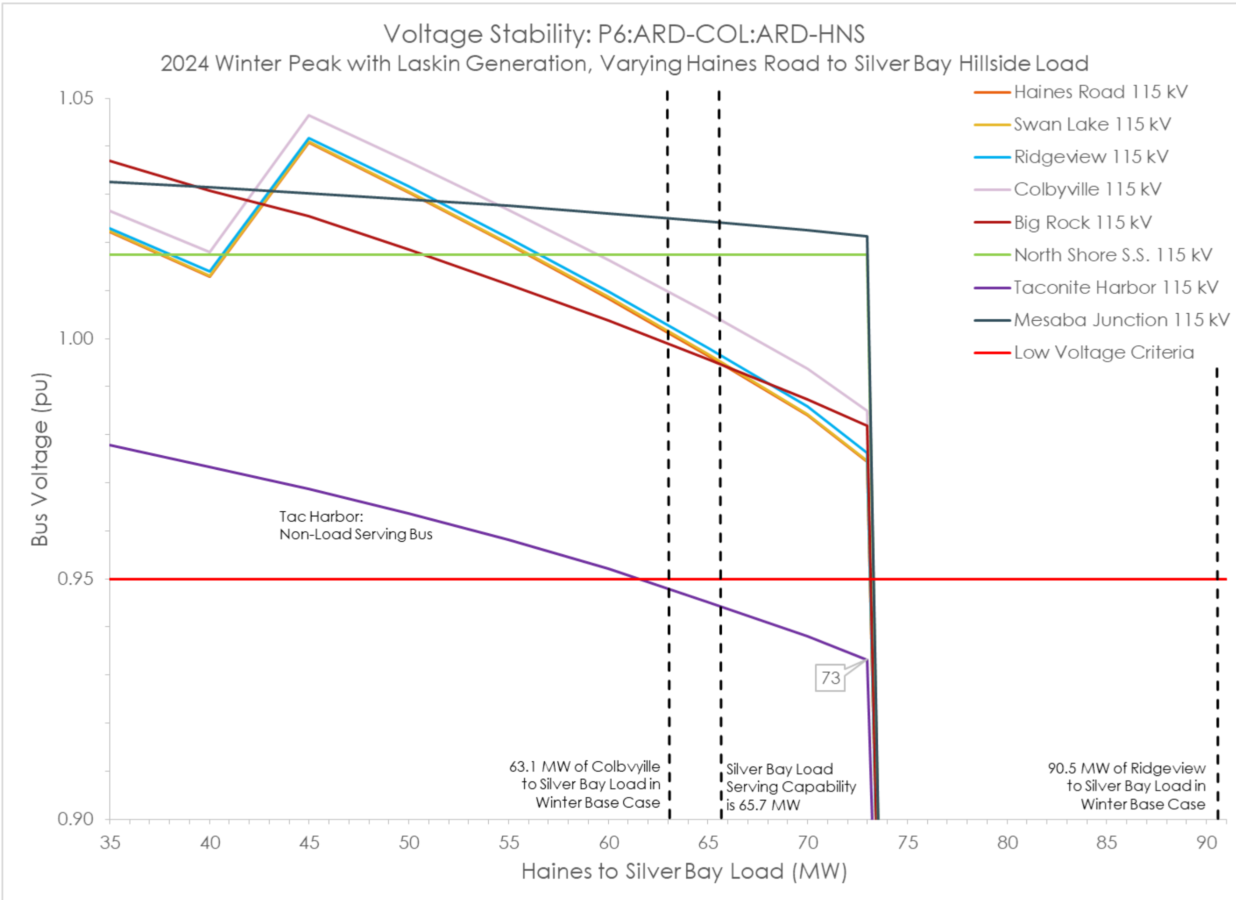


Figure 4.2: PV Curves for Duluth Loop Voltage Stability Threshold with Laskin Generation Online

Figure 4.3 below shows PV curves at substations in the Duluth Loop and North Shore Loop for scaled load levels from Haines Road to Silver Bay Hillside substations with Laskin Generation offline. A voltage collapse occurs when this load level exceeds 60 MW. This is an optimistic load level prior to reaching a voltage collapse as capacitor banks were switched on manually as the load was increased. In reality, having these capacitor banks online prior to the second transmission line tripping offline could lead to high voltage violations at some buses.

- Duluth Loop voltage stability threshold with Laskin generation offline: 90% * 60 MW = 54 MW

The Duluth Loop voltage stability threshold is 54 MW with Laskin Generation offline. Modeled peak load from French River to Silver Bay Hillside substations is 42.2 MW, within this threshold, but an additional 20.9 MW of modeled peak load at the Colbyville Substation exceeds this threshold.

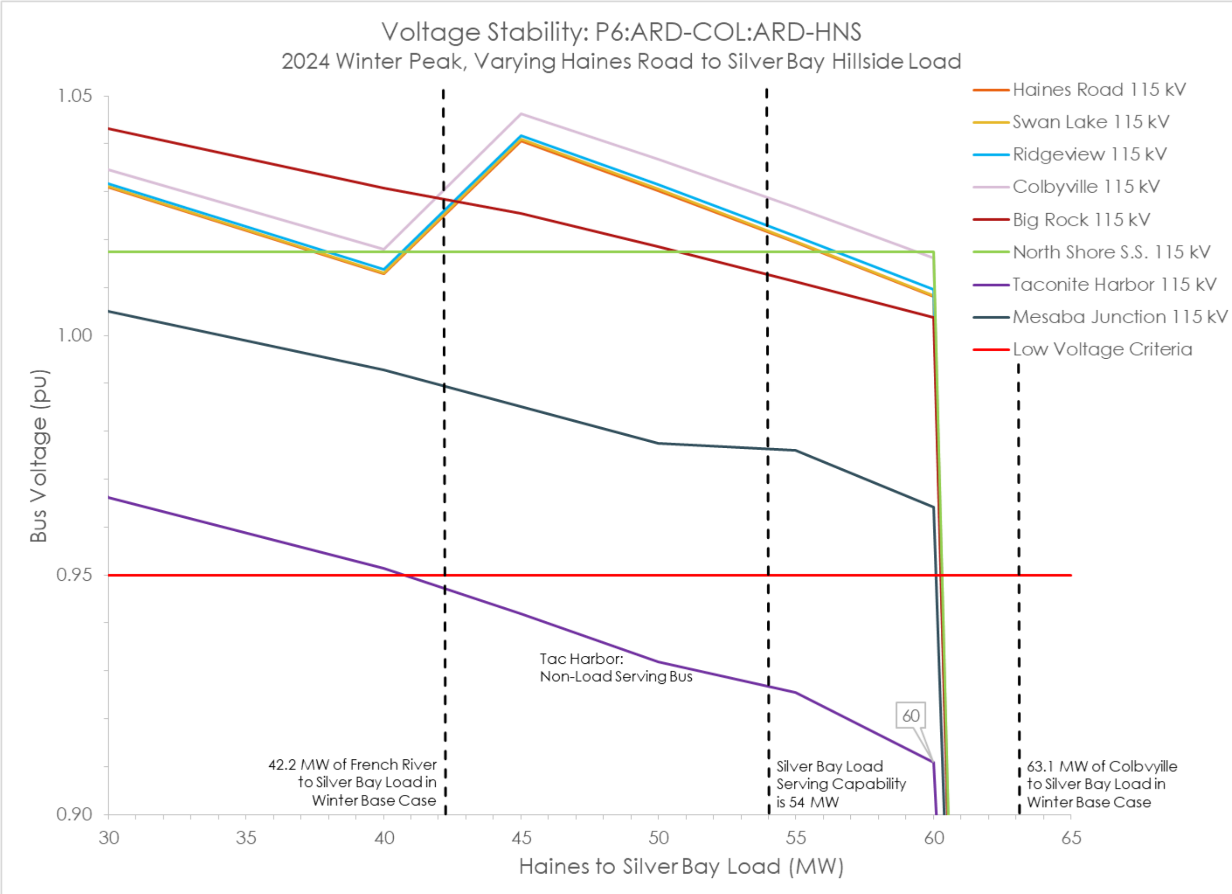


Figure 4.3: PV Curves for Duluth Loop Voltage Stability Threshold with Laskin Generation Offline

These PV curves illustrate how the Duluth Loop voltage stability thresholds were identified and how this threshold has degraded since the 2014 timeframe. As generation in the North Shore Loop has retired, idled, or transitioned to peaking operation, the Duluth Loop voltage stability threshold has steadily reduced, effectively reducing reliable load-serving capability for the Duluth Loop. With all North Shore Loop generation online in the 2014 timeframe, serving Swan Lake Road Substation load from Silver Bay during peak loading was unacceptable. With only Laskin generation online, serving Ridgeview Substation load from Silver Bay during peak loading is unacceptable. With no North Shore Loop generation online, serving Colbyville Substation load from Silver Bay during peak loading is unacceptable. This is clearly shown when comparing the calculated Duluth Loop voltage stability threshold over time, as shown in Table 4.17.

Year	North Shore Loop Generators Online (Output)	Voltage Stability Threshold
2014	All North Shore Loop Generators Online (459 MW)	108.0 MW
2020	Only Laskin Energy Center Online (118 MW)	65.7 MW
2020	No North Shore Loop Generators Online (0 MW)	54.0 MW

Table 4.17: Duluth Loop Voltage Stability Thresholds

Section 5: Alternatives Analysis

The Base Case study results illustrate a project is needed to resolve the outstanding issues listed below which remain in the North Shore Loop and Duluth Loop:

- Taconite Harbor – North Shore 115 kV (128 Line) overloads and Duluth Loop voltage stability issues for loss of two Duluth Loop transmission lines are significant issues that must be resolved
    - The Winter Base Case voltage collapse scenario when serving Colbyville Substation load from Silver Bay is an issue that can be managed with Laskin generation online. Depending on the solutions evaluated, additional analysis may be required to determine whether this issue should be resolved
- Reliability of Duluth-Area transmission sources for loss of both Arrowhead 230/115 kV transformers is a significant issue that must be resolved
- Duluth Loop transmission line overloads for loss of a Duluth Loop transmission line and North Shore Loop continuity at the Taconite Harbor Substation are significant issues that must be resolved

Resolving the North Shore Loop voltage stability issue is not considered a need at this time due to the existing operational guides in place. Significant distance separates this issue from the other related issues in the Duluth area. For this reason, a transmission solution would likely require significant additional investment to resolve the North Shore Loop voltage stability issue. If a non-transmission solution is selected to resolve the outstanding issues listed above, the location of this solution could be carefully selected to also resolve the North Shore Loop voltage stability issue.

Based on the severity of the Duluth Loop voltage collapse scenarios, Duluth Loop line overloads, and 128 Line overloads:

- A third transmission path into the Duluth Loop connecting to the Ridgeview Substation should resolve most of the Duluth Loop related issues listed above. Connecting this third transmission path to the Colbyville Substation would resolve the Winter Base Case collapse scenario when serving Colbyville Substation from Silver Bay. This transmission line alone will not resolve the issue concerning the reliability of Duluth-Area transmission sources.
- The Duluth Loop voltage collapse scenarios begin with a severe depression in voltage at the Taconite Harbor Substation due to a very large amount of power flowing through this substation towards the Duluth Loop. For these collapse scenarios, generation in the Duluth Loop or along the North Shore would reduce the power flowing through the Taconite Harbor Substation and could mitigate these voltage collapse scenarios.
- Generation at the Ridgeview Substation or up the North Shore to Silver Bay would reduce 128 Line overloads, Duluth Loop line overloads, and Duluth Area transformer loading.

The following solutions will be evaluated to resolve these outstanding issues.

5.1 Solution Screening

5.1.1 Transmission Solutions

The Duluth Loop and North Shore Loop consist of 115 kV lines with two connections to 230/115 kV Arrowhead Substation. For transmission level voltage in the Duluth area, Minnesota Power owns and operates only 115 kV and 230 kV. For these reasons, only 115 kV and 230 kV transmission solutions will be considered for a new transmission path into the Duluth Loop.

115 kV Transmission Line Endpoints

Ridgeview Substation and Colbyville Substation

Serving Ridgeview Substation load from Silver Bay is a significant voltage collapse issue that must be resolved. Serving Colbyville Substation load from Silver Bay is a marginal voltage collapse issue that, depending on the solutions evaluated, may require additional analysis to determine whether this issue should be resolved. A third transmission path into the Duluth Loop at a minimum should connect to the Ridgeview Substation and extending this further to the Colbyville Substation would resolve additional issues.

Hilltop 230/115 kV Substation

The Hilltop 230/115 kV Substation will be considered as an endpoint for a new Duluth Loop 115 kV transmission path. This substation was constructed in the 1990's with a single 230 kV transmission source and one 230/115 kV transformer. The substation was designed to accommodate a 230 kV ring bus expansion and a second 230/115 kV transformer. Two existing 115 kV transmission lines could be reconfigured and converted to 230 kV to create a new Arrowhead – Hilltop 230 kV Line into the Hilltop Substation.

Arrowhead 230/115 kV Substation

Both existing Duluth Loop transmission paths originate at the Arrowhead Substation. There are two 115 kV main buses at this substation, one with Arrowhead – Colbyville 115 kV (57 Line) and one with Arrowhead – Haines Road 115 kV (58 Line). Due to the configuration of the Arrowhead 115 kV Substation, it would be very difficult to create a new 115 kV bus. Voltage collapse concerns will remain if a third transmission path into the Duluth Loop shares a bus connection with one of the existing Duluth Loop transmission paths. For these reasons it was decided that a third 115 kV transmission path into the Duluth Loop should not originate at the Arrowhead Substation. For similar reasons, the following transmission lines and substations were ruled as a starting point for a new 115 kV transmission path into the Duluth Loop:

- Arrowhead – GRE Four Corners 115 kV (129 Line): This transmission line and the GRE Four Corners Substation is radially fed from the Arrowhead Substation. These sources were removed from consideration because voltage collapse concerns would remain.
- 3-Terminal Arrowhead – Eveleth Taconite – Virginia 115 kV (16 Line): This transmission line is approximately 58 Miles in length and most of the line is relatively small 4/0 conductor which would need to be rebuilt and reconductored. The Eveleth Taconite and Virginia substations are both more than 47 Miles from the Arrowhead Substation, a long distance to serve significant Duluth Loop load from 115 kV sources. These sources were removed from consideration because of significant upgrade costs and voltage collapse concerns could remain.

Arrowhead – 15th Avenue West 115 kV (71 Line)

The Arrowhead – 15th Avenue West 115 kV Line passes in close proximity to the Hilltop 230/115 kV substation. This line could be reconfigured into an Arrowhead – Hilltop 115 kV Line which could become a 3-terminal line connecting into the Duluth Loop. Operating this as a 3-terminal line would introduce some operational and relaying complexity and therefore is not preferable.

230 kV Transmission Line Endpoints

Arrowhead 230/115 kV Substation

The Arrowhead Substation will be considered as an endpoint for a new Duluth Loop 230 kV transmission path. The 230 kV yard has two open bays for new 230 kV transmission lines and there are no known single points of failure that would disconnect both a new Duluth Loop 230 kV transmission line and an existing Duluth Loop 115 kV transmission path.

Conceptual Rice Lake 230/115 kV Substation

Due to space constraints at existing 115 kV substations in the Duluth Loop to accommodate a 230 kV substation expansion, it is likely a new substation would need to be developed to accommodate a new 230 kV Duluth Loop transmission path. Existing Arrowhead – Colbyville 115 kV (57 Line) and Ridgeview – Colbyville 115 kV (56 Line) share a common corridor heading West from the Colbyville Substation until 56 Line turns South just East of Rice Lake Road. A new 230/115 kV substation located near the West end of this common corridor will be considered which will allow the two existing Duluth Loop 115 kV transmission paths to be looped into.

Double Circuiting

Establishing a third transmission path into the Duluth Loop is primarily needed to ensure the Duluth Loop remains connected to Duluth at all times. Without generation online in the North Shore Loop, the Duluth Loop cannot be served radially from Silver Bay. For outages in the Duluth Loop, an operational guide directs the North Shore Loop connection at Colbyville to be opened. This leaves all North Shore load on a radial connection from the Hoyt Lakes area and all Duluth Loop load on a radial connection from the Arrowhead Substation. For the following reasons, double circuiting any two transmission paths from Duluth into the Duluth Loop is not acceptable:

- During maintenance on the independent Duluth Loop transmission path, a common tower failure involving two Duluth Loop transmission paths would likely lead to a voltage collapse scenario. The possibility of this voltage collapse during this outage could cause the existing operational guide to be utilized where the North Shore Loop connection at the Colbyville Substation is opened.
- During maintenance on the two double circuit Duluth Loop transmission paths requiring an outage of both circuits, an outage of the independent Duluth Loop transmission path would likely lead to a voltage collapse scenario. The possibility of a voltage collapse would cause the existing operational guide to be utilized where the North Shore Loop connection at the Colbyville Substation is opened.

The following transmission lines make up the two existing Duluth Loop transmission paths:

- Arrowhead – Colbyville 115 kV Line (57 Line)
- Arrowhead – Haines Road 115 kV Line (58 Line)
- Haines Road – Swan Lake Road 115 kV Line (52 Line)
- Swan Lake Road – Ridgeview 115 kV Line (19 Line)
- Ridgeview – Colbyville 115 kV Line (56 Line)

It is acceptable to double circuit a Duluth Loop transmission path with other transmission lines not associated with the Duluth Loop. Some of the following transmission lines were considered:

- Arrowhead – 15th Avenue West 115 kV (71 Line)
- Iron Range – Arrowhead – Hilltop 230 kV Line (Existing 98 Line)

5.1.2 Non-Transmission Solutions

Various non-transmission solutions were evaluated, including new peaking generation, distributed generation, renewable generation, battery energy storage, demand side management, and reactive resources. A viable solution must resolve Duluth Loop voltage stability issues, relieve transmission line overloads, and enhance the reliability of Duluth-area transmission sources.

To adequately resolve the Duluth Loop voltage stability issues, the operational characteristics of any generation or non-wire alternative must enable it to effectively offset a significant amount of load in the Duluth Loop during an outage of either Arrowhead – Colbyville 115 kV (57 Line) or Arrowhead – Haines Road 115 kV (58 Line). This generation will be utilized to proactively reduce the amount of load effectively seen by the transmission system in order to remain within the Duluth Loop voltage stability threshold until the outage is restored. Therefore, the generation or non-wire alternative must be located at or near the Duluth Loop substations and must be available at the necessary time, with the necessary response, and for the necessary duration to address the Duluth Loop voltage stability issues. This generation must be available for dispatch, able to ramp up quickly, capable of matching the system load, and operate for the appropriate duration based on the restoration time of the transmission line outage.

As identified in Section 4.7, the Duluth Loop voltage stability threshold with none of the North Shore Loop generators online is 54 MW, increasing to 65.7 MW if the peaking units at the Laskin Energy Center are online. Therefore, a minimum generation or non-wire solution must be able to produce enough power to offset any Duluth Loop load above this threshold during peak-hour loading. The historical peak load for the area in the 2019 data set examined in Section 5.5 is 139.7 MW and occurs on January 29th at 6:00 PM. Based solely on the historical peak load, therefore, a generation or non-wire alternative must be able to offset a minimum of 74 MW of Duluth Loop load, as shown in the equation below.

139.7 MW (Historical Peak) – 65.7 MW (Voltage Stability Threshold) = 74 MW

This is the absolute minimum as it assumes Laskin generation may be must-run for reliability during prior outages in the Duluth Loop and leaves no room for load additions beyond the 2019 historical winter peak level. A more appropriate minimum generation or non-wire alternative would include some margin for load growth or unforeseen system conditions, likely pushing the actual need well above 100 MW. However, for the purpose of the following discussion of generation and non-wire alternatives, the minimum 74 MW requirement was used.

5.2 Transmission Solutions

The existing Duluth Area transmission network is shown in Figure 5.1 below.

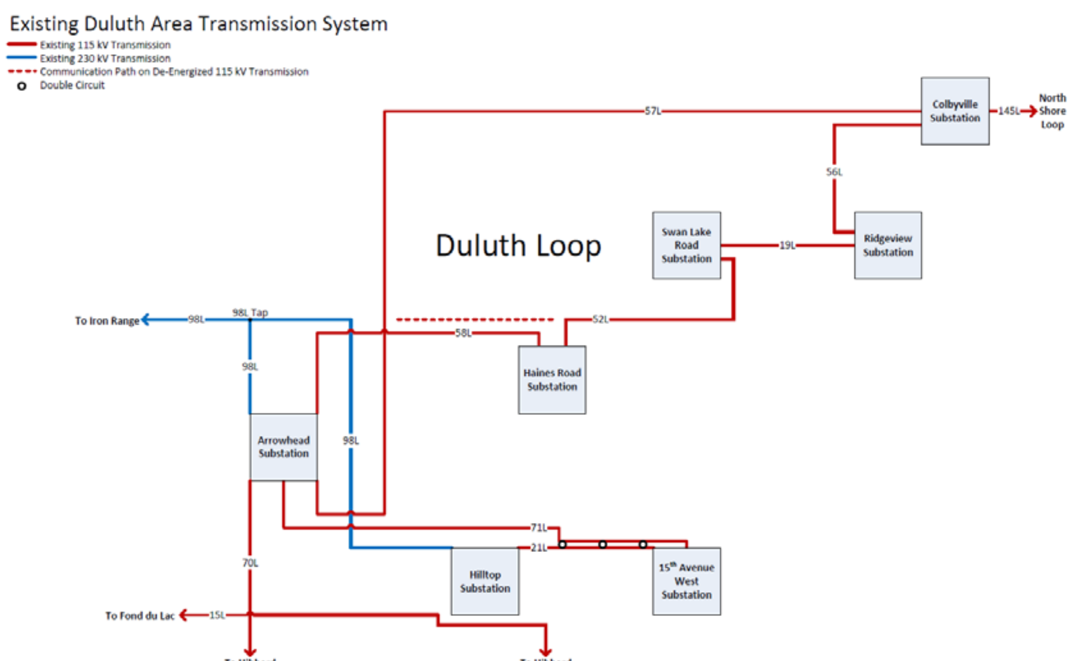


Figure 5.1: Existing Duluth Area Transmission System

5.2.1 71L Tap – Ridgeview: 3 Configurations

Overview

The 71L Tap – Ridgeview configurations were developed by modifying the Duluth Area 115 kV transmission network in the Base Case models. Three separate configurations were studied which involved modifying the existing Arrowhead – 15th Ave West 115 kV Line (71 Line) into a 3-Terminal line connecting the Arrowhead, Hilltop, and Haines Road Substations. The purposed of the 71L Tap – Ridgeview study was to evaluate simplistic 115 kV transmission solutions for resolving outstanding issues realized in the Base Case analysis.

