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Maximum reactive power injected = 149.81 kVAR

Table 12. Load Flow results for Discharging/Charging of BESS under Volt-Var mode

Scenario	**Control Mode**	**Site Operation**	**Load Flow at POI (PriOH1124375 (Kerrick))**	**Load Flow at POI (PriOH330983 (Askov))**	**Load Flow at CBBCR Substation**
Peak	Volt Var Mode	Discharging at 1.5 MVA each (Cumulative 3 MW)	P = -1484.0 kW Q = 234.0 kVAR	P = -1483.9 kW Q = 235.9 kVAR	P = -1178.7 kW Q = 746.5 kVAR
Peak	Volt Var Mode	Charging at 1.5 MVA each (Cumulative 3 MVA)	P =1525.5 kW Q =89.6 kVAR	P = 1552.2 kW Q = 89.7 kVAR	P = 4965.6 kW Q = -568.3 kVAR
Off Peak	Volt Var Mode	Discharging at 1.5 MVA each (Cumulative 3 MVA)	P = -1484.0 kW Q =233.8 kVAR	P =-1483.9 kW Q =234.4 kVAR	P =-2261.6 kW Q = -105.5 kVAR
Off Peak	Volt Var Mode	Charging at 1.5 MVA each (Cumulative 3 MVA)	P =1522.4 kW Q = 89.7kVAR	P = 1545.6 kW Q =89.8 kVAR	P = 3821.61 kW Q = -1138.2 kVAR

Table 13. Voltage results for Discharging of BESS under Volt-Var mode

Scenario	**1.50 MVA PriOH1124375 (Kerrick)**	**1.50 MVA PriOH330983 (Askov)**	**Substation [V]**	**POI (PriOH1124375 (Kerrick)) [V]**	**POI (PriOH330983 (Askov)) [V]**	**Vmax [V]**	**Vmin [V]**
Peak (Base Volt = 124.7V, 1.039 p.u.)	OFF	OFF	124.1	123.1	122.9	125.4	104.0 (Sec) 120.8 (Prim)
	Charging	Charging	124.7	122.3	124.4	125.4	103.0 (Sec) 119.9 (Prim)
	Discharging	Discharging	124.1	123.9	123.1	124.4	104.7
Off-peak (Base Volt = 122.5V, 1.02 p.u.)	OFF	OFF	123.1	123.5	123.4	125.9	106.9
	Charging	Charging	123.3	122.0	123.9	125.8	105.6
	Discharging	Discharging	123.0	124.2	123.7	125.9	108.2

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VI. Voltage Change Analysis

A Voltage Change Analysis was performed to determine the instantaneous change in voltage (voltage change/flicker) that would occur in the distribution system upon sudden loss of the 3.0 MW project. IEEE 1547-2018 requires the voltage flicker at the POI given a 100% loss of the project must be "< / = 3%". Similarly, the voltage change at the line regulators and substation LTC must be less than or equal to half their bandwidths "< / = 1.5 V" and "< / = 1.0 V", respectively.

OPTION 1:

Table 14. Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI	125.4	123.4	1.61%	125.3	123.2	1.68%	125.4	123.5	1.56%
Substation Bus	124.4	124.1	0.24	124.3	124.1	0.24	124.4	124.2	0.22

Table 15. Voltage change assuming 100% BESS Drop at Off-peak Load Condition with Unity PF

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI	125.8	124.2	1.26%	125.0	122.6	1.93%	125.2	123.4	1.44%
Substation Bus	123.5	123.4	0.13	123.1	122.9	0.24	123.2	123.1	0.13

OPTION 2:

The distance between POIs **PriOH1124375 (Kerrick) and PriOH330983 (Askov)** is greater than 0.75 miles, so voltage change analysis is done independently.

Table 16. Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF at PriOH1124375 (Kerrick)

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI **(**PriOH1124375 (Kerrick)**)**	124.9	123.8	0.83%	124.5	123.4	0.97%	124.8	123.8	0.83%

Substation Bus	124.4	124.3	0.10	124.4	124.3	0.12	124.4	124.4	0.10

Table 17. Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF at PriOH330983 (Askov)

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI **(**PriOH330983 (Askov)**)**	123.5	123.8	0.20%	123.6	123.8	0.20%	123.7	123.9	0.20%
Substation Bus	124.3	124.4	0.17	124.2	124.4	0.168	124.3	124.4	0.17

Table 18. Voltage change assuming 100% BESS Drop at Off- Peak Load Condition with Unity PF at PriOH1124375 (Kerrick)