The following modifications were made to the Duluth Area 115 kV transmission network for this case:

- **71 Line**: Arrowhead – 15th Ave West 115 kV Line was connected to the nearby Hilltop Substation, creating an Arrowhead – Hilltop 115 kV Line; this line was then tapped where 57 Line turns North away from this line and connected to Haines Road, creating an **Arrowhead – Hilltop – Haines Road 115 kV Line**
- **72 Line**: Hilltop – LSPI 115 kV Line was connected to the existing 71 Line just outside of Hilltop Substation, creating an **Hilltop – 15th Ave West 115 kV Line**
- **21 Line**: Hilltop – 15th Ave West 115 kV Line was connected to the existing 72 Line just outside of Hilltop Substation, creating an **15th Ave West – LSPI 115 kV Line**
- **58 Line**: Arrowhead – Haines Road 115 kV Line was uncrossed with the existing 57 Line, creating an **Arrowhead – Colbyville 115 kV Line**
- **57 Line**: Arrowhead – Colbyville 115 kV Line was uncrossed with the existing 58 Line and extended from Haines Road to Swan Lake, creating an **Arrowhead – Swan Lake 115 kV Line**
- **52 Line**: Haines Road – Swan Lake 115 kV Line was extended from Swan Lake Substation to Ridgeview Substation, creating an **Haines Road – Ridgeview 115 kV Line**

This first configuration (To RGV) was the most simplistic configuration studied and is shown in Figure 5.2 below.

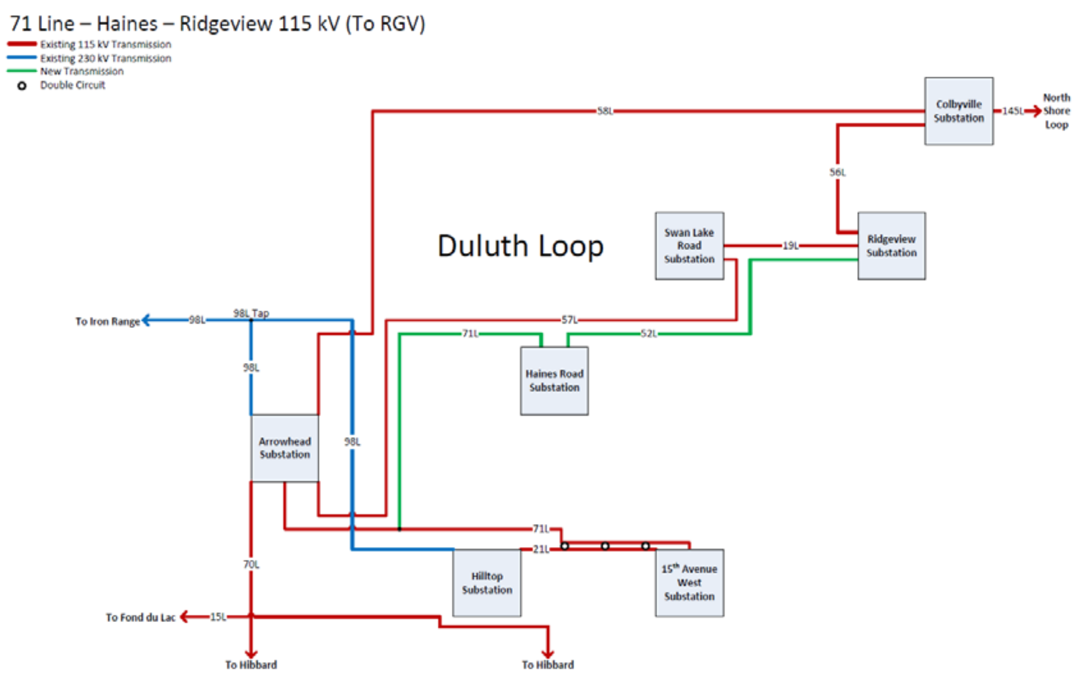


Figure 5.2: New 115 kV Transmission from 71L Tap to Haines to Ridgeview (To RGV)

The second configuration (To COL) was similar to the first configuration (To RGV) but included a second 115 kV transmission path between the Ridgeview and Colbyville substations. This configuration is shown in Figure 5.3 below. Due to apparent corridor constraints along the existing Ridgeview – Colbyville 115 kV Line, both Ridgeview – Colbyville 115 kV Lines were evaluated as double circuit transmission lines.

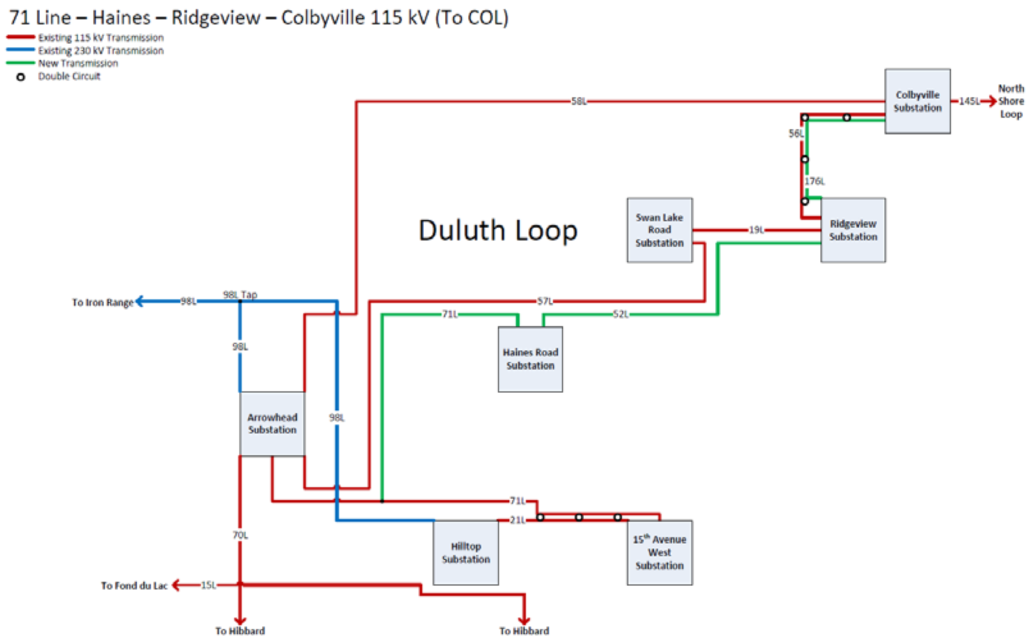


Figure 5.3: New 115 kV Transmission from 71L Tap to Haines to Ridgeview to Colbyville (To COL)

The third configuration (To 145L) was similar to the first configuration (To RGV) with the existing Big Rock – Colbyville 115 kV Line (145 Line) removed from Colbyville and extended to Ridgeview Substation. Additionally, the Ridgeview Substation layout was converted to a ring bus design. This configuration is shown in Figure 5.4 below. Due to apparent corridor constraints along the existing Ridgeview – Colbyville 115 kV Line, this line and 145 Line were evaluated as double circuit transmission lines.

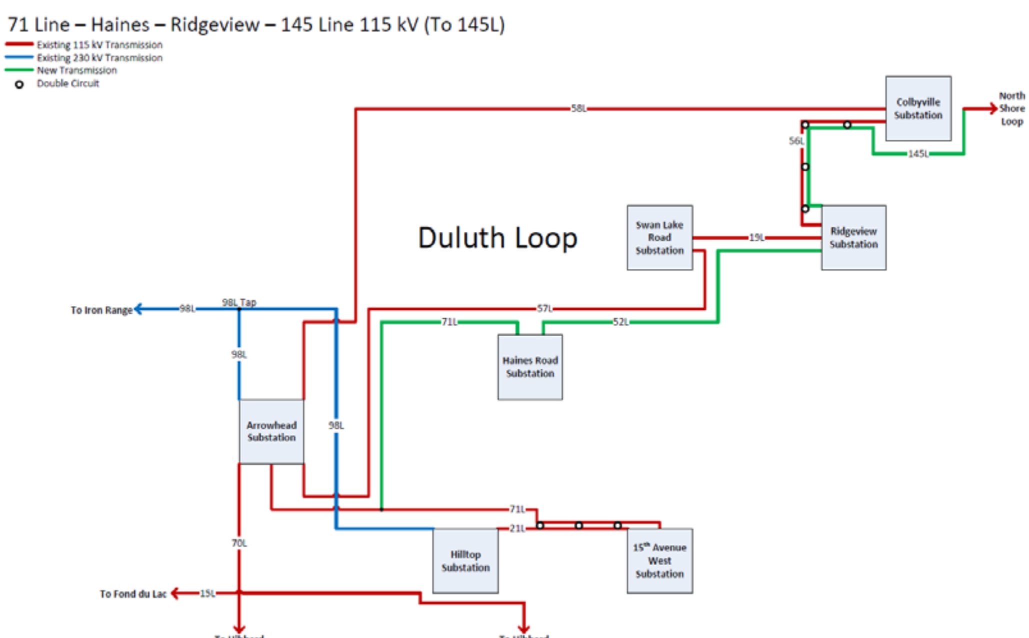


Figure 5.4: New 115 kV Transmission from 71L Tap to Haines to Ridgeview (Ring Bus) to 145 Line (To 145L)

Conclusion

The 71L Tap – Ridgeview study results illustrate that many significant issues can be resolved in the North Shore Loop and Duluth Loop by connecting a third transmission source from Duluth to the Ridgeview Substation. Of the three configurations which were studied, the configuration which creates a new 71L Tap – Ridgeview 115 kV transmission path with Colbyville – Big Rock 115 kV (145 Line) extended to a Ridgeview Substation ring bus (To 145L) resolves the most Duluth 115 kV Loop collapse scenarios. Table 5.1 below shows Winter Case voltage collapse scenarios which remain in the Duluth Loop for some of the 71L Tap – Ridgeview configurations:

- To RGV: Voltage collapse scenarios exist for loss of Arrowhead – Colbyville 115 kV (57 Line) and loss of Colbyville – Ridgeview 115 kV (56 Line) which leaves Colbyville load being served from Silver Bay
- To COL: Voltage collapse scenarios exist for loss of Arrowhead – Colbyville 115 kV (58 Line) and a single point of failure disconnecting both Colbyville – Ridgeview 115 kV lines (56 Line & 176 Line) which leaves Colbyville load being served from Silver Bay
- To 145L: The ring bus configuration and the extension of 145 Line from Colbyville to Ridgeview Substation eliminates single points of failure disconnecting multiple 115 kV paths between the Arrowhead Substation and Duluth – Big Rock 115 kV (145 Line). This configuration prevents a Duluth Loop substation from being served from Silver Bay.

71L Tap – Ridgeview: Duluth Loop Voltage Collapse Scenarios				
Sensitivity	**Base Case**	**To RGV**	**To COL**	**To 145L**
P61:115-115:MP:ARD-COL:COL-RGV	WTR	WTR		
ARD-COL Prior Outage: P22:RGV:BUS1	WTR	WTR		**N/A**
ARD-COL Prior Outage: P24:RGV:115MW	WTR	WTR	WTR	**N/A**
ARD-COL Prior Outage: P71:COL-RGV1:COL-RGV2	**N/A**	**N/A**	WTR	**N/A**

Table 5.1: 71L Tap - Ridgeview Voltage Collapse Scenarios

For all three configurations, the following upgrades would mitigate Base Case post-contingent overloads in the Duluth area:

- Upgrade existing Haines Road – Swan Lake Road 115 kV (52 Line) to 100C
- Upgrade Hilltop – 71L Tap 115 kV (HIL 71 Line) to 100C
- Reconductor Arrowhead – 71L Tap 115 kV (ARD 71 Line) and rebuild the 71 Line entrance at the Arrowhead Substation with 2000 Amp equipment
- Upgrade Hilltop – 98L Tap 230 kV Line (HIL 98 Line) to 60C
- Replace the Hilltop 230/115 kV transformer or add a transformer in parallel at the Hilltop Substation

For the To RGV configuration, a 90C upgrade of the Ridgeview – Colbyville 115 kV Line would be necessary. The other two configurations involve building a line from Ridgeview Substation to either Colbyville Substation or the end of 145 Line.

Concerns with the 71L Tap – Ridgeview configurations:

- Severe of the overloads on Arrowhead – 71L Tap 115 kV Line would require a reconductor of Arrowhead – 71L Tap 115 kV (ARD 71L) and a rebuild of the 71L Line entrance at the Arrowhead Substation with 2000 Amp equipment

- Relaying and operational complexity with establishing a 3-terminal line into the Duluth Loop
- Overloads on the Hilltop 230/115 kV transformer and on the sole 230 kV line into the Hilltop Substation need to be addressed

Benefits of the 71L Tap – Ridgeview configurations:

- Establishing a new 115 kV path from Duluth to a ring bus at an expanded Ridgeview Substation resolves the following:
  - Duluth Loop voltage collapse scenarios in the Base Case when Haines Road, Swan Lake Road, or Ridgeview substations are served from Silver Bay
  - 128 Line overloads for loss of two Duluth Loop transmission lines
  - Duluth Loop 115 kV line overloads for:
    - Outage of either Arrowhead – Colbyville 115 kV (57 Line) or Arrowhead – Haines Road 115 kV (58 Line)
    - Outage of Taconite Harbor – North Shore Switching Station 115 kV (128 Line) and a Duluth Loop 115 kV line
- Removing 145 Line from the Colbyville Substation and extending this to a ring bus at an expanded Ridgeview Substation resolves the remaining voltage collapse scenarios. This line can be double circuited with existing Ridgeview – Colbyville 115 kV (56 Line) due to constraints along much of this corridor.

Due to the concerns and benefits stated above with the 71L Tap – Ridgeview configurations, it was decided to evaluate two additional transmission configurations.

The HIL – COL configuration involves constructing a new Hilltop – Ridgeview 115 kV transmission path and removing Colbyville – Big Rock 115 kV (145 Line) from Colbyville Substation and extending this line to Ridgeview Substation. This configuration should eliminate many of the concerns with the Arrowhead – 71L Tap 115 kV facility and will allow for a ring bus versus a tie breaker comparison at Ridgeview Substation.

The HIL 230 kV configuration is similar to the 71L Tap – Ridgeview (To 145L) configuration with the following significant modifications to the Duluth Area transmission network:

- Convert and reconfigure segments of two existing 115 kV lines to 230 kV, creating an Arrowhead – Hilltop 230 kV Line and an Hilltop – Hibbard 115 kV Line but eliminating the Arrowhead – Hibbard 115 kV Line (70 Line)
- At the Hilltop Substation, create a 4 position 230 kV ring bus with a second 187 MVA transformer. Add a tie breaker on the 115 kV bus and create a new line entrance for the Hilltop – Hibbard 115 kV Line

5.2.2 HIL – COL and HIL 230 kV Configurations

Overview

The HIL – COL configuration was developed by modifying the Duluth Area 115 kV transmission network in the Base Case models. This configuration will avoid relaying and operational complexity associated with the 71L Tap – Ridgeview configurations and avoid the need to rebuild the Arrowhead – 71L Tap 115 kV to a rating above the capability of existing 1200 Amp equipment at the Arrowhead Substation. The 71L Tap – Ridgeview configurations illustrate that connecting three transmission paths from Duluth and extending Colbyville – Big Rock 115 kV (145 Line) into a ring bus layout at the Ridgeview Substation resolves many of the must solve issues in the Base Case. As an alternative to the Ridgeview Substation ring bus layout, two transmission paths from Duluth will share a bus with 145 Line and the third transmission path from Duluth will be on the opposite bus.

The following modifications were made to the Duluth Area 115 kV transmission network for this case:

- **71 Line**: A portion of the Arrowhead – 15th Ave West 115 kV Line was constructed as a double circuit line with the new Hilltop – Haines Road 115 kV Line (176 Line)
- **7 Line**: Hilltop – Hibbard 115 kV Line was moved to a new line entrance position at the Hilltop Substation
- **72 Line**: Hilltop – LSPI 115 kV Line was move to the existing 7 Line entrance position at the Hilltop Substation
- **58 Line**: Arrowhead – Haines Road 115 kV Line was uncrossed with the existing 57 Line, creating an **Arrowhead – Colbyville 115 kV Line**
- **57 Line**: Arrowhead – Colbyville 115 kV Line was uncrossed with the existing 58 Line and extended from Haines Road to Swan Lake, creating an **Arrowhead – Swan Lake 115 kV Line**
- **52 Line**: Haines Road – Swan Lake 115 kV Line was extended from Swan Lake Substation to Ridgeview Substation, creating an **Haines Road – Ridgeview 115 kV Line**
- **145 Line**: Colbyville – Big Rock 115 kV Line was extended to Ridgeview Substation by building double circuit with Arrowhead – Colbyville 115 kV Line (existing 57 Line) and Ridgeview – Colbyville 115 kV Line (56 Line), creating a **Ridgeview – Big Rock 115 kV Line**
- **176 Line**: **Hilltop – Haines Road 115 kV Line** was created by double circuiting 71 Line between Hilltop and 57 Line and constructing a new transmission line alongside existing 57 Line and 58 Line from this point to the Haines Road substation

The Hilltop – Haines Road 115 kV Line and modifications to the Duluth Area transmission network are shown in Figure 5.5 below.

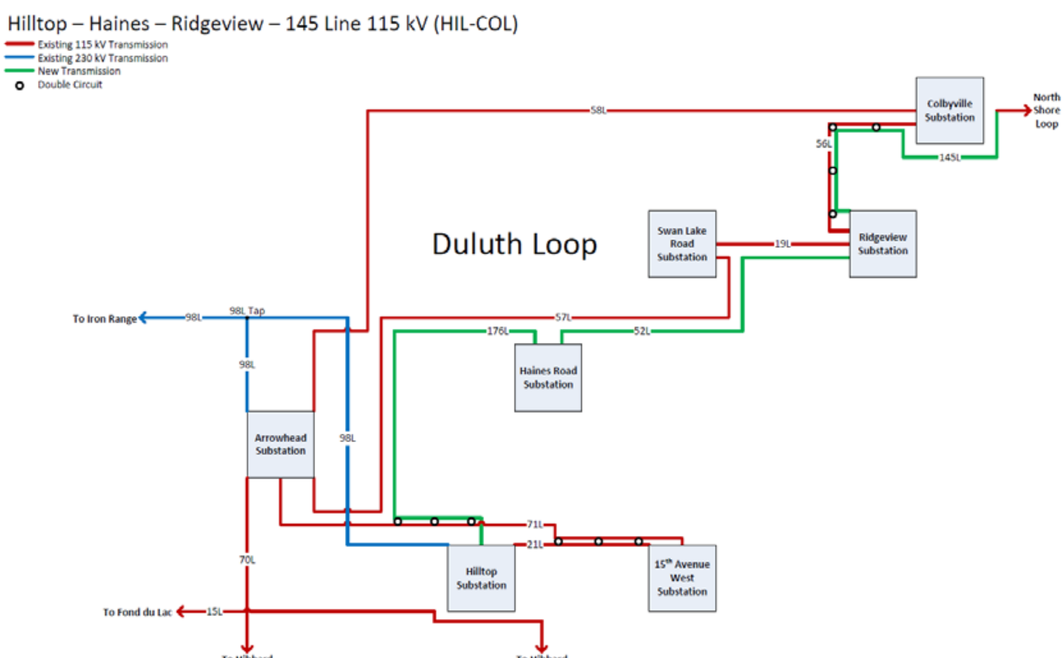


Figure 5.5: New 115 kV Transmission from Hilltop to Haines to Ridgeview to 145L (HIL-COL)

The HIL 230 kV configuration was developed by modifying the Duluth Area 115 kV transmission network in the Base Case models. This configuration could avoid the need to rebuild the Arrowhead – 71L Tap 115 kV to a rating above the capability of existing 1200 Amp equipment at the Arrowhead Substation.

Contingencies which isolate Arrowhead 115 kV Bus 1 are driving the need to rebuild Arrowhead – 71L Tap 115 kV in the 71L Tap – Ridgeview Analysis. Arrowhead – Hibbard 115 kV (70 Line) is connected to this bus and by converting this to an Arrowhead – Hilltop 230 kV line, the most severe overloads on 71 Line likely will be reduced. The 71L Tap – Ridgeview configurations illustrate that connecting three transmission paths from Duluth and extending Colbyville – Big Rock 115 kV (145 Line) into a ring bus layout at Ridgeview Substation resolves many of the must solve issues in the Base Case. As an alternative to the Ridgeview Substation ring bus layout, two transmission paths from Duluth will share a bus with 145 Line and the third transmission path from Duluth will be on the opposite bus.

The following modifications were made to the Duluth Area 115 kV transmission network for this case:

- **71 Line**: Arrowhead – 15th Ave West 115 kV Line was connected to the nearby Hilltop Substation, creating an Arrowhead – Hilltop 115 kV Line; this line was then tapped where 57 Line turns North away from this line and connected to Haines Road, creating an **Arrowhead – Hilltop – Haines Road 115 kV Line**
- **72 Line**: Hilltop – LSPI 115 kV Line was connected to the existing 71 Line just outside of Hilltop Substation, creating an **Hilltop – 15th Ave West 115 kV Line,** and was moved to the existing 7 Line entrance position at the Hilltop Substation
- **21 Line**: Hilltop – 15th Ave West 115 kV Line was connected to the existing 72 Line just outside of Hilltop Substation, creating an **15th Ave West – LSPI 115 kV Line**
- **7 Line**: Hilltop – Hibbard 115 kV Line was moved to a the existing 21 Line entrance position at the Hilltop Substation
- **15 Line**: Fond du Lac – Hibbard 115 kV Line was uncrossed with the existing 70 Line, leaving this as a Fond du Lac – Hibbard 115 kV Line but utilizing the existing 70 Line entrance at Hibbard
- **70 Line**: Arrowhead – Hibbard 115 kV Line was shortened to an **Hilltop – Hibbard 115 kV Line** utilizing the existing 15 Line between Hilltop and Hibbard, include the existing 15 Line entrance at Hibbard
- **58 Line**: Arrowhead – Haines Road 115 kV Line was uncrossed with the existing 57 Line, creating an **Arrowhead – Colbyville 115 kV Line**
- **57 Line**: Arrowhead – Colbyville 115 kV Line was uncrossed with the existing 58 Line and extended from Haines Road to Swan Lake, creating an **Arrowhead – Swan Lake 115 kV Line**
- **52 Line**: Haines Road – Swan Lake 115 kV Line was extended from Swan Lake Substation to Ridgeview Substation, creating an **Haines Road – Ridgeview 115 kV Line**
- **145 Line**: Colbyville – Big Rock 115 kV Line was extended to Ridgeview Substation by building double circuit with 58 Line and Ridgeview – Colbyville 115 kV Line (56 Line), creating a **Ridgeview – Big Rock 115 kV Line**
- **107 Line**: **Arrowhead – Hilltop 230 kV Line** was created by converting existing 70 Line and 15 Line between Arrowhead and Hilltop to 230 kV

The 71L Tap – Haines Road 115 kV Line, Arrowhead – Hilltop 230 kV Line, and other modifications to the Duluth Area transmission network are shown in Figure 5.6 below.

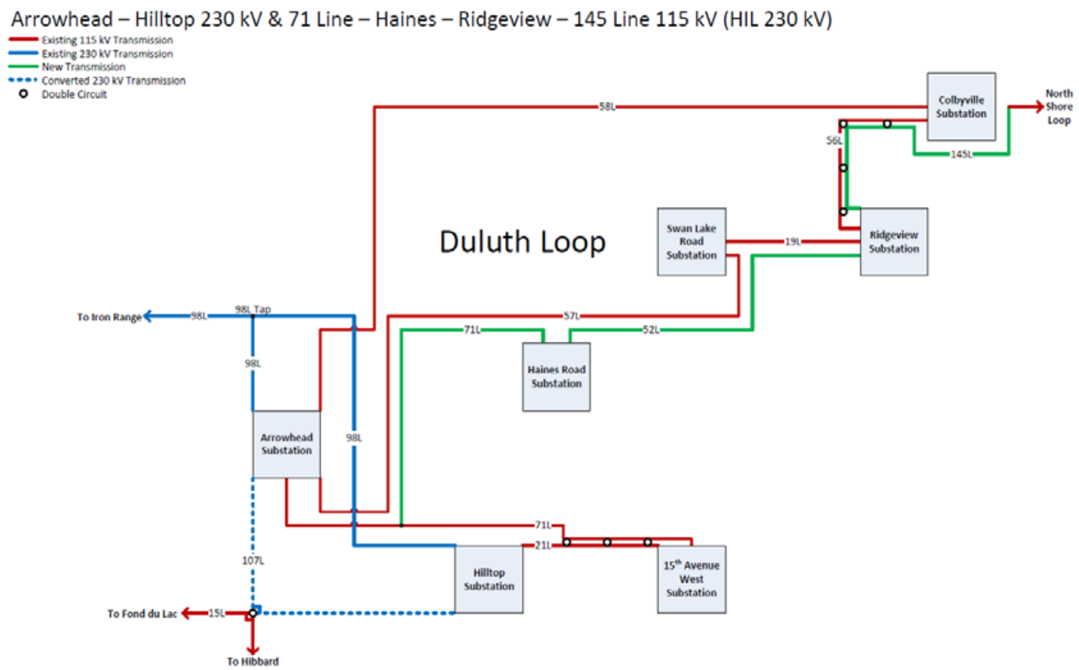


Figure 5.6: New Transmission from 71L Tap – HNS – RGV – 145L & Hilltop 230 kV (HIL 230 kV)

Conclusion

The HIL – COL configuration and HIL 230 kV configuration study results illustrate that many significant issues can be resolved in the North Shore Loop and Duluth Loop by connecting a third transmission source from Duluth to the Ridgeview Substation. A tie breaker at the Ridgeview Substation with 145 Line sharing a bus with two other transmission lines can mitigate Duluth Loop voltage collapse scenarios. However, Colbyville – Big Rock 115 kV (145 Line) should be extended to Ridgeview Substation as part of the initial project. Otherwise, during a prior outage of the Arrowhead – Colbyville 115 kV line, a bus fault at Ridgeview disconnecting the lines to Haines Road and Swan Lake would leave Ridgeview load being served from Silver Bay, potentially leading to a voltage collapse scenario. A ring bus layout at the Ridgeview Substation provides better reliability to the North Shore Loop by minimizing breaker maintenance outage impacts and minimizing the number of transmission sources disconnected by a single contingency.

The HIL 230 kV configuration mitigates the overloads on the Arrowhead 230/115 kV transformers to within their respective normal ratings and mitigates overloads on the Hilltop 230/115 kV transformer to within its emergency rating. Without a redundant 230 kV line and transformer at the Hilltop Substation, the existing 230/115 kV transformer is severely overloaded above its emergency rating in the Winter, Summer, and Shoulder cases for a loss of one Arrowhead 230/115 kV Transformer during a prior outage of the other Arrowhead 230/115 kV Transformer.

In the HIL 230 kV configuration, overloads on Arrowhead – 71L Tap 115 kV Line are reduced to within the existing emergency rating of 636 ACSR at 100C. This would eliminate the need to rebuild the 71 Line entrance at the Arrowhead Substation with 2000 Amp equipment and reconductor Arrowhead – 71L Tap 115 kV Line.

For these configurations, the following upgrades would mitigate Base Case post-contingent overloads in the Duluth area:

- HIL – COL configuration and HIL 230 kV configuration:
    - Upgrade existing Haines Road – Swan Lake Road 115 kV (52 Line) to 100C

- HIL – COL configuration:
  - Upgrade Hilltop – 98L Tap 230 kV Line (HIL 98 Line) to 60C
  - Replace the Hilltop 230/115 kV transformer or add a transformer in parallel at the Hilltop Substation
- HIL 230 kV configuration:
  - Upgrade Hilltop – 71L Tap 115 kV (HIL 71 Line) to 100C

Concerns with the HIL – COL configuration:

- Relaying and reliability concerns exist today with the 3-terminal Arrowhead – Hilltop – Iron Range 230 kV line (98 Line) which are not addressed; this line is approximately 72 Miles in length and is the sole 230 kV line into the Hilltop Substation
- Overloads on the Hilltop 230/115 kV transformer and on the sole 230 kV line into the Hilltop Substation need to be addressed

Concerns with the HIL 230 kV configuration:

- Arrowhead – Hilltop – Haines Road 115 kV (71 Line) has significantly higher loading for a prior outage of Arrowhead – Swan Lake 115 kV (57 Line). Loading on the Hilltop segment of this line for a multiple contingency event is approaching the maximum normal rating of this line. The longevity of this solution is concerning when load growth in the Duluth Loop or North Shore Loop is considered.
- Arrowhead – Hilltop – Haines Road 115 kV (71 Line) would continue to connect the Arrowhead and Hilltop substations, taking an outage of Arrowhead – Colbyville 115 kV (58 Line) requires 71L breaker at Arrowhead Substation to be opened up. This opens one of the transmission paths from the Arrowhead Substation toward some significant load serving substations in Duluth. The transmission grid becomes more reliant on the remaining transmission lines from Arrowhead and Hilltop towards 15th Avenue West, LSPI, and Hibbard.
- Relaying and reliability concerns exist today with the 3-terminal Arrowhead – Hilltop – Iron Range 230 kV line (98 Line) which are not addressed; this line is approximately 72 Miles in length and is the sole 230 kV line into the Hilltop Substation
- Relaying and operational complexity with establishing a 3-terminal line into the Duluth Loop

Benefits with the HIL – COL configuration and the HIL 230 kV configuration:

- Establishing a new 115 kV path from Duluth to an expanded Ridgeview Substation resolves the following:
  - Duluth Loop voltage collapse scenarios in the Base Case when Haines Road, Swan Lake Road, or Ridgeview substations are served from Silver Bay
  - 128 Line overloads for loss of two Duluth Loop transmission lines
  - Duluth Loop 115 kV line overloads for:
    - Outage of either Arrowhead – Colbyville 115 kV (57 Line) or Arrowhead – Haines Road 115 kV (58 Line)
    - Outage of Taconite Harbor – North Shore Switching Station 115 kV (128 Line) and a Duluth Loop 115 kV line
- Removing 145 Line from the Colbyville Substation and extending this to an expanded Ridgeview Substation resolves the remaining voltage collapse scenarios. This line can be double circuited with existing Ridgeview – Colbyville 115 kV (56 Line) due to constraints along much of this corridor.

Due to the reasons listed above, solutions involving a 71L Tap – Ridgeview 115 kV were removed from consideration moving forward. The preferred long-term 115 kV solution is the HIL – COL configuration described above with a ring bus at Ridgeview Substation. The ring bus provides greater reliability and allows the extension of Colbyville – Big Rock 115 kV (145 Line) to the Ridgeview Substation to be deferred until a future need arises, such as a retirement of Laskin generation or load growth between the Colbyville and Silver Bay Hillside substations. It was decided to study the HIL – HNS configuration with a second 230 kV line and 230/115 kV transformer at the Hilltop Substation. A 230 kV alternative will also be studied which involves building a new 230 kV line from Arrowhead along existing transmission corridor to a new substation between the Ridgeview and Colbyville substations.

5.2.3 ARD – HIL & ARD – RLK Configurations

Overview

The ARD – HIL configuration and the ARD – RLK configuration were developed by modifying the Duluth Area 115 kV transmission network in the Base Case models. The purpose of evaluating and comparing these configurations was to identify a transmission solution which resolves both the Duluth Loop 115 kV and Hilltop 230 kV outstanding issues realized in the Base Case analysis.

The following modifications were made to the Duluth Area 115 kV transmission network for the ARD – HIL configuration:

- **71 Line**: A portion of the Arrowhead – 15th Ave West 115 kV Line was constructed as a double circuit line with the new Hilltop – Haines Road 115 kV Line (176 Line)
- **7 Line**: Hilltop – Hibbard 115 kV Line was moved to a new line entrance position at the Hilltop Substation
- **72 Line**: Hilltop – LSPI 115 kV Line was move to the existing 7 Line entrance position at the Hilltop Substation
- **58 Line**: Arrowhead – Haines Road 115 kV Line was uncrossed with the existing 57 Line, creating an **Arrowhead – Colbyville 115 kV Line**
- **57 Line**: Arrowhead – Colbyville 115 kV Line was uncrossed with the existing 58 Line and extended from Haines Road to Swan Lake, creating an **Arrowhead – Swan Lake 115 kV Line**
- **52 Line**: Haines Road – Swan Lake 115 kV Line was extended from Swan Lake to Ridgeview, creating an **Haines Road – Ridgeview 115 kV Line**
- **145 Line**: Colbyville – Big Rock 115 kV Line was extended to Ridgeview by building double circuit with Arrowhead – Colbyville 115 kV Line (existing 57 Line) and Ridgeview – Colbyville 115 kV Line (56 Line), creating a **Ridgeview – Big Rock 115 kV Line**
- **176 Line**: **Hilltop – Haines Road 115 kV Line** was created by double circuiting 71 Line between Hilltop and 57 Line and constructing a new transmission line alongside existing 57 Line and 58 Line from this point to the Haines Road substation
- **15 Line**: Fond du Lac – Hibbard 115 kV Line was uncrossed with the existing 70 Line, leaving this as a Fond du Lac – Hibbard 115 kV Line but utilizing the existing 70 Line entrance at Hibbard
- **107 Line**: **Arrowhead – Hilltop 230 kV Line** was created by converting existing 70 Line and 15 Line between Arrowhead and Hilltop to 230 kV
- **70 Line**: Arrowhead – Hibbard 115 kV Line was uncrossed with the existing 15 Line and converted to 230 kV (**107 Line**) between Arrowhead and Hilltop; the existing segment of 15 Line between Hilltop and Hibbard was abandoned in place; in the future, this abandoned segment could be utilized to make 21 Line a 3 terminal line for mitigating post-contingent overloads for a Hilltop 115MW breaker failure
- **Ridgeview Substation**: Existing Ridgeview Substation was converted to a 6-position ring bus

- **Hilltop Substation**: Existing 230 kV bus at the Hilltop Substation was converted to a 4-position ring bus; a second 230/115 kV 187 MVA transformer and a 115 kV tie breaker was added

The Hilltop – Haines Road 115 kV Line, Arrowhead – Hilltop 230 kV Line, and other modifications to the Duluth Area transmission network are shown in Figure 5.7 below.

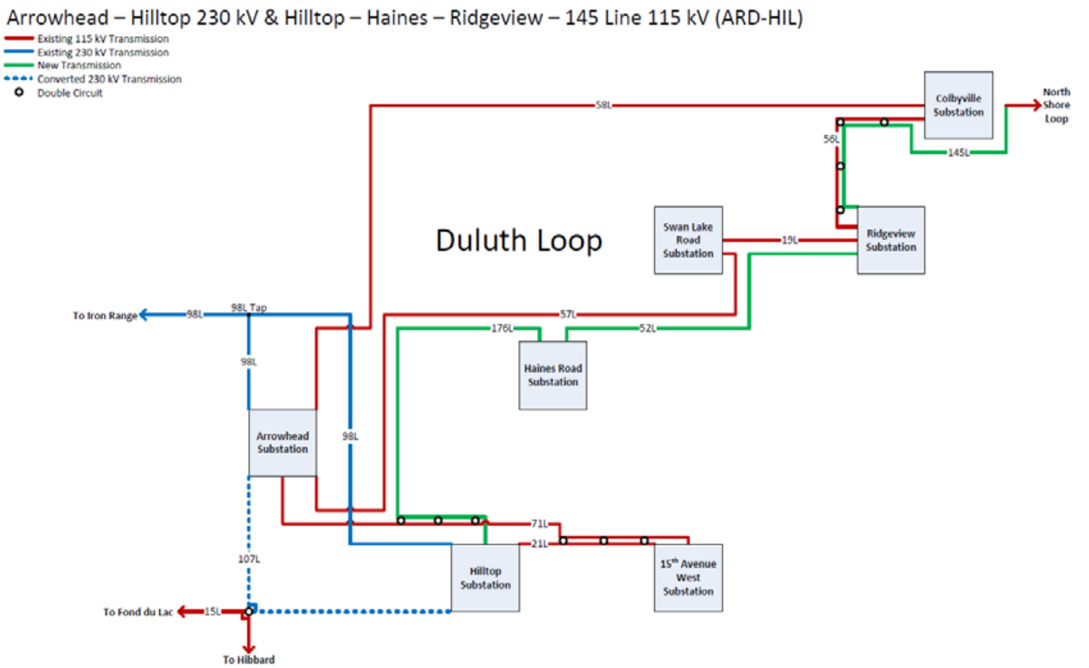


Figure 5.7: New Transmission between Arrowhead, Hilltop, Haines Road, Ridgeview, and Colbyville (ARD-HIL)

The following modifications were made to the Duluth Area 115 kV transmission network for the ARD – RLK configuration:

- **58 Line**: Arrowhead – Haines Road 115 kV Line was uncrossed with the existing 57 Line and looped into Rice Lake, creating an **Arrowhead – Rice Lake 115 kV Line**
- **175 Line**: Existing Arrowhead – Colbyville 115 kV Line was looped into Rice Lake, creating an **Rice Lake – Colbyville 115 kV Line**
- **57 Line**: Arrowhead – Colbyville 115 kV Line was uncrossed with the existing 58 Line creating an **Arrowhead – Haines Road 115 kV Line**
- **145 Line**: Colbyville – Big Rock 115 kV Line was extended to Rice Lake by building double circuit with Rice Lake – Colbyville 115 kV Line (175 Line), creating a **Rice Lake – Big Rock 115 kV Line**
- **19 Line**: Swan Lake – Ridgeview 115 kV Line was removed from Ridgeview and extended to Rice Lake by building double circuit with Ridgeview – Rice Lake 115 kV Line (174 Line), creating an **Swan Lake – Rice Lake 115 kV Line**
- **174 Line**: Existing Swan Lake – Ridgeview 115 kV Line (19 Line) out of Ridgeview was extended to Rice Lake by building double circuit with Swan Lake – Rice Lake 115 kV Line (19 Line), creating an **Ridgeview – Rice Lake 115 kV Line**
- **107 Line**: **Arrowhead – Rice Lake 230 kV Line** was created by building new line between Arrowhead and Rice Lake following existing transmission corridor
- **Rice Lake Substation**: A new Rice Lake Substation would be constructed near the West end of existing transmission corridor shared between existing Arrowhead – Colbyville 115 kV Line and Ridgeview – Colbyville 115 kV Line

The Arrowhead – Rice Lake 230 kV Line and modifications to the Duluth Area transmission network are shown in Figure 5.8 below. The new double circuit construction from Rice Lake Substation towards Ridgeview prevents an outage of three Duluth Loop substations for loss of two transmission lines.

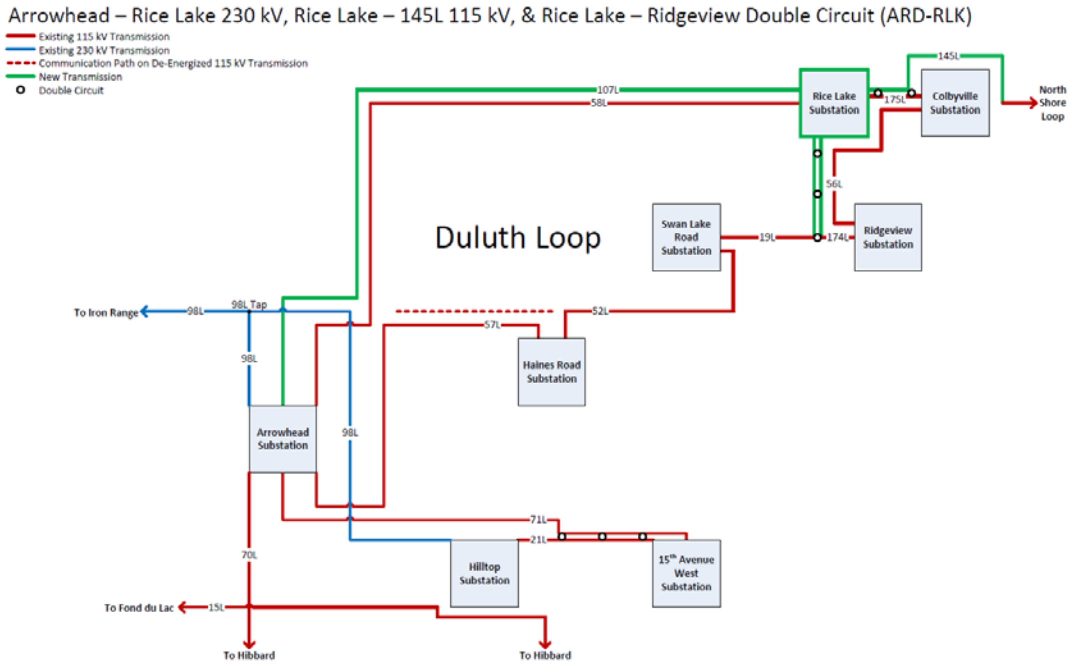


Figure 5.8: New Transmission between Arrowhead, Rice Lake, Ridgeview, and Colbyville (ARD-RLK)

Conclusion

The ARD – HIL configuration and ARD – RLK configuration study results illustrate that many significant issues can be resolved in the North Shore Loop and Duluth Loop by extending Colbyville – Big Rock 115 kV (145 Line) to a substation in the Duluth Loop with three independent transmission sources from Duluth. In both configurations, a ring bus layout with 145 Line and the transmission sources from Duluth provides better reliability to the North Shore Loop by minimizing breaker maintenance outage impacts and minimizing the number of transmission sources disconnected by a single contingency. Both configurations resolve the Duluth Loop voltage collapse scenarios.

Both configurations include the addition of a 230/115 kV transformer in the Duluth area which mitigates the overloads on the Arrowhead 230/115 kV transformers to within their respective normal ratings. Overloads on the Hilltop 230/115 kV transformer are within the normal rating in the ARD – RLK configuration and 1.7% above the normal rating in the ARD – HIL configuration, well within the transformer emergency rating.