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI(PriOH1124375 (Kerrick)**)**	124.8	124.5	0.17%	123.8	123.1	0.56%	123.9	123.5	0.34%
Substation Bus	123.2	123.3	0.12	122.8	122.9	0.07	122.9	123.0	0.11

Table 19. Voltage change assuming 100% BESS Drop at Off- Peak Load Condition with Unity PF at PriOH330983 (Askov)

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI(PriOH330983 (Askov))	124.4	124.3	0.07%	123.1	122.8	0.25%	123.7	123.7	0.01%
Substation Bus	123.2	123.3	0.09	122.8	122.85	0.05	122.9	123.0	0.12

VII. Short Current Analysis

A short circuit analysis was performed to determine the fault duty at various points and to identify any distribution protection equipment that exceeds its interrupting capability as a result of the project interconnection.

Below is a summary of the maximum fault levels on the 34 kV Kerrick feeder. There is a limited ability for the simulation software windmill defining the short current contribution of the inverters. Therefore, a simplified CYME model is used to simulate the short current contribution impact due to the proposed BESS.

Option 1:

Table 20. Short Current Analysis

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	681	637	590	524
ON	POI	732	858	611	820
Difference		7.49%	34.69%	3.56%	56.5%
OFF	Substation	2017	2132	1747	2180
ON	Substation	2072	2200	1770	2261
Difference		2.73%	3.19%	1.32%	3.72%

There are significant short current contributions at the POI due to the interconnection of the BESS. However, the increase at the substation is still within the 10%, and the post interconnection short current levels are less than the short current interrupting ability of the protection devices.

Option 2:

Table 21. Short Current Analysis (POI: PriOH1124375 (Kerrick))

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	1691	1597	1449	1401
ON	POI	1827	1968	1505	1873
Difference		8.04%	23.23%	3.86%	33.7%
OFF	Substation	2070	2209	1769	2264
ON	Substation	2119	2256	1790	2307
Difference		2.37%	2.13%	1.19%	1.90%

Table 22. Short Current Analysis (POI: PriOH330983 (Askov))

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Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	2717	2637	2317	2542
ON	POI	2860	2986	2376	2947
Difference		5.26%	13.23%	2.55%	15.93%
OFF	Substation	2068	2193	1769	2245
ON	Substation	2119	2256	1790	2307
Difference		2.47%	2.87%	1.19%	2.76%

There are significant short current contributions at the POI due to the interconnection of the BESS. However, the increase at the substation is still within the 10%, and the post interconnection short current levels are less than the short current interrupting ability of the protection devices.

VIII. Effective Grounding Analysis

Option 1:

Table 23. Effective grounding at POI

Status	POI		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.784	1.949	1.75	2.125
With Project	0.051	0.332	1.75	2.125

Option 2:

Table 24. Effective grounding at POI

Status	POI (**PriOH1124375 (Kerrick)**)		POI (**PriOH330983 (Askov)**)		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.554	1.629	0.328	1.227	1.75	2.125
With Projects	0.135	0.688	0.120	0.653	1.75	2.125

There are no effective grounding issues at the POI with the interconnecting of the BESS.

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IX. Protection Coordination

The scope of this study is to provide detailed analysis for the protection coordination on the interconnected substation and all the distribution circuits from it.

Table 25. Proposed POI Protection Equipment for Both Option 1 & Option 2

POI Switch	Primary Breaker	Primary Relay
Lockable, Group-Operated Air Break (GOAB) Disconnect Switch Readily Accessible to the Utility at All Times Blade visibility not specified	KYLE NOVA	SEL-651R

Table 26. Shall Trip Abnormal Conditions (BESS) for Both Option 1 & Option 2

Shall Trip – Inverter Based DER – Abnormal Voltage			Shall Trip – Inverter Based DER – Abnormal Frequency		
Shall Trip Function	Clearing Time (s)	Volage Nominal	Shall Trip Function	Clearing Time (s)	Frequency (Hz)
UV2	0.16	0.50	UF1	0.16	59.3
UV1	2.0	0.88	OF1	0.16	61.2
OV1	1.0	1.10			
OV2	0.16	1.20			

Table 27. Required Settings for New Protection Devices on Option 1

Device	Model	TYPE/Function	Pick Up	TD	Curve	Reclosing Scheme	Directional Control	Harmonic Booking
POI Recloser [BESS]	SEL-651R with NOVA-STS. 35 kV	SEL 651R 51P	**60**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**30**	**1.0**	**U3**			
R1	SEL-651R with NOVA-STS. 35 kV	SEL 651R 51P	**160**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**80**	**1.0**	**U3**			
R2	SEL-651R with NOVA-STS. 35 kV	SEL 651R 51P	**280**	**1.0**	**U3**	Enabled	Disabled	Enabled
	SEL-651R with NOVA-STS. 35 kV	SEL 651R 51P	**160**	**1.0**	**U3**			

Note: The setting is recommended based on the BESS size, the final setting would be determined by Minnesota Power based on the upstream breaker setting and protections devices downstream.