For these configurations, the following upgrades would mitigate Base Case post-contingent overloads in the Duluth area:

- ARD – HIL configuration:
  - Upgrade existing Haines Road – Swan Lake Road 115 kV (52 Line) to 100C
  - Upgrade Hilltop – 98L Tap 230 kV Line (HIL 98 Line) to 65C
- ARD – RLK configuration:
  - Upgrade existing Haines Road – Swan Lake Road 115 kV (52 Line) to 85C
  - Upgrade Hilltop – 98L Tap 230 kV Line (HIL 98 Line) to 60C

Concerns with the ARD – HIL configuration:

- For contingencies which disconnect the double circuit Hilltop – Hibbard 115 kV (7 Line) and Hilltop – LSPI 115 kV (72 Line), the reconfiguration of Arrowhead – Hibbard 115 kV (70 Line) causes additional loading on Arrowhead – Gary 115 kV (131 Line), Thomson – Fond du Lac 115 kV (8 Line), and Fond du Lac – Hibbard 115 kV (15 Line). Although significant overloads do not show up in the analysis, future load growth in Superior or at LSPI, Hibbard, or Gary substations could cause overloads on these three transmission lines.
- Relaying and reliability concerns exist today with the 3-terminal Arrowhead – Hilltop – Iron Range 230 kV line (98 Line) which are not addressed; this line is approximately 72 Miles in length and is the sole 230 kV line into the Hilltop Substation

Concerns with the ARD – RLK configuration:

- For a prior outage of 57 Line or 19 Line, both Swan Lake and Haines Road substations would be served on a radial transmission path consisting of 52 Line and the remaining line. This is concerning due to the reliance on one substation to back up the distribution load at the other in the case of a substation outage.
- Relaying and reliability concerns exist today with the 3-terminal Arrowhead – Hilltop – Iron Range 230 kV line (98 Line) which are not addressed; this line is approximately 72 Miles in length and is the sole 230 kV line into the Hilltop Substation

Benefits with the ARD – HIL configuration and the ARD – RLK configuration:

- Establishing a new 115 kV path from Duluth to a ring bus in the Duluth Loop along with extending 145 Line to this ring bus resolves the following:
    - Duluth Loop voltage collapse scenarios in the Base Case
    - 128 Line overloads for loss of two Duluth Loop transmission lines
    - Duluth Loop 115 kV line overloads for:
        - Outage of either Arrowhead – Colbyville 115 kV (57 Line) or Arrowhead – Haines Road 115 kV (58 Line)
        - Outage of Taconite Harbor – North Shore Switching Station 115 kV (128 Line) and a Duluth Loop 115 kV line

The ARD – HIL configuration and the ARD – RLK configuration are both very robust solutions which resolve many post-contingent issues in the Duluth Loop and North Shore Loop. The required transmission upgrades for both cases are similar based on available information.

The ARD – HIL configuration has a favorable electrical configuration with only one Duluth Loop substation between a robust Duluth 230 kV substation and the expanded Ridgeview Substation.

The ARD – RLK configuration provides a reasonable technical alternative to the ARD – HIL configuration but is not preferred for the following reasons:

- Establishment of a large new 230/115 kV substation on a greenfield site in the Rice Lake area would have significant human and environmental impacts compared to expanding the existing Ridgeview and Hilltop substations in the ARD – HIL configuration.
- Establishment of a new Arrowhead – Rice Lake 230 kV transmission line would involve constructing a new 230 kV line at least 12 miles long if located adjacent to existing 115 kV lines. The ARD – HIL configuration involves approximately 8 miles of entirely new 115 kV transmission right-of-way where not being double circuited with an existing 115 kV line or overtaking an existing de-energized transmission line that is presently only carrying critical communications infrastructure. The new 230 kV line adjacent to existing Duluth Loop lines would also not present

any viable double circuiting opportunities with the existing lines, and would require a wider right-of-way compared to a new 115 kV line. Therefore, the amount of new right-of-way required for the ARD – RLK configuration would greatly exceed what is needed for the ARD – HIL configuration, increasing the human and environmental impacts of the 230 kV alternative.

Due to the reasons listed above, the preferred long-term solution is the ARD – HIL configuration described above along with disconnecting the Hilltop 230 kV line from Arrowhead – Iron Range 230 kV (98 Line) and extending this line to the Arrowhead Substation. This preferred long-term solution is described in more detail in Section 6.

5.3 Non-Transmission Solutions

Peaking Generation

Minnesota Power considered peaking generation as a non-transmission solution. Peaking generation, in this context, means dispatchable generation that is interconnected to the transmission system and is able to run continuously when called upon, most likely using natural gas as the fuel source. Minnesota Power considered two general configurations for peaking generation. One peaking generation option is to install a bank of several relatively small natural gas reciprocating internal combustion engine (RICE) generators. Given the 74 MW minimum generation requirement for resolving the voltage stability issues, a RICE solution would likely require between 8-12 individual units.

A second peaking generation option is to install a relatively large natural gas combustion turbine in the Duluth area. For either of these solutions, the optimal point of interconnection for resolving voltage stability and transmission line loading concerns is at or near the Colbyville Substation. In addition to concerns with siting a new generation station in a primarily residential area of Duluth, there are also concerns about the permitting, cost-effectiveness, fuel supply availability, and longevity of such a solution. The addition of new peaking generation is not a more reasonable and prudent alternative to the ARD – HIL configuration.

Distributed Generation

Minnesota Power considered distributed generation in the Duluth Loop as a non-transmission solution. Distributed generation, in this context, means dispatchable generation that is connected to the local distribution system and is able to run continuously when called upon, most likely on natural gas. Renewable distributed generation and battery energy storage are also discussed in subsequent sections. While Minnesota Power considered various configurations of distributed generation and dynamic reactive support for the Duluth Loop and the North Shore, distributed generation has the same fundamental concerns as transmission-connected peaking generation – and likely at a greater cost if consisting of a number of smaller generators in diverse locations. Therefore, the addition of new distributed generators is not a more reasonable and prudent alternative to the ARD – HIL configuration.

Renewable Generation

Minnesota Power considered renewable generation as a non-transmission solution. Renewable generation, in this context, means either solar or wind generation. The renewable generation may be interconnected at a single location on the transmission system or at multiple locations on the transmission or distribution system. As discussed in at the beginning of Section 5.3, in order to adequately address voltage stability concerns in the Duluth Loop, a system solution is needed that will provide a significant amount of reliable power (a minimum of 74 MW, but potentially over 100 MW) to the Duluth Loop and North Shore during an outage of either Arrowhead – Colbyville 115 kV or Arrowhead – Haines Road 115 kV.

This power also needs to be available when called upon in the amount required to mitigate the risk of a voltage collapse. Because renewable generation is dependent on natural events, such as sunlight or wind speed, and cannot be dispatched if those conditions are not met, neither wind generation nor solar generation alone is a viable alternative to the ARD – HIL configuration. Energy from these resources is not necessarily available at the times when it would be most necessary to support reliability in the Duluth Loop. For example, evaluating 2019 historical data, the Winter peak for the Duluth Loop area occurred on January 29, 2019 at 6:00 P.M., when a minimum of 74 MW of generation is needed to mitigate the risk of voltage collapse. As the sunsets at around 5 P.M. in January, solar energy output at 6 P.M. is generally non-existent. Wind energy output is unpredictable, sometimes decreasing during the evening hours of the day. Therefore, the addition of new renewable generation, by itself, is not a more reasonable and prudent alternative to the ARD – HIL configuration. The combination of renewable generation with energy storage is discussed below.

Energy Storage

Minnesota Power considered energy storage, both by itself and combined with new renewable generation, as a non-transmission solution. Energy storage, in this context, means a battery or some other energy storage technology capable of being charged and discharged when called upon to do so as long as there is sufficient energy available. As discussed in at the beginning of Section 5.3, in order to adequately address voltage stability concerns in the Duluth Loop, a system solution is needed that will provide a significant amount of power (a minimum of 74 MW on peak, but potentially over 100 MW) to the Duluth Loop and North Shore for an extended duration during an outage of either Arrowhead – Colbyville 115 kV or Arrowhead – Haines Road 115 kV. Given the nature of the transmission reliability concerns, the generation should also be able to run continuously for at least 7 days to allow adequate time for restoration in the event of a catastrophic transmission failure. Within that 7 days, there may be little or no opportunity to recharge an energy storage solution from the transmission system due to high Duluth Loop area load levels relative to the Duluth Loop voltage stability threshold. The duration of 7 days as a restoration time was selected for study purposes. Actual transmission line restoration times can vary significantly by severity, location and other factors. Minnesota Power follows best utility practice to prioritize and expedite restoration of transmission failures as soon as possible. Many unplanned transmission outages and failures can be corrected in less than 7 days; however, several restorations of Minnesota Power's transmission facilities resulting from severe weather within the last two years have exceeded this 7-day duration by a factor of 2 or more.

Evaluating 2019 historical load data, the maximum daily average over 7 days for Duluth Loop load was 1238.3 MWh above the stability threshold and occurred between January 25, 2019 and February 1, 2019. During this 7 day period, the minimum load level was 96.9 MW, which is well above the 65.7 MW stability threshold with Laskin generation online. Therefore, an energy storage solution would have had to discharge continuously from a minimum of 31.2 MW to a maximum of 74 MW during this 7 day duration and would not have been able to recharge from the transmission system. For an energy storage solution by itself, a minimum rating of 8,668 MWh would be necessary to adequately and reliably support the transmission system during a 7 day transmission outage of both Arrowhead – Colbyville 115 kV and Arrowhead – Haines Road 115 kV. An energy storage solution of this magnitude – as of August 2021, over 5 times larger than the largest in the world[1] – is not a reasonable alternative to the ARD – HIL configuration.

Given that there is no or limited opportunity to recharge an energy storage solution from the transmission system, Minnesota Power also examined pairing the energy storage solution with new solar generation.

[1] https://www.powermag.com/vistra-energizes-massive-1-2-gwh-battery-system-at-california-gas-plant/

If solar could produce the needed generation during daylight hours, energy storage could supply the needed generation outside of daylight hours. Evaluating 2019 historical data, a 24 hour peak of 1370.7 MWh of energy was needed above the stability threshold in the Duluth Loop area. This occurred beginning at sunrise on January 29, 2019, the day when peak loading occurred in the Duluth Loop, and there was approximately 9.5 hours of possible daylight between sunrise and sunset. In the most idealized and optimistic scenario, 144.3 MW of solar generation paired with a 852.4 MWh rated energy storage solution would be the minimum alternative to mitigate the risk of voltage collapse in the Duluth Loop. The solar generation would support the daytime battery charging load of 89.7 MW. This also assumes that peaking generation at the Laskin Energy Center is running throughout the 7 day outage. If Laskin was not running or became unavailable, then the Duluth Loop voltage stability threshold would diminish and additional solar and storage capacity would be required. The numbers above also do not provide any room for load growth above the historical 2019 peak, or for periods of reduced solar output due to weather.

Minnesota Power utilized the MISO MTEP21 Transmission Cost Estimation Guide to estimate the cost of the 852.4 MWh energy storage solution. Excluding the cost of the 144.3 MW solar generation facility, the estimated cost of an energy storage solution with a rated instantaneous charge/discharge of 89.7 MW and an energy rating of 852.4 MWh is $276.4 million[2] based on the MISO assumptions for lithium ion energy storage "grid supporting devices."

Idealized Duluth Loop Solar and Storage Solution					
24 Hours Beginning at Sunrise on January 29th, 2019		Tramsission Cost Estimation Guide for MTEP21		Storage Cost for Duluth Loop	
Nightime Load (MWh):	852.4	Battery System (per KWh):	$300	Battery System:	$255,720,007
Peak Battery Output (MW):	74.0	Inverter (per KW):	$80	Inverter:	$7,178,105
Daytime Charging Load (MW):	89.7	Transformer (per KW to 69 kV):	$150	Transformer:	$13,458,948
Daylight (Hours):	9.5			**Total:**	**$276,357,060**
Daytime Average Load (MW):	54.6				
Total Solar Need (MW):	144.3				

Table 5.2: Idealized Duluth Loop Solar and Storage Solution

As shown from the numbers discussed above, any combination of energy storage and solar generation meeting the minimum requirements for resolving the voltage stability concerns in the Duluth Loop would be very substantial in both size and cost. In addition to the economics of such a solution, siting, operational complexity, and the long-term effectiveness for the solution would all be significant concerns. Therefore, the addition of new energy storage in the Duluth Loop, whether by itself or in combination with new renewable generation, is not a more reasonable and prudent alternative to the ARD – HIL configuration.

Demand Side Management and Conservation

Minnesota Power considered demand-side management and conservation as a non-transmission solution. In this context, demand side management and conservation are assumed to encompass all forms of peak shaving programs, such as interruptible loads and dual fuel programs, as well as more general energy conservation programs, such as energy-efficiency rebates. As noted in the previous section on energy storage, total Duluth Loop area load during the most demanding 7-day period in 2019 would have needed to be reduced by 31.2 – 74 MW in order to mitigate the risk of voltage collapse following unplanned outages during that period of time. This represents approximately 22 – 53 percent of the 139.7 MW historical peak demand for the Project area. Although conservation programs will continue to be implemented in the Duluth Loop area to encourage efficient use of electricity, these programs are insufficient to reach these significant levels of load reduction in the Duluth Loop. For these reasons,

[2] https://cdn.misoenergy.org /Transmission%20Cost%20Estimation%20Guide%20for%20MTEP21337433.pdf

solutions involving demand side management and conservation are not a viable alternative to the ARD – HIL configuration.

Reactive Power Additions

As a final non-transmission solution, Minnesota Power considered implementing additional reactive power additions to support the area and prevent voltage collapse. Reactive power additions, in this context, mean transmission technology capable of providing reactive power and voltage support to the system through the use of traditional electromechanical devices such as switched capacitor banks and reactors, flexible AC transmission system (FACTS) devices such as static VAR compensators (SVCs) or static synchronous compensators (STATCOMs), or synchronous condensers. Unlike generation or energy storage solutions, reactive power additions do not produce any active power (e.g. MWs) for consumption by end-use customers, meaning this alternative is not capable of directly offsetting Duluth Loop load as discussed for previous generation and non-wire alternatives. While a reactive power addition alone may contribute to resolving or reducing the severity of the Duluth Loop voltage stability issues, reactive power additions alone cannot satisfy any needs discussed at the beginning of Section 5. Reactive power additions would not reduce overloads on the Hilltop 230/115 kV transformer or increase the ratings of transmission lines in the Duluth Loop or the North Shore Loop, meaning that many existing system upgrades would also be required. For these reasons, solutions involving only reactive power additions are not a viable alternative to the ARD – HIL configuration.**Error! Reference source not found.**

5.4 Historical Analysis of Duluth 230/115 kV Transformer Loading

The Hilltop Substation transformer is the smallest of the three Duluth-area 230/115 kV transformers, with a normal rating of 187 MVA compared to 373 MVA for both of the Arrowhead Substation transformers. During planned maintenance or unplanned outages of one Arrowhead transformer, there is considerable risk of extreme post-contingent overloading on the Hilltop transformer if the second Arrowhead 230/115 kV transformer were to trip offline. Figure 5.9 below shows the expected post-contingent loading on the Hilltop 230/115 kV transformer for loss of both Arrowhead 230/115 kV transformers based on 2019 hourly historical load data and power flow modeling.

The orange line on Figure 5.9 represents the normal or continuous rating of the Hilltop 230/115 kV transformer, while the red line represents the short-term emergency rating of the transformer. Minnesota Power's facility ratings methodology prescribes short-term emergency ratings for power transformers up to 125 percent of the transformer's nameplate rating. The duration for which this condition is acceptable varies from 30 minutes up to potentially continuous operation depending on ambient temperatures, direct winding temperature measurements from the transformer (if available), and the original manufacturing specifications (if known). Where other equipment in series with the transformer, such as substation conductors or other apparatus, is more limiting than the transformer itself, the magnitude and duration of the short-term emergency rating may be more restrictive. In the case of the Hilltop 230/115 kV transformer, the summer emergency rating is limited by a substation conductor and therefore is shown on the chart to be more restrictive. The summer normal rating and the winter normal and emergency ratings are all associated with the nameplate capacity of the transformer itself.

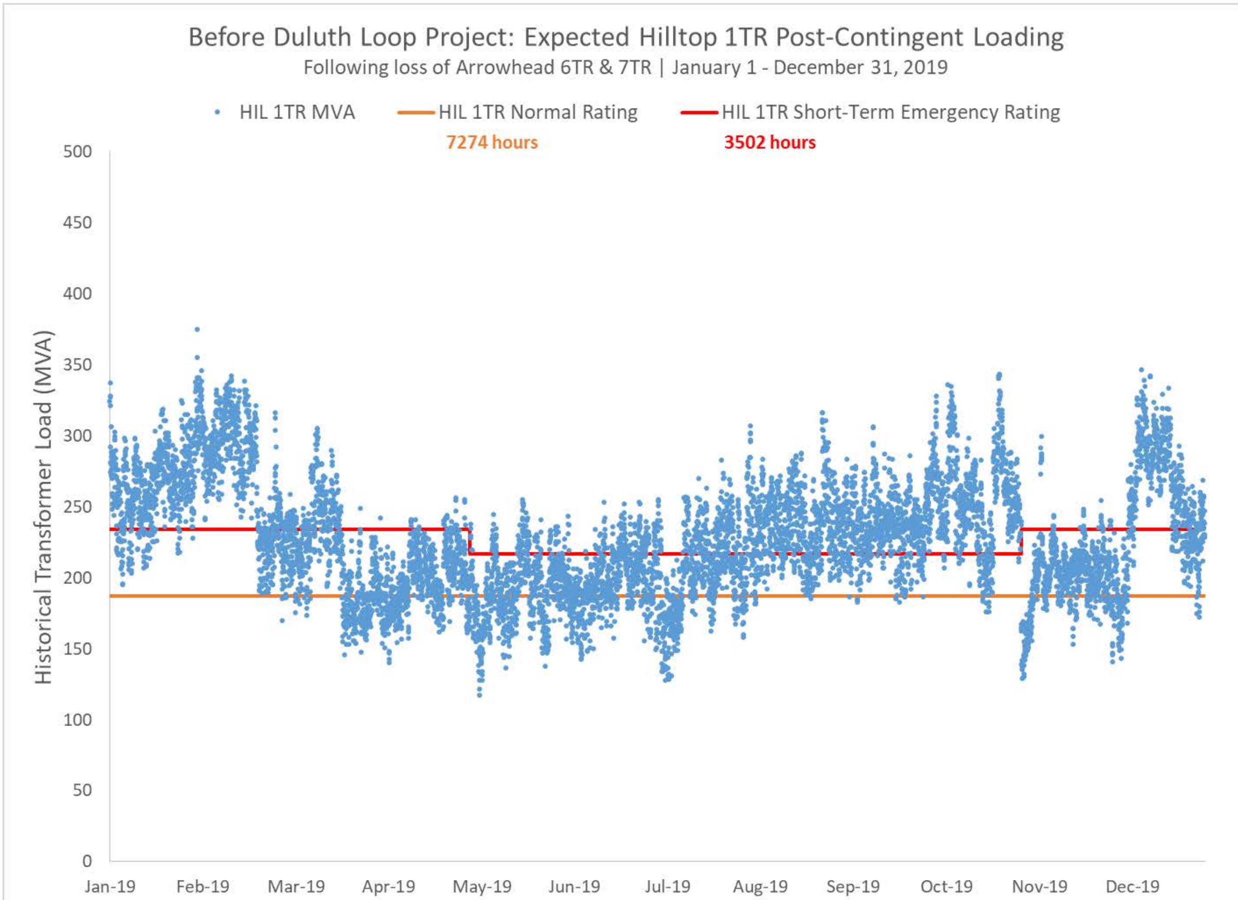


Figure 5.9: Expected Hilltop Transformer Post-Contingent Loading (Existing 187 MVA Transformer)

As shown in Figure 5.9, there are relatively few hours throughout the year during which an Arrowhead transformer could be taken out of service without risking overloads on the Hilltop transformer if the remaining Arrowhead transformer were to trip unexpectedly. If the overloads did occur, they would be so severe that they could potentially exceed the transformer's short-term emergency rating by over 100 MVA.

In practice, outages on the Arrowhead transformers would be avoided during the at-risk hours noted above or the system would be adjusted to reduce the loading on the Duluth area 230/115 kV transformers. However, with most of the dispatchable generation capability removed from the Duluth area, options for reducing loading on the Hilltop transformer to a manageable level during this scenario have become very limited. The problem is further compounded by the fact that the Arrowhead 230/115 kV transformers are nearing 50 years old and longer duration outages will become more likely due to age and condition-related issues such as component failures, increased maintenance, or targeted replacements. The Arrowhead transformers will also be targeted for replacement sometime in the next 10-15 years as part of Minnesota Power's normal asset renewal program activities – ensuring that long-duration outages will become necessary at some point.

The preferred ARD – HIL long-term solution described in Section 5.2.3 resolves extreme post-contingent overloading on the Hilltop transformer by adding a parallel 187 MVA Hilltop transformer, constructing a 4-position 230 kV ring bus at the Hilltop Substation, and establishing a second 230 kV transmission line into the Hilltop Substation. These upgrades provide significant benefits to the Hilltop Substation and Duluth area by increasing the 230/115 kV transformation capacity, establishing a redundant transformer at the Hilltop Substation, and establishing a redundant 230 kV source to the Hilltop Substation. There are significant cost and environmental impacts associated with these improvements. One alternative which reduces these impacts while meeting the near-term needs involves:

- Replacing the existing Hilltop Substation transformer with a new 373 MVA rated transformer
- Replacing other limiting equipment in series with the transformer to ensure the full rated capability of the transformer is available at all times
- Extending the existing Hilltop 230 kV tap to a dedicated line entrance at the Arrowhead Substation and completing a 100C thermal upgrade on this transmission line.

Removing the Hilltop 230 kV tap from existing three-terminal Iron Range – Arrowhead – Hilltop 230 kV (98 Line) will further enhance reliability of the Hilltop Substation. Establishing a dedicated Arrowhead – Hilltop 230 kV Line will significantly reduce outage exposure, from 72 Miles to approximately 8 Miles, and will allow significant relaying improvements to be made on 98 Line and the newly created Arrowhead – Hilltop 230 kV transmission line. The additional breaker at the Arrowhead Substation associated with this 230 kV tap extension will eliminate an existing breaker failure scenario which disconnects a 230/115 kV transformer at both the Arrowhead and Hilltop substations. The increased reliability and capacity for the Hilltop 230/115 kV transformer will help ensure that reliable 230/115 kV transmission sources are available for the Duluth area throughout the year. As shown in Figure 5.10 below, there is very little risk of overloading a 373 MVA Hilltop transformer and what risk there is appears to be manageable and well within the emergency rating of the new transformer. The existing 187 MVA Hilltop transformer can likely replace an existing older transformer of similar size on Minnesota Power's transmission system.

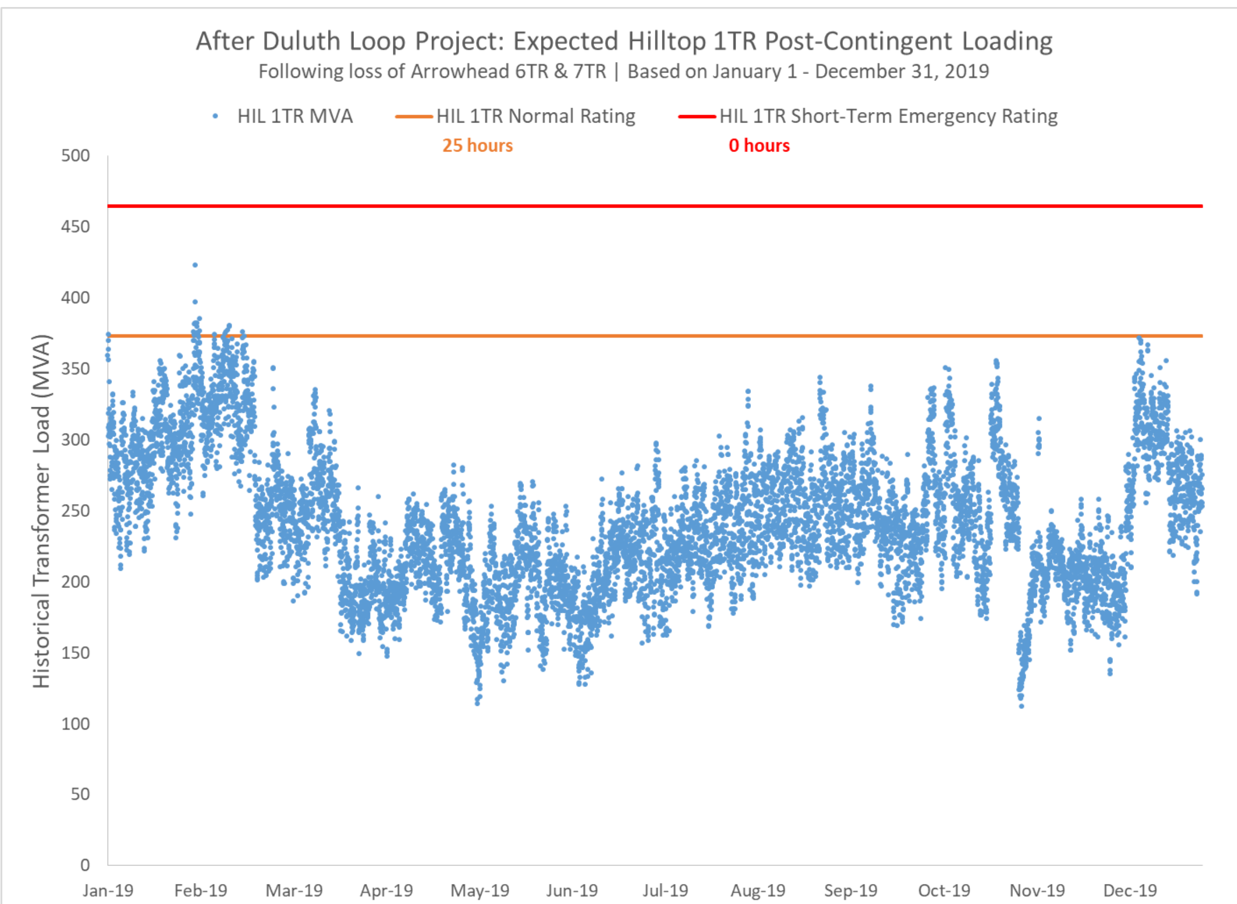


Figure 5.10: Expected Hilltop Transformer Post-Contingent Loading (Replacement 373 MVA Transformer)

5.5 Duluth Loop Voltage Stability Threshold and Historical Data Analysis

Generator transitions in the North Shore Loop have significantly impacted the ability to serve Duluth Loop and North Shore load from Silver Bay during the loss of both transmission paths between the Arrowhead and Colbyville substations. Figures 5.11 – 5.14 below illustrate the severity of the Duluth Loop voltage stability issues relative to historical load levels in the area. Each plot shows the historical loading on the transmission system between a Duluth Loop substation and the North Shore Switching Station. Silver Bay Hillside is the first substation towards the City of Duluth from the North Shore Switching Station. Historical data for 2019 represents a typical year for the area with heavy winter peak loading, moderate to high summer peak loading, and lighter loading in the shoulder months. These plots also show the voltage stability thresholds from Table 4.17 along with the hours, days, and consecutive days which loading was below the threshold. The green line indicates the stability threshold with all historical North Shore Loop generation online. The orange line indicates the stability threshold with only Laskin generation online. The red line indicates the stability threshold with no North Shore Loop generation online, which is the normal condition in today's system.

Figure 5.11 below shows 2019 historical loading between the Haines Road and Silver Bay Hillside substations. Historical loading is depicted by the black dots in Figure 5.11. For time periods where loading remains below the voltage stability thresholds, a maintenance outage would be acceptable on the Arrowhead – Colbyville 115 kV line or the Arrowhead – Haines Road 115 kV line without incurring the risk of a voltage collapse for loss of a second Duluth Loop 115 kV line.

With all North Shore Loop generation online as indicated by the green line, there were significant opportunities for maintenance outside the summer and winter peak seasons, with up to 116 consecutive days at one point throughout the year for maintenance work to occur on these lines.

With only Laskin generation online as indicated by the orange line, there are no days throughout the year during which loading is within the voltage stability threshold for the entire day. This means there are very limited opportunities for maintenance work to occur without putting the Duluth Loop and the North Shore Loop at additional reliability risk.

With no North Shore Loop generation online as indicated by the red line, there also are no days throughout the year and only 45 hours total when loading is within the voltage stability threshold. This means that any planned maintenance in the Duluth Loop will result in putting a considerable amount of load at risk of outage with no other available mitigation. With the transition away from local baseload generation in the North Shore Loop, outages along either the Arrowhead – Colbyville 115 kV Line or the Arrowhead – Haines Road 115 kV Line have become significant reliability issues which must be resolved.

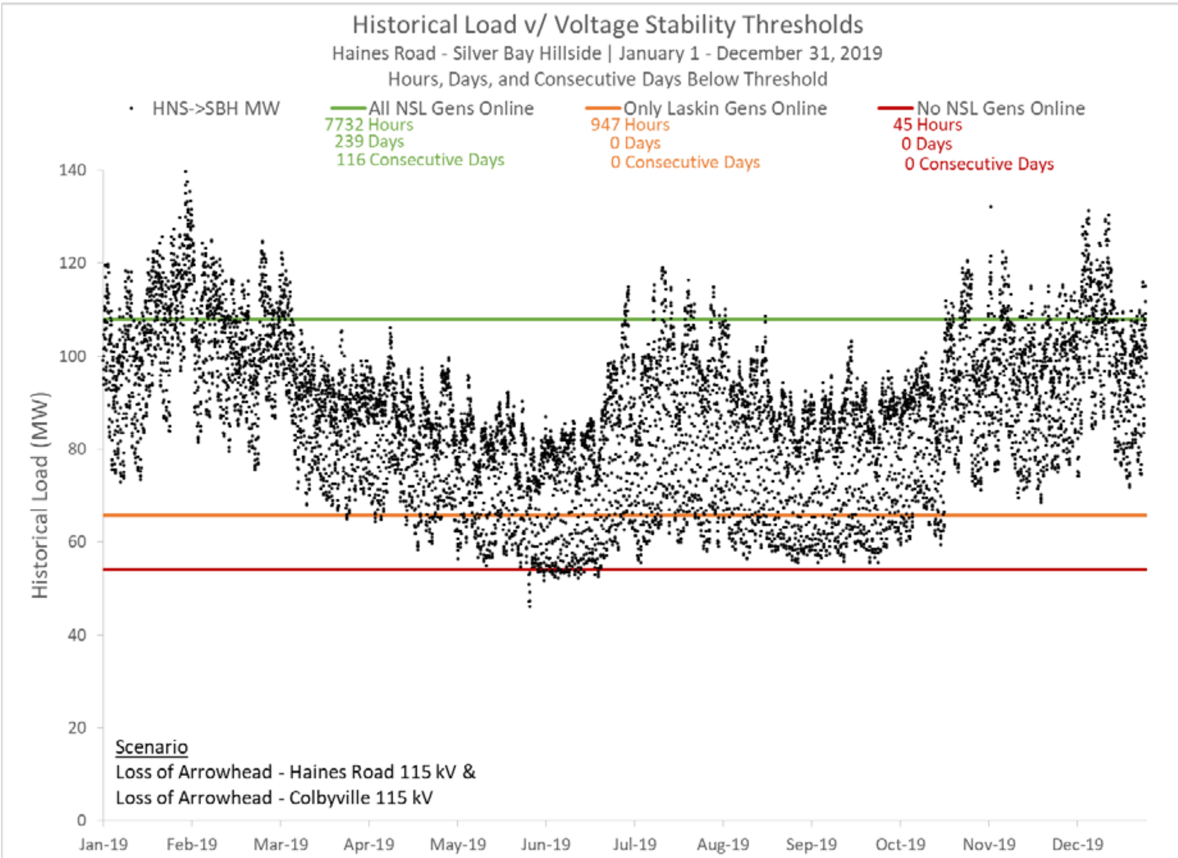


Figure 5.11: 2019 Historical Load (Haines Road Substation to Silver Bay) Compared to Voltage Stability Thresholds

Figure 5.12 to Figure 5.14 below show 2019 historical loading between the Swan Lake Road, Ridgeview, and Colbyville substations and the Silver Bay Hillside substation. As illustrated by these figures, the risk of voltage collapse diminishes as less Duluth Loop load is potentially being served from the North Shore Loop. Historical loading from Swan Lake Road to Silver Bay Hillside is above the Duluth Loop voltage stability threshold, similar to Haines Road discussed above, showing that there is significant risk of voltage collapse when taking the Haines Road – Swan Lake Road 115 kV Line out of service. Loading from Ridgeview to Silver Bay Hillside is well above the voltage stability threshold during summer and winter peak seasons and marginal during the shoulder months, providing some opportunity for planned maintenance on the Swan Lake Road – Ridgeview 115 kV Line without incurring risk of voltage collapse. This opportunity would be unpredictable from year to year, depending heavily on local weather and electricity usage patterns and eroding with any substantive load growth. Loading from Colbyville to Silver Bay Hillside is within the voltage stability threshold for most of the year, demonstrating that outages on the Ridgeview – Colbyville 115 kV Line can generally be taken without risk of voltage collapse as long as peak load periods (typically in winter months) are avoided.

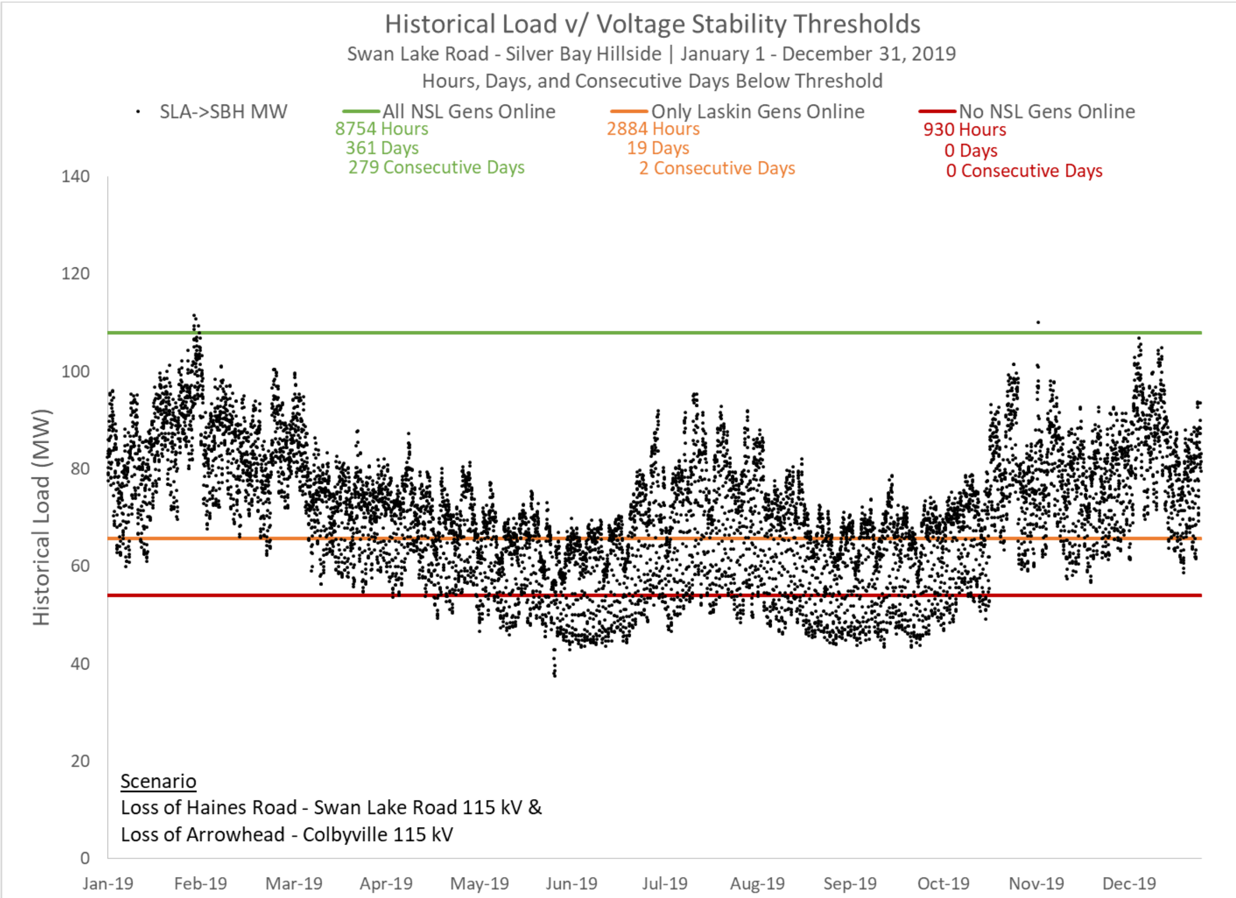


Figure 5.12: 2019 Historical Load (Swan Lake Road Substation to Silver Bay) Compared to Voltage Stability Thresholds

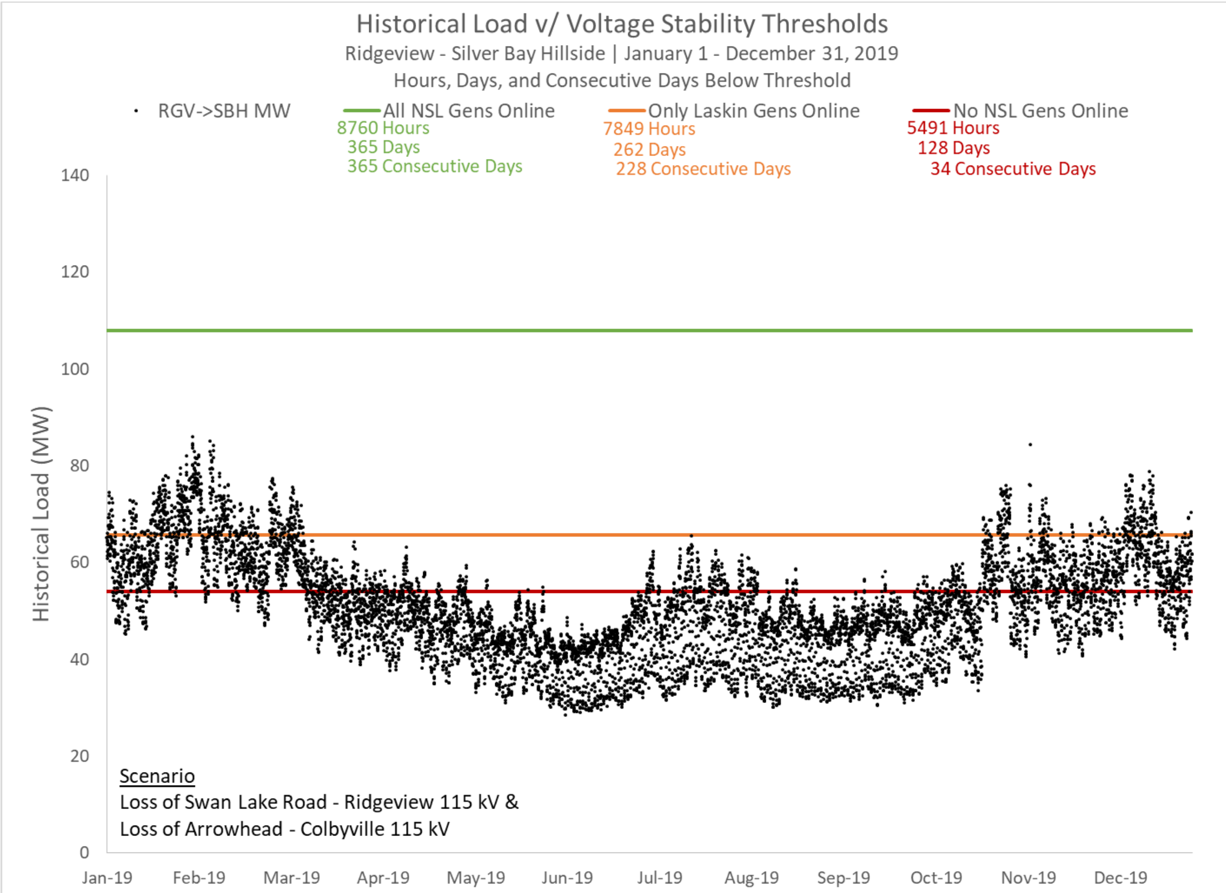


Figure 5.13: 2019 Historical Load (Ridgeview Substation to Silver Bay) Compared to Voltage Stability Thresholds

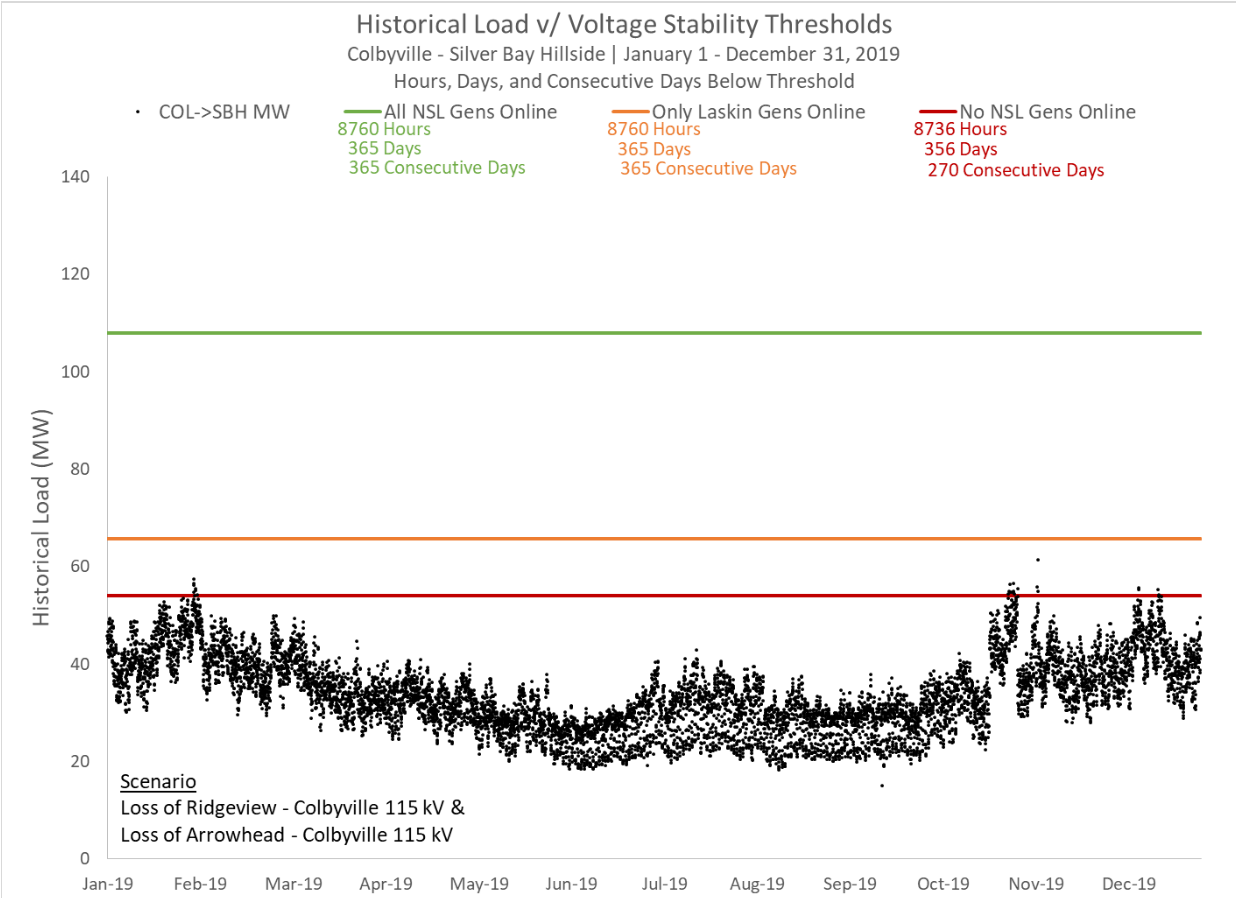


Figure 5.14: 2019 Historical Load (Colbyville Substation to Silver Bay) Compared to Voltage Stability Thresholds

The following conclusions may be derived from the above historical data analysis:

- Loss of Arrowhead – Colbyville 115 kV line and Arrowhead – Haines Road 115 kV line (Figure 5.11) poses a risk of voltage collapse practically any time the condition is encountered, and must be resolved
- Loss of Arrowhead – Colbyville 115 kV line and Haines Road – Swan Lake Road 115 kV line (Figure 5.12) also poses a risk of voltage collapse practically any time the condition is encountered, and must be resolved
- Loss of Arrowhead – Colbyville 115 kV line and Swan Lake Road – Ridgeview 115 kV line (Figure 5.13) poses a risk of voltage collapse any time the condition is encountered during peak load periods and also at times during shoulder months, and should be resolved
- Loss of Arrowhead – Colbyville 115 kV line and Ridgeview – Colbyville 115 kV line (Figure 5.14) is manageable, with only limited risk of voltage collapse during peak seasons where it would be appropriate to continue to utilize the operating guide in the event of unplanned outages

Analysis of 2019 historical data illustrates how the idling of North Shore Loop generation and associated loss of the support they historically provided to the transmission system has impacted Minnesota Power's ability to perform maintenance on transmission lines and substation components that require a transmission outage on any of the Duluth Loop 115 kV lines.

5.6 Historical Data Analysis of Transmission Line Overloads

Generator transitions on the North Shore have significantly increased the loading on Duluth Loop and North Shore Loop area transmission lines. Figure 5.15 to Figure 5.18 below illustrate the severity of potential transmission line overloads relative to historical load levels in the area. The plots illustrate post-contingent transmission line loading utilizing historical load data for the Duluth Loop and North Shore Loop transmission system, which is possible because of the configuration of the transmission system that becomes radial following the most limiting contingencies. Historical data for 2019 represents a typical year for the area with heavy winter peak loading, moderate to high summer peak loading, and lighter loading in the shoulder months.

Figure 5.15 below shows historical loading between the Haines Road and Finland substations along with the seasonal ratings of Taconite Harbor – North Shore 115 kV (128 Line) as indicated by the red line. For the historical data which was considered, loss of Arrowhead – Haines Road 115 kV (58 Line) and Arrowhead – Colbyville 115 kV (57 Line) resulted in the highest loading scenario on 128 Line. As noted above, in most cases this contingency would cause a voltage collapse. However, even if the contingency were stable, it would have caused overloads on 128 Line for 1,608 hours or 18.4% of the year. The ARD – HIL configuration provides a redundant transmission connection parallel to 57 Line and 58 Line that will prevent 128 Line from being forced to carry load exceeding its capacity.

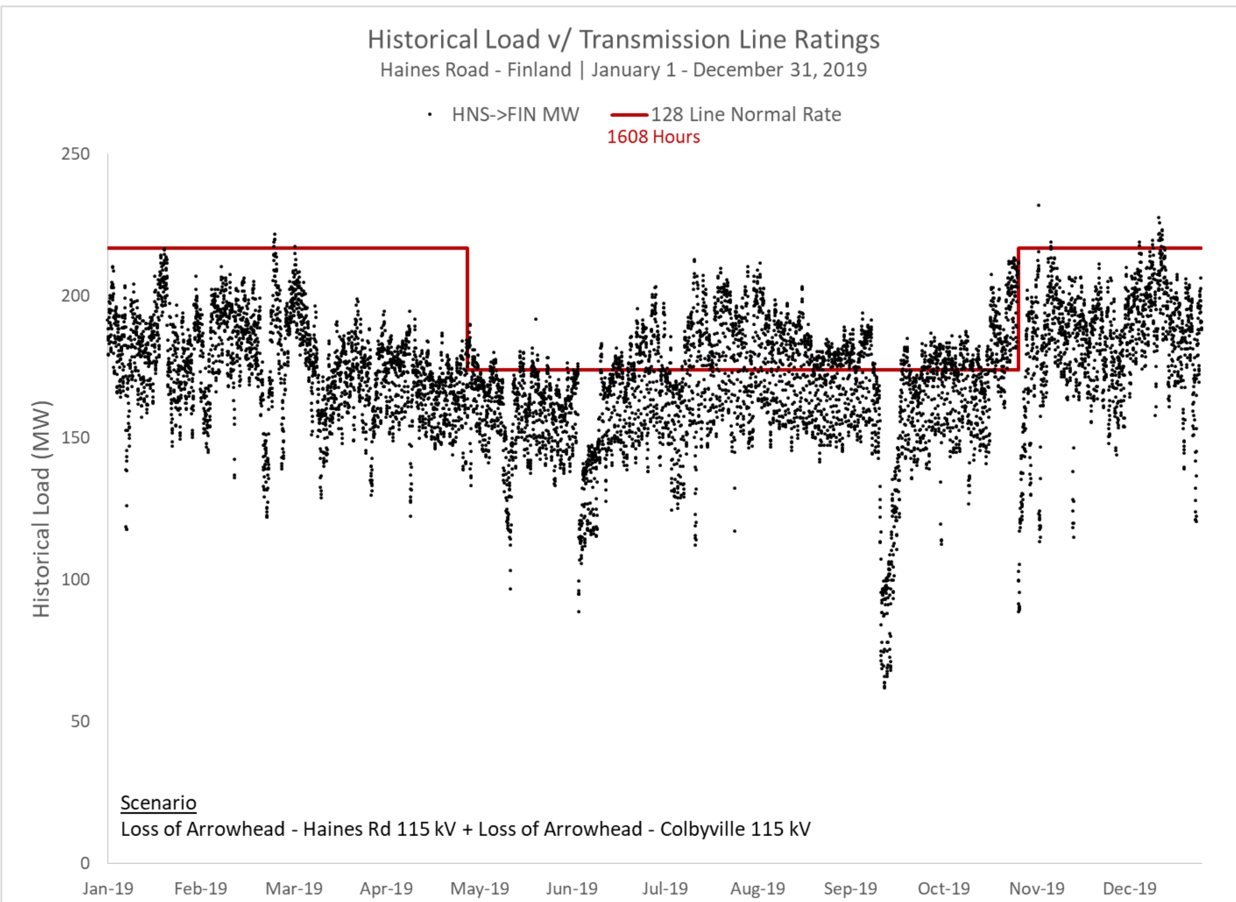


Figure 5.15: 2019 Historical Load (Haines Road Substation to Finland) Compared to 128 Line Normal Rating

If a new 115 kV transmission line is constructed between the Hilltop and Ridgeview substations, the loss of Ridgeview – Colbyville 115 kV (56 Line) and 57 Line becomes the highest loading scenario on 128 Line. Figure 5.16 below shows historical loading between the Colbyville and Finland substations along with the seasonal ratings of 128 Line as indicated by the red line. For the historical data which was considered, there would have been no overloads on 128 Line with this parallel 115 kV path.

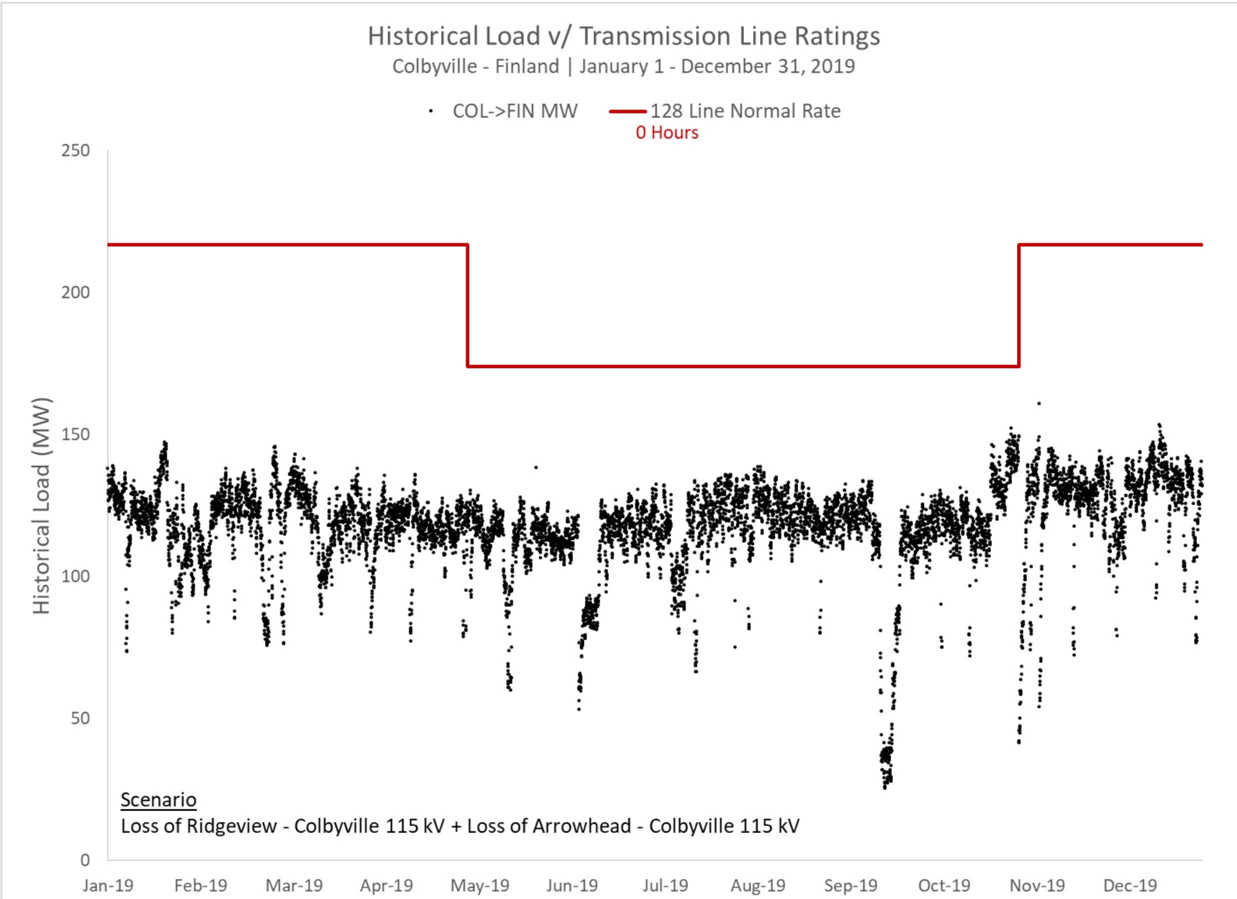


Figure 5.16: 2019 Historical Load (Colbyville Substation to Finland) Compared to 128 Line Normal Rating

Figure 5.17 below shows historical loading between the Haines Road and Taconite Harbor substations along with the seasonal ratings of Arrowhead – Haines Road 115 kV (58 Line), as indicated by the red dashed line, and Arrowhead – Colbyville 115 kV (57 Line), as indicated by the blue line. For the historical data which was considered, loss of the Mesaba Junction – Taconite Harbor Double Circuit 115 kV lines (1 & 2 Line) and a connection from the Arrowhead Substation into the Duluth Loop, either 58 Line or 57 Line would have caused overloads on the remaining Duluth Loop line (57 Line or 58 Line) for 2,509 hours or 28.6% of the year. The ARD – HIL configuration provides a redundant transmission connection parallel to 57 Line and 58 Line that will prevent either line from being forced to carry load exceeding its capacity under the conditions described above.

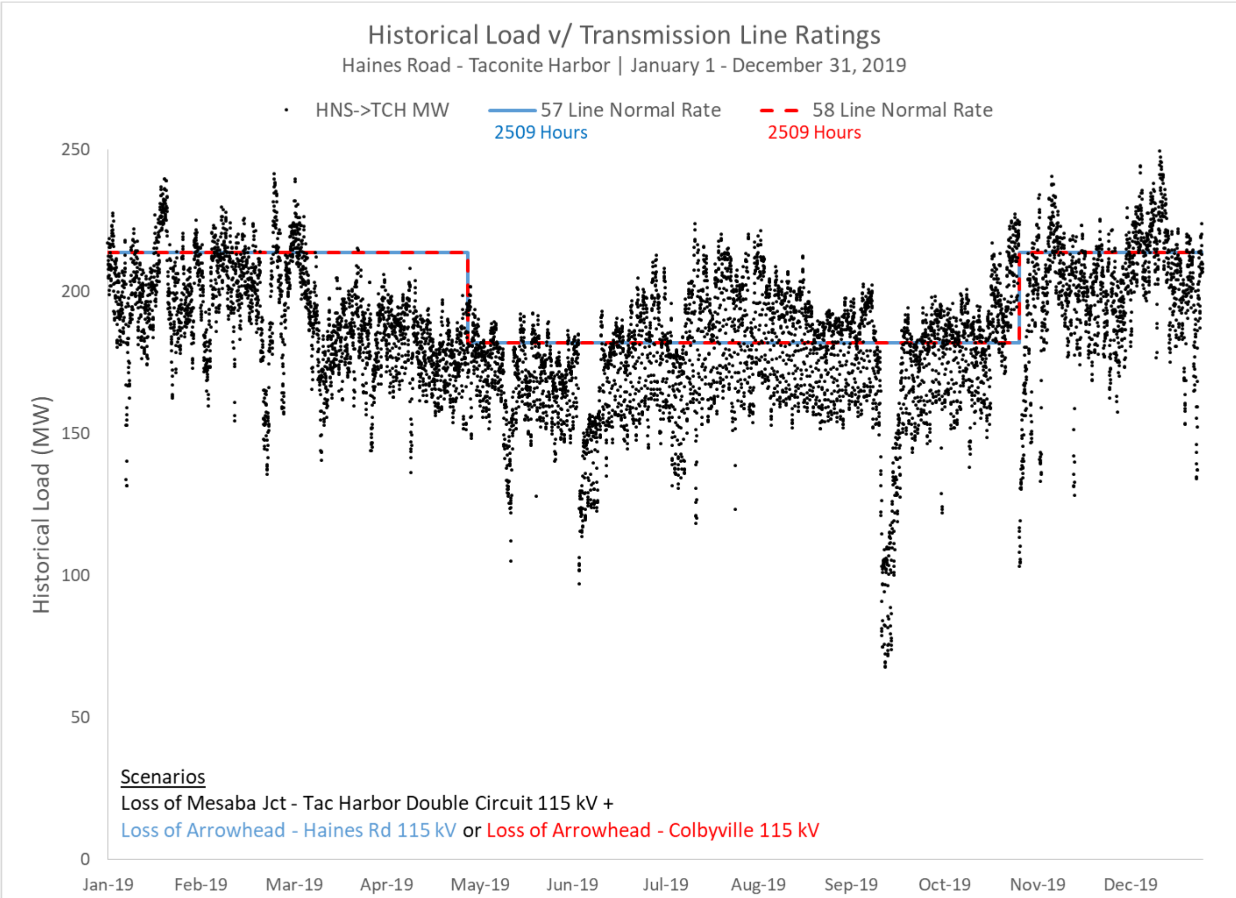


Figure 5.17: 2019 Historical Load (Haines Road to Taconite Harbor Substations) Compared to 57 and 58 Line Normal Ratings

If a new 115 kV transmission line is constructed between the Hilltop and Ridgeview substations, the loss of the 1 & 2 Line double circuit and a Duluth Loop connection into the Colbyville Substation becomes the highest loading scenario on either 56 Line or 57 Line. Figure 5.18 below shows historical loading between the Colbyville and Taconite Harbor substations along with the seasonal ratings of 56 Line as indicated by the red dashed line and 57 Line as indicated by the blue line. For the historical data which was considered, there would have been no overloads on Arrowhead – Colbyville 115 kV and overloads on Ridgeview – Colbyville 115 kV for 923 hours or 10.5% of the year.

The ARD – HIL configuration connection between the Hilltop and Ridgeview substations is sufficient to resolve the overload concerns on 57 Line. Overloads on 56 Line are more prevalent during the summer months due to a lower summer rating. As part of the ARD – HIL configuration, this line will be rebuilt on double circuit structures and a capacity upgrade will be achieve. If this portion of the project is deferred, a relatively minor capacity upgrade may still be necessary on this line at some point in the future.

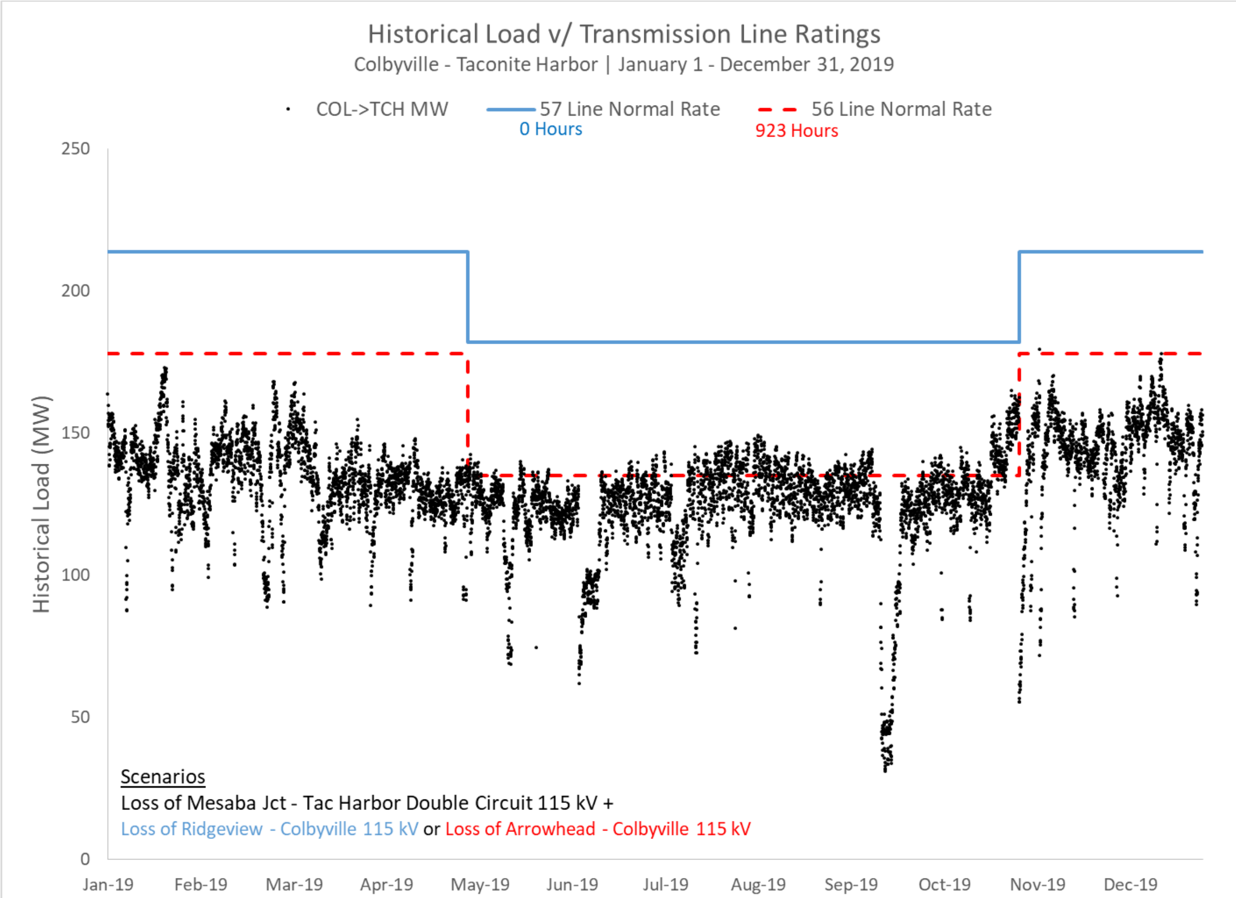


Figure 5.18: 2019 Historical Load (Colbyville to Taconite Harbor Substations) Compared to 57 and 58 Line Normal Ratings

5.7 Conclusions

Based on the 2019 historical data analysis in Sections 5.4, 5.5, and 5.6, several components of the preferred ARD – HIL configuration can be deferred until a future need.

At the Hilltop Substation, the ARD – HIL configuration includes expanding the 230 kV bus to a four position ring bus, installing a parallel 187 MVA transformer, installing a tie breaker on the 115 kV bus, and establishing a second 230 kV transmission source by reconfiguring and converting portions of existing 15 Line and 70 Line to 230 kV. These modifications resolve the reliability of Duluth Area 230/115 kV transmission sources. Instead of these modifications, the near-term recommendation includes replacing the existing 187 MVA Hilltop 230/115 kV transformer with a new 373 MVA rated transformer, replacing other limiting equipment in series with the transformer, extending the existing Hilltop 230 kV tap to a dedicated line entrance at the Arrowhead Substation, and completing a 100C thermal upgrade on the newly configured Arrowhead – Hilltop 230 kV line. This near-term recommendation should be significantly less expensive than adding a redundant 230 kV transmission line and 230/115 kV transformer at Hilltop. This also shifts Arrowhead 6TR loading which exceeds the emergency rating from being a single contingency overload involving a tie breaker failure to a multiple contingency overload involving an outage of Arrowhead 7TR and the Hilltop 230 kV line or transformer. Arrowhead 7TR loading exceeding the emergency rating remains a single contingency issue. 2019 historical data analysis in Section 5.4 illustrates these improvements to the Hilltop Substation and Hilltop 230 kV transmission line can bridge the present need for additional Duluth Area 230/115 kV transformation capacity and reliability to a future need for a second Hilltop 230/115 kV transformer and 230 kV source into Hilltop.

The ARD – HIL configuration also includes removing existing Big Rock – Colbyville 115 kV (145 Line) from the Colbyville Substation and extending this line to the Ridgeview Substation on double circuit structures with an existing 115 kV transmission line. This modification resolves the voltage collapse scenario in the Winter Base Case for loss of 56 Line and 57 Line into the Colbyville Substation as well as some transmission line overloads. 2019 historical data analysis in Section 5.5 and 5.6 illustrates that these are marginal issues that can be managed by running Laskin generation during prior outage events and completing a thermal upgrade on existing Ridgeview – Colbyville 115 kV (56 Line). Section 6 includes the analysis of the recommended Near-Term solution and Section 7 includes the analysis of the recommended Long-Term solution.

Section 6: Recommended Near-Term Solution

Overview

The historical data analysis of Duluth 230/115 kV transformer loading in Section 5.4, Duluth Loop voltage stability analysis in Section 5.5, and transmission line overloads in Section 5.6 illustrate that the following components of the preferred long-term ARD – HIL configuration can be deferred until a future need arises:

- Removing the existing Big Rock – Colbyville 115 kV (145 Line) from the Colbyville Substation and extending this line to the Ridgeview Substation on new double circuit structures with existing Ridgeview – Colbyville 115 kV (56 Line).
    - By operating Laskin generation at maximum output during an outage of either Arrowhead – Colbyville 115 kV or Ridgeview – Colbyville 115 kV, load at the Colbyville Substation can be served radially from Silver Bay for loss of the second transmission line.
- At the Hilltop Substation, convert the existing 230 kV bus to a 4-position ring bus, install a parallel 230/115 kV 187 MVA transformer, and add a 115 kV tie breaker between both transformer connections on the 115 kV bus. Existing Arrowhead – Hibbard 115 kV (70 Line) will be uncrossed from Fond du Lac – Hibbard 115 kV (15 Line) and converted to Arrowhead – Hilltop #2 230 kV (107 Line).
    - By upgrading the existing Hilltop 230 kV tap to 100C operation and replacing the existing 187 MVA 230/115 kV transformer at the Hilltop Substation with a 373 MVA transformer, post-contingent overloads on these facilities can be resolved.
    - By disconnecting the Hilltop 230 kV tap from existing Arrowhead – Iron Range 230 kV (98 Line) and extending this approximately 0.7 Miles to an open position at the Arrowhead Substation, the reliability of the sole 230 kV source into the Hilltop Substation can be greatly improved.

From the Base Case, the following modifications were made to the Duluth Area 115 kV transmission network for the recommended Near-Term solution:

- **71 Line**: A portion of the Arrowhead – 15th Ave West 115 kV Line was constructed as a double circuit line with the new Hilltop – Haines Road 115 kV Line (176 Line)
- **58 Line**: Arrowhead – Haines Road 115 kV Line was uncrossed with the existing 57 Line, creating an **Arrowhead – Colbyville 115 kV Line**
- **57 Line**: Arrowhead – Colbyville 115 kV Line was uncrossed with the existing 58 Line and extended from Haines Road to Swan Lake, creating an **Arrowhead – Swan Lake 115 kV Line**
- **52 Line**: Haines Road – Swan Lake 115 kV Line was extended from Swan Lake to Ridgeview, creating an **Haines Road – Ridgeview 115 kV Line**
- **176 Line**: **Hilltop – Haines Road 115 kV Line** was created by double circuiting 71 Line between Hilltop and 57 Line and constructing a new transmission line alongside existing 57 Line and 58 Line from this point to the Haines Road substation
- **98 Line**: The Hilltop 230 kV Tap was removed from this existing 3-Terminal line, becoming **Arrowhead – Iron Range 230 kV Line**
- **108 Line**: **Arrowhead – Hilltop 230 kV Line** was created by extending the Hilltop 230 kV Tap, which was removed from 98 Line, to a new 230 kV line entrance at the Arrowhead Substation
- **Ridgeview Substation**: Existing Ridgeview Substation was converted to a 6-position ring bus
- **Hilltop Substation**: The 230/115 kV 187 MVA transformer was replaced with a 373 MVA transformer and a new 115 kV line entrance was establish for new 176 Line
- **Arrowhead Substation**: A new 230 kV line entrance was established for 108 Line

The modifications to the Duluth Area transmission network are shown in Figure 6.1 below.

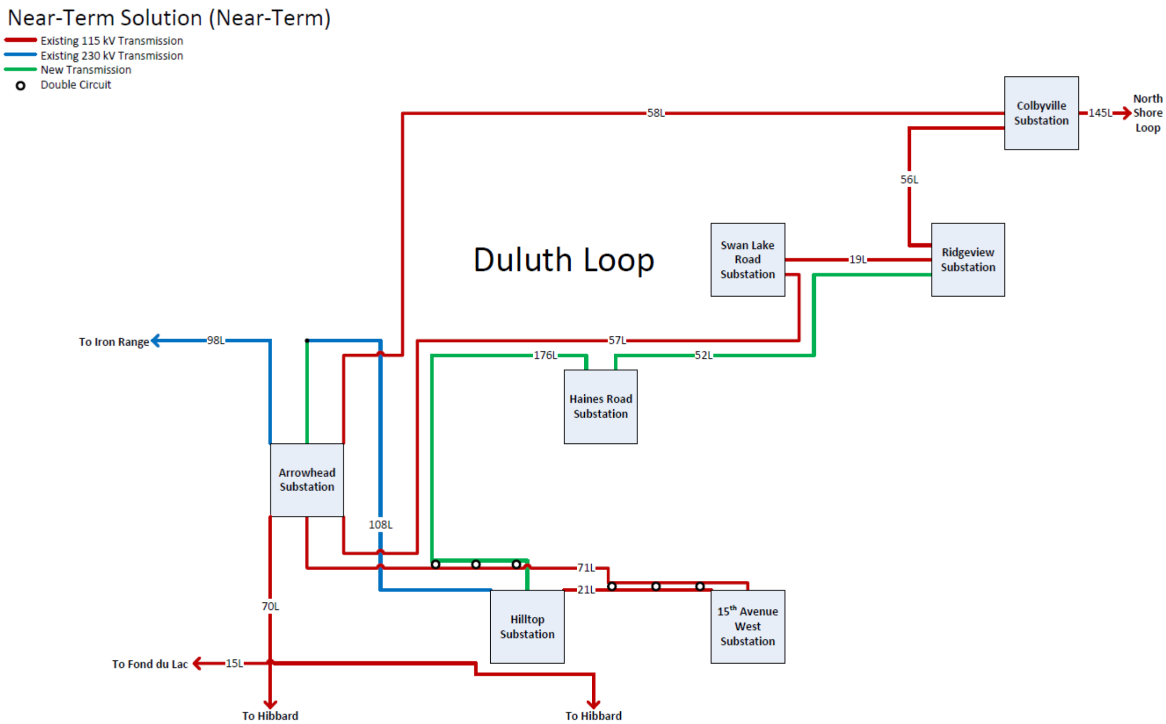


Figure 6.1: New Transmission between Arrowhead, Hilltop, Haines Road and Ridgeview (Near-Term)

6.1 System Intact Voltage Violations

There were no system intact voltage violations.

6.2 Non-Converged Contingencies

A "non-converged" contingency is one that the power flow software program (*PSS/E*) was not able to solve. There could be a number of explanations for why a solution could not be reached, but in general non-converged contingencies are indicative of severe contingencies and in some cases potential voltage or transient stability problems. The following non-converged contingencies result in voltage collapse scenarios which were not able to be resolved with existing infrastructure in the models.

Near-Term: Voltage Collapse Scenarios	
Contingency	**Near-Term**
P61:115-115:MP:BGR-COL:TCH-DKA	WTR
P61:115-115:MP:ARD-COL:COL-RGV	WTR

Table 6.1: Near-Term Voltage Collapse Scenarios

North Shore Loop Voltage Stability

The first voltage collapse scenario listed in Table 6.1 exists in the Winter Near-Term model and involves loss of Big Rock – Colbyville 115 kV (145 Line) in conjunction with the loss of either double circuited Taconite Harbor – Dunka Road 115 kV line (1 Line or 2 Line). It may be acceptable for planned outages on these three lines to occur during times of lighter North Shore Loop loading, such as during favorable Spring or Fall weather or during planned outages for a large industrial customer in Silver Bay. Unplanned outages on these three lines during times of higher North Shore Loop loading would likely result in an operational guide placing additional customers at risk of outage for loss of another line. The **North Shore Loop Voltage Stability** issue is discussed at length in Section 1.

Duluth Loop Voltage Stability

The second voltage collapse scenario listed in Table 6.1 exists in the Winter Near-Term model and involves loss of Arrowhead – Colbyville 115 kV (57 Line) and loss of Colbyville – Ridgeview 115 kV (56 Line). This leaves the Colbyville Substation served radially from Silver Bay. Planned outages on both of these lines could occur during times when loading between the Colbyville Substation and Silver Bay remains within Duluth stability thresholds identified in Section 4.2.1, 54 MW with Laskin generation offline and 65.7 MW with Laskin generation online at maximum output. Unplanned outages of either line when loading exceeds the stability threshold may result in an operational guide placing additional customers at risk of outage for loss of another line, either for the duration of the outage or until Laskin generation is online at maximum output. The **Duluth Loop Voltage Stability** issue is discussed at length in Section 1.

6.3 Post-Contingent Voltage Violations

All relevant post-contingent voltage violations were mitigated by switching local capacitor banks.

6.4 Transformer Overloads

Two overloaded transformers were identified in the Duluth area and are discussed below.

In Table 6.2, overloads on Arrowhead 6TR 230/115 kV transformer remain within the emergency rating following an outage of one Duluth area transformer during a prior outage of another. Without Arrowhead 7TR 230/115 kV transformer and Hilltop 230/115 kV transformer, Arrowhead 6TR 230/115 kV transformer becomes the only 230/115 kV source to the Duluth area. Maintenance outages on either transformer should be planned during times of lighter loading on Duluth area 230/115 kV transformers. This overload is resolved with a second 230 kV line and transformer at the Hilltop Substation.

Near-Term: Post-Contingent Loading of Arrowhead 230/115 kV Transformer #6					
Branch Name:	608615 ARROWHD4 230.00 3WNDTR ARD6 WND 1 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Near-Term MVA**	**Corrective Action**
WTR	P61:230-230:MP:ARD:7TR:HIL:1TR	**373.0**	**438.0**	414.05	Long-Term second 230 kV Line and transformer at the Hilltop Substation

Table 6.2: Post-Contingent Overloads on Arrowhead 230/115 kV "6TR"

In Table 6.3, overloads on Arrowhead 7TR 230/115 kV transformer remain within the emergency rating following a 230 kV breaker fault at the Arrowhead Substation. A 108L breaker failure results in the loss of Arrowhead 6TR 230/115 kV transformer, Arrowhead – Hilltop 230 kV (108 Line), and the Hilltop 230/115 kV transformer. Arrowhead 7TR 230/115 kV transformer becomes the only 230/115 kV source to the Duluth area. Arrowhead 108L breaker should be opened during a maintenance outage on Arrowhead 7TR transformer to avoid potentially having all three Duluth area 230/115 kV transformers disconnected. This overload is resolved with a second 230 kV line and transformer at the Hilltop Substation.

Near-Term: Post-Contingent Loading of Arrowhead 230/115 kV Transformer #7					
Branch Name:	608615 ARROWHD4 230.00 3WNDTR ARD7 WND 1 2				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Near-Term MVA**	**Corrective Action**
WTR	P24:230:MP:ARD:108L	**373.0**	**438.0**	416.24	Long-Term second 230 kV Line and transformer at the Hilltop Substation

Table 6.3: Post-Contingent Overloads on Arrowhead 230/115 kV "7TR"

6.5 Transmission Line Overloads

6.5.1 Single contingency overloads

No single contingency overloads were identified in the study area.

6.5.2 Multiple contingency overloads

Multiple contingency overloads are listed below which do not have a readily available system adjustment to mitigate the violation within a reasonable timeframe.

The overload on Arrowhead – Swan Lake Road 115 kV (57 Line) listed in table 6.4 below is caused by the loss of a Duluth Loop transmission line during a prior outage of another Duluth Loop transmission line. As part of the Near-Term solution, existing Haines Road – Swan Lake Road 115 kV (52 Line) will be upgraded and become part of 57 Line. The upgrade of existing 52 Line will resolve this overload.

Near-Term: Post-Contingent Loading of Arrowhead – Swan Lake Road 115 kV Line (57 Line)					
Branch Name:	608673 ARROWHD7 115.00 608685 SWAN LK7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Near-Term MVA**	**Corrective Action**
WTR	P61:115-115:MP:ARD-COL:HIL-HNS	**185.0**	**204.0**	213.28	Upgrade existing Haines Road – Swan Lake Road 115 kV (52 Line)

Table 6.4: Post-Contingent Overloads on Arrowhead – Swan Lake Road 115 kV Line

Overloads on Ridgeview – Colbyville 115 kV (56 Line) listed in table 6.5 below are caused by the loss of a Duluth Loop transmission line and the North Shore – Taconite Harbor 115 kV (128 Line) connection into Taconite Harbor. A thermal upgrade of this line could resolve these overloads but is not part of the Near-Term solution. The Long-Term solution discussed in Section 7 includes rebuilding 56 Line on double-circuit structures while extending Colbyville – Big Rock 115 kV (145 Line) to the Ridgeview Substation. Near-term upgrades to 56 Line will likely be rebuilt as part of the Long-Term solution. For this reason, 56 Line loading will continue to be monitored and an appropriate corrective action will be implemented when necessary.

Near-Term: Post-Contingent Loading of Ridgeview – Colbyville 115 kV Line (56 Line)					
Branch Name:	608675 RIDGEVW7 115.00 608688 COLBYVL7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Near-Term MVA**	**Corrective Action**
SUM	P61:115-115:MP:ARD-COL:NTS-TCH	**135.0**	**148.0**	152.78	Long-Term 56 Line Rebuild
SUM	P61:115-115:MP:ARD-COL:TCH TR4	**135.0**	**148.0**	159.11	Long-Term 56 Line Rebuild
SSH	P61:115-115:MP:ARD-COL:NTS-TCH	**135.0**	**148.0**	138.09	Long-Term 56 Line Rebuild
SSH	P61:115-115:MP:ARD-COL:TCH TR4	**135.0**	**148.0**	142.52	Long-Term 56 Line Rebuild

Table 6.5: Post-Contingent Overloads on Arrowhead – Swan Lake Road 115 kV Line

Overloads on Arrowhead – Hilltop 230 kV (98 Line) listed in table 6.6 below are caused by the loss of two Arrowhead 230/115 kV transformers. As part of the Near-Term solution, a 100C thermal upgrade of this line will resolve these overloads.

Near-Term: Post-Contingent Loading of Arrowhead – Hilltop 230 kV Line (108 Line)					
Branch Name:	608615 ARROWHD4 230.00 608616 HILLTOP4 230.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Near-Term MVA**	**Corrective Action**
SUM	P61:230-230:MP:ARD:6T:ARD:7TR	**252.0**	**277.0**	293.45	100C Thermal Upgrade
SSH	P61:230-230:MP:ARD:6T:ARD:7TR	**252.0**	**277.0**	285.85	100C Thermal Upgrade

Table 6.6: Post-Contingent Overloads on Arrowhead – Hilltop 230 kV Line

Overloads listed in Table 6.7 below are caused by the loss of the Big Rock – Colbyville 115 kV Line during a prior outage of one of the double circuit Taconite Harbor – Dunka Road 115 kV Lines. All of the North Shore Loop load from Taconite Harbor to Two Harbors is being served through a single set of 477 ACSR conductor on the remaining Taconite Harbor – Dunka Road 115 kV Line. This scenario causes severe overloads in the Summer and Shoulder Cases and a voltage collapse scenario in the Winter Case. It may be acceptable for planned outages on these three lines to occur during times of lighter North Shore Loop loading, such as during favorable Spring or Fall weather or during planned outages for a large industrial customer in Silver Bay. However, these customer outage periods typically occur at most twice a year and are typically short in duration. Unplanned outages on these three lines would likely result in an operational guide placing additional customers at risk of outage for loss of another line. The same interim operational solutions which apply to the **North Shore Loop Voltage Stability** issue is discussed at length in Section 1 would resolve overload listed in Table 6.7 below.

Near-Term: Post-Contingent Loading of Taconite Harbor – Dunka Road 115 kV Lines (1 & 2 Line)					
Branch Name:	608697 TAC HBR7 115.00 608699 DUNKARD7 115.00 1 608697 TAC HBR7 115.00 608699 DUNKARD7 115.00 2				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Near-Term MVA**	**Corrective Action**
SUM	P61:115-115:MP:BGR-COL:TCH-DKA	**123.0**	**135.0**	**170.69**	Interim: Operational Guide as Discussed
SSH	P61:115-115:MP:BGR-COL:TCH-DKA	**123.0**	**135.0**	**145.61**	Interim: Operational Guide as Discussed

Table 6.7: Post-Contingent Overloads on Taconite Harbor – Dunka Road 115 kV Lines

6.6 Near-Term Outstanding Issues

Transmission line overloads listed above for 57 Line and 108 Line will be resolved with the Near-Term solution. As discussed in Section 7, overloads on Arrowhead 6TR, Arrowhead 7TR, and 56 Line are resolved by the Long-Term solution. The Near-Term solution study results illustrate that voltage collapse and thermal violations remain for the loss of Big Rock – Ridgeview 115 kV (145 Line) and a Taconite Harbor – Dunka Road 115 kV line (1 or 2 Line). This **North Shore Loop Voltage Stability** issue is discussed at length in Section 1 and Section 4.6 and is not resolved by the Near-Term solution. The near-term transfer trip scheme and operational guides will be implemented to help manage this issue. Minnesota Power will continue to monitor this issue and explore reasonable opportunities to resolve this issue.

6.7 Near-Term Solution Timing & Cost

Analysis of historical Duluth area 230/115 kV transformer loading in Section 5.4 indicates the Near-Term solution sufficiently resolves these existing overload concerns while providing the opportunity for load growth in the Duluth area. Analysis of historical loading between the Colbyville Substation and Silver Bay in Section 5.5 indicates the Near-Term solution sufficiently resolves existing Duluth Loop voltage stability concerns with Laskin generation online. Analysis of historical loading between the Colbyville Substation and Silver Bay in Section 5.6 indicates the Near-Term solution sufficiently resolves existing 128 Line and Duluth Loop transmission line overloads. Without the support previously provided by the local baseload generators in the North Shore Loop, implementation of the Near-Term solution should be completed as soon as reasonably possible to resolve these existing issues. A preliminary engineering estimate for the Near-Term solution is $50 - $70 Million in 2021 dollars which includes some additional asset renewal components and existing route adjustments.

Section 7: Recommended Long-Term Solution

Overview

After construction of the Near-Term solution, the recommended Long-Term solution involves disconnecting the existing Big Rock – Colbyville 115 kV (145 Line) from the Colbyville Substation and extending this line to the Ridgeview Substation on new double circuit structures with existing Ridgeview – Colbyville 115 kV (56 Line). In addition, the existing 230 kV bus at the Hilltop Substation will be converted to a 4-position ring bus, a parallel 230/115 kV 373 MVA transformer will be installed, and a 115 kV tie breaker will be added between both transformer connections on the 115 kV bus. Existing Arrowhead – Hibbard 115 kV (70 Line) will be uncrossed with existing Fond du Lac – Hibbard 115 kV (15 Line) and converted to Arrowhead – Hilltop #2 230 kV (107 Line). From the Base Case, the following modifications were made to the Duluth Area 115 kV transmission network for the recommended Long-Term solution:

- **71 Line**: A portion of the Arrowhead – 15th Ave West 115 kV Line was constructed as a double circuit line with the new Hilltop – Haines Road 115 kV Line (176 Line)
- **58 Line**: Arrowhead – Haines Road 115 kV Line was uncrossed with the existing 57 Line, creating an **Arrowhead – Colbyville 115 kV Line**
- **57 Line**: Arrowhead – Colbyville 115 kV Line was uncrossed with the existing 58 Line and extended from Haines Road to Swan Lake, creating an **Arrowhead – Swan Lake 115 kV Line**
- **52 Line**: Haines Road – Swan Lake 115 kV Line was extended from Swan Lake to Ridgeview, creating an **Haines Road – Ridgeview 115 kV Line**
- **145 Line**: Colbyville – Big Rock 115 kV Line was extended to Ridgeview by building double circuit with Arrowhead – Colbyville 115 kV Line (existing 57 Line) and Ridgeview – Colbyville 115 kV Line (56 Line), creating a **Ridgeview – Big Rock 115 kV Line**
- **176 Line**: **Hilltop – Haines Road 115 kV Line** was created by double circuiting 71 Line between Hilltop and 57 Line and constructing a new transmission line alongside existing 57 Line and 58 Line from this point to the Haines Road substation
- **15 Line**: Fond du Lac – Hibbard 115 kV Line was uncrossed with the existing 70 Line, leaving this as a Fond du Lac – Hibbard 115 kV Line but utilizing the existing 70 Line entrance at Hibbard
- **107 Line**: **Arrowhead – Hilltop #2 230 kV Line** was created by converting existing 70 Line and 15 Line between Arrowhead and Hilltop to 230 kV
- **70 Line**: Arrowhead – Hibbard 115 kV Line was uncrossed with the existing 15 Line and converted to 230 kV (**107 Line**) between Arrowhead and Hilltop; the existing segment of 15 Line between Hilltop and Hibbard was abandoned in place; in the future, this abandoned segment could be utilized to make 21 Line a 3 terminal line for mitigating post-contingent overloads for a Hilltop 115MW breaker failure
- **98 Line**: The Hilltop 230 kV Tap was removed from this existing 3-Terminal line, becoming **Arrowhead – Iron Range 230 kV Line**
- **108 Line**: **Arrowhead – Hilltop #1 230 kV Line** was created by extending the Hilltop 230 kV Tap, which was removed from 98 Line, to a new 230 kV line entrance at the Arrowhead Substation
- **Ridgeview Substation**: Existing Ridgeview Substation was converted to a 6-position ring bus
- **Hilltop Substation**: The existing 230 kV bus at the Hilltop Substation was converted to a 4-position ring bus; the existing 230/115 kV 187 MVA transformer was removed and two parallel 230/115 kV 373 MVA transformers were added; a 115 kV tie breaker was added between these transformers on the 115 kV bus; a new 115 kV line entrance was establish for new 176 Line
- **Arrowhead Substation**: A new 230 kV line entrance was established for 108 Line

The modifications to the Duluth Area transmission network are shown in Figure 7.1 below.

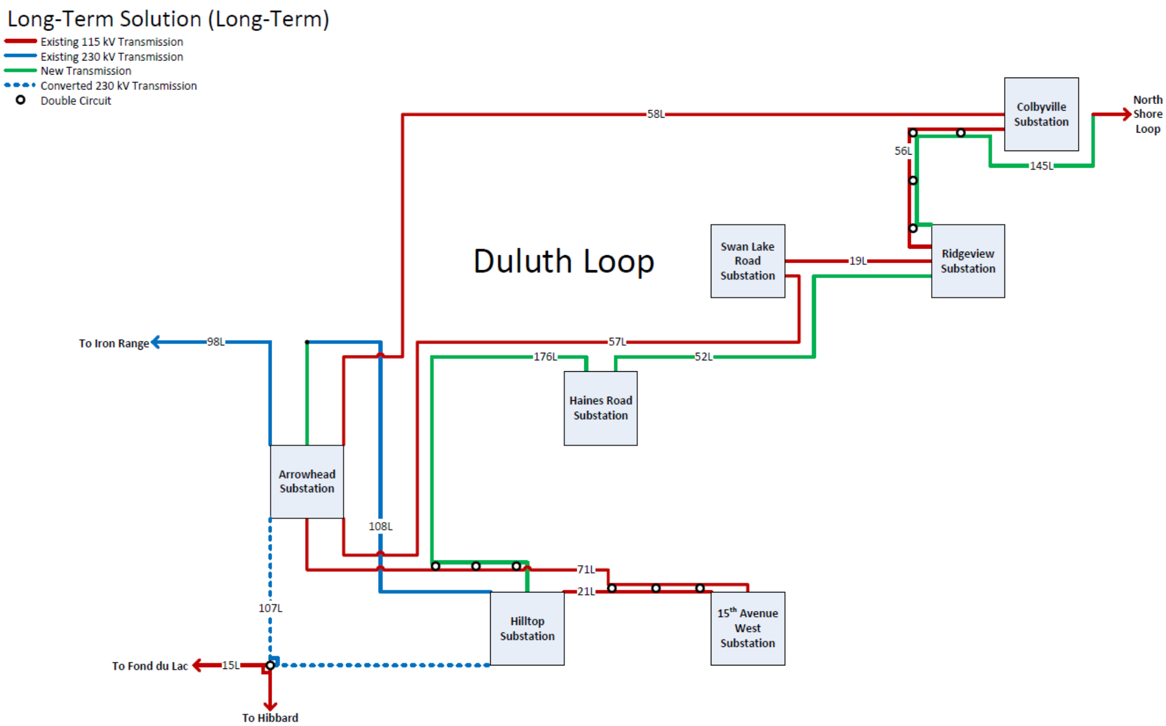


Figure 7.1: New Transmission between Arrowhead, Hilltop, Haines Road, Ridgeview, and Colbyville (Long-Term)

7.1 System Intact Voltage Violations

There were no system intact voltage violations.

7.2 Non-Converged Contingencies

A "non-converged" contingency is one that the power flow software program (*PSS/E*) was not able to solve. There could be a number of explanations for why a solution could not be reached, but in general non-converged contingencies are indicative of severe contingencies and in some cases potential voltage or transient stability problems. The following non-converged contingencies result in voltage collapse scenarios which were not able to be resolved with existing infrastructure in the models.

Long-Term: Voltage Collapse Scenarios	
Contingency	**Long-Term**
P61:115-115:MP:BGR-RGV:TCH-DKA	WTR

Table 7.1: Long-Term Voltage Collapse Scenarios

North Shore Loop Voltage Stability

The only voltage collapse scenario listed in Table 7.1 exists in the Winter Long-Term model and involves loss of Big Rock – Ridgeview 115 kV (145 Line) in conjunction with the loss of either double circuited Taconite Harbor – Dunka Road 115 kV line (1 Line or 2 Line). This voltage collapse scenario exists in the Winter Base Case. It may be acceptable for planned outages on these three lines to occur during times of lighter North Shore Loop loading, such as during favorable Spring or Fall weather or during planned outages for a large industrial customer in Silver Bay. Unplanned outages on these three lines during times of higher North Shore Loop loading would likely result in an operational guide placing additional customers at risk of outage for loss of another line. The **North Shore Loop Voltage Stability** issue is discussed at length in Section 1.

7.3 Post-Contingent Voltage Violations

All relevant post-contingent voltage violations were mitigated by switching local capacitor banks.

7.4 Transformer Overloads

No overloaded transformers were identified in the study area.

7.5 Transmission Line Overloads

7.5.1 Single contingency overloads

Single contingency overloads are listed below which do not have a readily available system adjustment to mitigate the violation within a reasonable timeframe.

Overloads listed in table 7.2 below are caused by the loss of Hilltop – Hibbard 115 kV (7 Line) and Hilltop – LSPI 115 kV (72 Line). With the conversion of existing Arrowhead – Hibbard 115 kV (70 Line) to Arrowhead – Hilltop 230 kV (107 Line), 8 Line is one of only two 115 kV transmission paths which remain in-service to serve the LSPI, Hibbard, Gary, and Superior area substations. Post-contingent loading on this transmission line exceeds the emergency rating. Near-term plans to reconductor this line as part of the 8 Line Relocation project will resolve these overloads.

Long-Term: Post-Contingent Loading of Thomson – Fond du Lac 115 kV Line (8 Line)					
Branch Name:	608665 THOMSON7 115.00 608666 FONDULAC 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Long-Term MVA**	**Corrective Action**
SSH	P24:115:MP:HIL:115MW	**78.0**	**86.0**	**86.19**	8 Line Relocation
SSH	P71:115-115:MP:HIL-MLH:HIL-LSP	**78.0**	**86.0**	**85.40**	8 Line Relocation

Table 7.2: Post-Contingent Overloads on Thomson – Fond du Lac 115 kV Line

7.5.2 Multiple contingency overloads

Multiple contingency overloads are listed below which do not have a readily available system adjustment to mitigate the violation within a reasonable timeframe.

The overload on Arrowhead – Swan Lake Road 115 kV (57 Line) listed in table 7.3 below is caused by the loss of a Duluth Loop transmission line during a prior outage of another Duluth Loop transmission line. As part of the Near-Term solution, existing Haines Road – Swan Lake Road 115 kV (52 Line) will become part of 57 Line. A reconductor or thermal upgrade of this line is part of the Near-Term solution which will resolve this overload.

Long-Term: Post-Contingent Loading of Arrowhead – Swan Lake Road 115 kV Line (57 Line)					
Branch Name:	608673 ARROWHD7 115.00 608685 SWAN LK7 115.00 1				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Long-Term MVA**	**Corrective Action**
WTR	P61:115-115:MP:ARD-COL:HIL-HNS	**185.0**	**204.0**	**214.50**	Upgrade existing Haines Road – Swan Lake Road 115 kV (52 Line)

Table 7.3: Post-Contingent Overloads on Arrowhead – Swan Lake Road 115 kV Line

Overloads listed in table 7.4 below are caused by the loss of the Big Rock – Ridgeview 115 kV Line during a prior outage of one of the double circuit Taconite Harbor – Dunka Road 115 kV Lines. All of the North Shore Loop load from Taconite Harbor to Two Harbors is being served through a single set of 477 ACSR conductor on the remaining Taconite Harbor – Dunka Road 115 kV Line. This scenario causes severe overloads in the Summer and Shoulder Cases and a voltage collapse scenario in the Winter Case. Planned outages on these three lines could occur during planned outages or during significantly reduced power consumption for the large industrial customer in Silver Bay. However, these customer outage or load reduction periods would likely be difficult to obtain and limited to a few days due to customer demands. Unplanned outages on these three lines would likely result in an operational guide placing additional customers at risk of outage for loss of another line. The same interim operational solutions which apply to the **North Shore Loop Voltage Stability** issue is discussed at length in Section 1 and should resolve overloads listed in table 7.4 below.

Long-Term: Post-Contingent Loading of Taconite Harbor – Dunka Road 115 kV Lines (1 & 2 Line)					
Branch Name:	608697 TAC HBR7 115.00 608699 DUNKARD7 115.00 1 608697 TAC HBR7 115.00 608699 DUNKARD7 115.00 2				
Case	**Contingency**	**N.Rate MVA**	**E.Rate MVA**	**Long-Term MVA**	**Corrective Action**
SUM	P61:115-115:MP:BGR-RGV:TCH-DKA	**123.0**	**135.0**	**170.56**	Interim: Operational Guide as Discussed
SSH	P61:115-115:MP:BGR-RGV:TCH-DKA	**123.0**	**135.0**	**145.48**	Interim: Operational Guide as Discussed

Table 7.4: Post-Contingent Overloads on Taconite Harbor – Dunka Road 115 kV Lines

7.6 Long-Term Outstanding Issues

Transmission line overloads listed above for 8 Line will be resolved with the near-term 8 Line Relocation Project and those listed for 57 Line will be resolved with the Near-Term solution. The Long-Term solution study results illustrate that voltage collapse and thermal violations remain for the loss of Big Rock – Ridgeview 115 kV (145 Line) and a Taconite Harbor – Dunka Road 115 kV line (1 or 2 Line). This **North Shore Loop Voltage Stability** issue is discussed at length in Section 1 and Section 4.6 and is not resolved by the Long-Term solution. The near-term transfer trip scheme and operational guides included in the Near-Term solution to help manage this issue. Minnesota Power will continue to monitor this issue and explore reasonable opportunities to resolve this issue.

7.7 Long-Term Solution Timing and Cost

Analysis of historical Duluth area 230/115 kV transformer loading in Section 5.4 indicates the Near-Term solution sufficiently resolves these existing overload concerns while providing the opportunity for load growth in the Duluth area. The most significant post-contingent loading on the Duluth area 230/115 kV transformers then becomes Arrowhead 7TR transformer loading for failure of the 108L 230 kV circuit breaker at the Arrowhead Substation. The expected post-contingent loading on this transformer for the 108L 230 kV circuit breaker failure based on 2019 hourly historical load data and power flow modeling is 408.3 MVA with Hibbard generation online and 457.2 MVA with Hibbard generation offline. With Hibbard generation online, expected post-contingent loading on Arrowhead 7TR exceeds the maximum obtainable 466 MVA emergency rating of this transformer in 2035 with a conceptual 1.0% annual load growth and in 2050 with a conceptual 0.5% annual load growth. With Hibbard generation offline, expected post-contingent loading on Arrowhead 7TR exceeds the maximum obtainable 466 MVA emergency rating of this transformer in 2024 with a conceptual 1.0% annual load growth and in 2029 with a conceptual 0.5% annual load growth. Minnesota Power will continue to monitor loading on these transformers along with operational plans for Hibbard generation and Arrowhead HVDC to determine the appropriate timing for establishing a second 230 kV transmission line and transformer at the Hilltop Substation.

Analysis of historical loading between the Colbyville Substation and Silver Bay in Section 5.5 indicates the Near-Term solution sufficiently resolves existing Duluth Loop voltage stability concerns if Laskin generation can be online during an outage of either Arrowhead – Colbyville 115 kV (57 Line) or Ridgeview – Colbyville 115 kV (56 Line). The 2019 historical peak is 57.4 MW for loading between the Colbyville

Substation and Silver Bay, above the voltage stability threshold with Laskin generation offline. With Laskin generation online, this load pocket exceeds the 65.7 MW voltage stability threshold in 2033 with a conceptual 1.0% annual load growth and in 2047 with a conceptual 0.5% annual load growth. Minnesota Power will continue to monitor load levels in this area along with operation plans for Laskin generation to determine the appropriate time for extending Big Rock – Colbyville 115 kV (145 Line) to the Ridgeview Substation.

Utilizing the MISO MTEP21 Transmission Cost Estimation Guide, a preliminary planning level estimate for the Long-Term solution is $37.9 Million in 2021 dollars.

Appendix A: Key Model Assumptions

The benchmark cases are derived from 2019 MTEP model series. The following Base Case modifications were made to address location-specific concerns, correct for topology errors or updates, incorporate planned transmission projects, and reflect existing operational conditions:

- Mesaba Junction Project (*P13485 - Mesaba JCT- Winter.py, P13485 - Mesaba JCT- Summer.py*)
    - o Mesaba Junction Switching Station near the Hoyt Lakes Substation with 2x28 MVAR capacitor banks
    - o Extend 38 Line from Laskin to Mesaba Junction Switching Station with 666 ACSS conductor
    - o Convert 138 kV system between Laskin and Taconite Harbor to 115 kV
- Babbitt 115 kV Project (*BabbittProject-WTR.py, BabbittProject-SUM.py*):
    - o New Dunka Road Substation intercepting both Taconite Harbor – Hoyt Lakes 115 kV Lines
    - o 12 MVAR capacitor bank at the Dunka Road Substation
    - o Upgrade the existing Embarrass – Babbitt 115 kV Line from Embarrass to the Babbitt Pit
    - o Extend the existing Embarrass – Babbitt 115 kV Line from the Babbitt Pit to the Dunka Road Substation
- Industrial Load (*Industrial_77.5MW_Total.py*):
    - o 70.852 MW of industrial load with 0.95 PF at the Hoyt Lakes Substation
    - o 6.674 MW of industrial load with 0.95 PF at the Dunka Road Substation
- Reconductor existing Forbes – Laskin 115 kV Line with 666 ACSS conductor (*P16804_38 Line Upgrade_Winter.py, P16804_38 Line Upgrade_Summer.py*)
- Improve modeling of the North Shore STATCOM and system capacitor banks (CorrectCapBanks.py)
- Add 4 MVAR STATCOM to the Arrowhead 69 kV bus (*ArrowheadGen_STATCOM_4.0MVAR.py*)
- Add transformer at Nemadji Switching Station for Husky load (*P- Husky XMFR - 2022+.py*)
- Change operations of the Stinson PST to normally operate around 0 MW (*ZeroStinsonPST.py*)
- Turned off Taconite Harbor generation which was idled in 2016
- Turned off Laskin generation which was converted to natural gas peaking generation in 2015
- Update and correct modeled load in the North Shore Loop, Duluth, Superior, and surrounding area, load data shown in greater detail in Appendix B.

After the Base Case results were gathered, an issue was realized with the North Shore cap bank modeling. Contingencies involving North Shore Bus #1 disconnected the STATCOM and 60 MVARs of capacitor banks. In reality, 40 MVARs of capacitor banks should have been disconnected with the STATCOM. This issue was resolved with the following python script after the Base Case analysis: *NorthShoreCapCorrection.py*

Appendix B: Historical Load Data

Updated 2024 modeled load for the North Shore Loop, Duluth, Superior, and surrounding area. Historical peak load data was scaled at a conservative 1% per year from a historical date.

Winter Peak(MW)																	
Scaled(1%/yr) From Historical Winter Peak	15thAve	Cloquet	Colbyville	FourCorners	GaryDist	Haines	Hibbard	Ridgeview	SwanLake	Taft	WinterSt	FarmontPark	StinsonAve	Wrenshall	Thomson	LSPI_Dist	LSPI_34kV
1/5/2017 17:00	31.2750	29.8513	19.3275	10.8825	9.9613	27.2835	3.5890	25.3000	32.2000	4.3085	24.5121	17.7000	27.6000	3.4812	2.4000	22.8045	8.8000
P2 Values (Industrial Load)	7.0000	10.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.9000	4.8000	0.0000	0.0000
2017-18	24.5178	20.0499	19.5208	10.9913	10.0609	27.5563	3.6249	25.5530	32.5220	4.3516	24.7572	17.8770	27.8760	3.9000	4.8000	23.0326	8.8880
2018-19	24.7629	20.2504	19.7160	11.1012	10.1615	27.8318	3.6611	25.8085	32.8472	4.3951	25.0047	18.0558	28.1548	3.9000	4.8000	23.2629	8.9769
2019-20	25.0106	20.4529	19.9131	11.2123	10.2631	28.1102	3.6977	26.0666	33.1757	4.4391	25.2548	18.2363	28.4363	3.9000	4.8000	23.4955	9.0666
2020-21	25.2607	20.6574	20.1123	11.3244	10.3658	28.3913	3.7347	26.3273	33.5074	4.4835	25.5073	18.4187	28.7207	3.9000	4.8000	23.7305	9.1573
2021-22	25.5133	20.8640	20.3134	11.4376	10.4694	28.6752	3.7721	26.5906	33.8425	4.5283	25.7624	18.6029	29.0079	3.9000	4.8000	23.9678	9.2489
2022-23	25.7684	21.0726	20.5165	11.5520	10.5741	28.9619	3.8098	26.8565	34.1809	4.5736	26.0200	18.7889	29.2980	3.9000	4.8000	24.2075	9.3414
2023-24	26.0261	21.2833	20.7217	11.6675	10.6799	29.2516	3.8479	27.1250	34.5228	4.6193	26.2802	18.9768	29.5909	3.9000	4.8000	24.4496	9.4348
2024-25	26.2863	21.4962	20.9289	11.7842	10.7867	29.5441	3.8864	27.3963	34.8680	4.6655	26.5430	19.1666	29.8868	3.9000	4.8000	24.6941	9.5291

WINTER PEAK (MW)									
Subset	**2016-17**	**2017-18**	**2018-19**	**2019-20**	**2020-21**	**2021-22**	**2022-23**	**2023-24**	**2024-25**
145L TAPS*	19.7818	19.9796	20.1794	20.3812	20.5850	20.7908	20.9988	21.2087	21.4208
TSS Dist	5.6244	5.6807	5.7375	5.7948	5.8528	5.9113	5.9704	6.0301	6.0904
145L Taps	14.1574	14.2989	14.4419	14.5863	14.7322	14.8795	15.0283	15.1786	15.3304
42L TAPS	19.1755	19.3672	19.5609	19.7565	19.9541	20.1536	20.3551	20.5587	20.7643
128L TAPS	4.6364	4.6827	4.7295	4.7768	4.8246	4.8729	4.9216	4.9708	5.0205
GRE 69KV	26.9939	27.2638	27.5365	27.8118	28.0899	28.3708	28.6546	28.9411	29.2305
TOTAL	*70.5875*	*71.2933*	*72.0063*	*72.7263*	*73.4536*	*74.1881*	*74.9300*	*75.6793*	*76.4361*
* Including Two Harbors Switching Station			1.00%	Annual Growth Rate					

Summer Peak(MW)																	
Scaled(1%/yr) From Historical Summer Peak	15thAve	Cloquet	Colbyville	FourCorners	GaryDist	Haines	Hibbard	Ridgeview	SwanLake	Taft	WinterSt	FarmontPark	StinsonAve	Wrenshall	Thomson	LSPI_Dist	LSPI_34kV
7/31/2017 15:00	25.9875	27.4785	14.2800	8.1675	9.5218	25.0495	5.3469	23.6627	32.6000	2.5397	26.3187	16.1000	25.2000	2.5956	4.0000	22.0721	9.4000
P2 Values (Industrial Load)	7.0000	10.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	3.9000	4.8000	0.0000	0.0000
2018	19.1774	17.6533	14.4228	8.2492	9.6170	25.3000	5.4003	23.8993	32.9260	2.5651	26.5819	16.2610	25.4520	3.9000	4.8000	22.2928	9.4940
2019	19.3691	17.8298	14.5670	8.3317	9.7132	25.5530	5.4543	24.1383	33.2553	2.5907	26.8477	16.4236	25.7065	3.9000	4.8000	22.5157	9.5889
2020	19.5628	18.0081	14.7127	8.4150	9.8103	25.8085	5.5089	24.3797	33.5878	2.6166	27.1162	16.5878	25.9636	3.9000	4.8000	22.7409	9.6848
2021	19.7585	18.1882	14.8598	8.4991	9.9084	26.0666	5.5640	24.6235	33.9237	2.6428	27.3874	16.7537	26.2232	3.9000	4.8000	22.9683	9.7817
2022	19.9561	18.3701	15.0084	8.5841	10.0075	26.3273	5.6196	24.8697	34.2629	2.6692	27.6612	16.9213	26.4855	3.9000	4.8000	23.1980	9.8795
2023	20.1556	18.5538	15.1585	8.6700	10.1076	26.5906	5.6758	25.1184	34.6056	2.6959	27.9379	17.0905	26.7503	3.9000	4.8000	23.4299	9.9783
2024	20.3572	18.7393	15.3101	8.7567	10.2087	26.8565	5.7326	25.3696	34.9516	2.7229	28.2172	17.2614	27.0178	3.9000	4.8000	23.6642	10.0781

SUMMER PEAK (MW)								
Subset	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
145L TAPS*	11.3333	11.4466	11.5611	11.6767	11.7935	11.9114	12.0305	12.1508
TSS Dist	5.4136	5.4677	5.5224	5.5776	5.6334	5.6897	5.7466	5.8041
145L Taps	5.9197	5.9789	6.0387	6.0991	6.1601	6.2217	6.2839	6.3467
42L TAPS	17.4840	17.6588	17.8354	18.0138	18.1939	18.3759	18.5596	18.7452
128L TAPS	4.6364	4.6827	4.7295	4.7768	4.8246	4.8729	4.9216	4.9708
GRE 69KV	12.8582	12.9867	13.1166	13.2478	13.3803	13.5141	13.6492	13.7857
TOTAL	*46.3118*	*46.7749*	*47.2427*	*47.7151*	*48.1923*	*48.6742*	*49.1609*	*49.6525*
* Including Two Harbors Switching Station			1.00%	Annual Growth Rate				