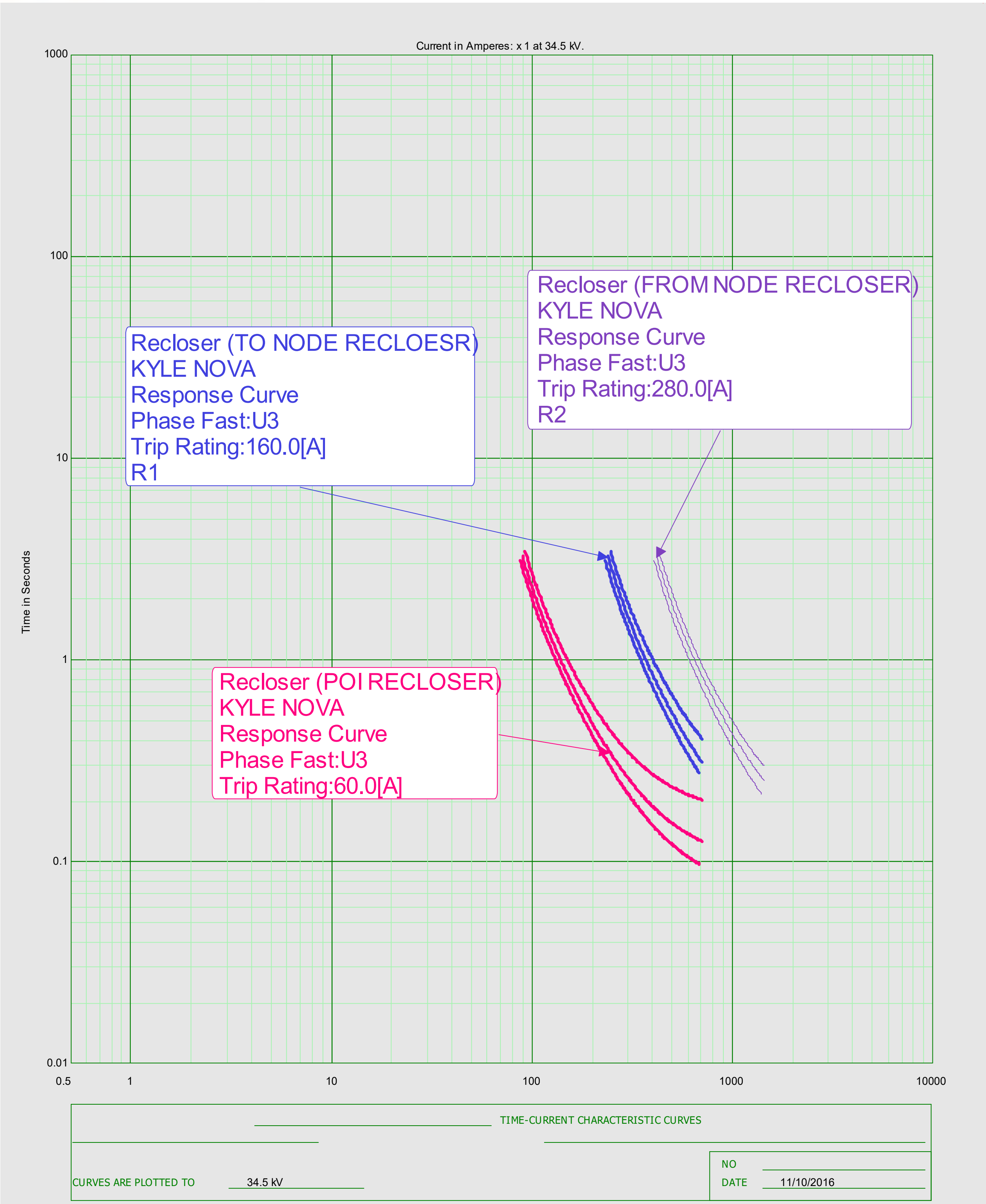

Figure 7. Branch Coordination among BESS, R1, R2.

Table 28. Required Settings for New Protection Devices on Option 2

Device	Model	TYPE/Function	Pick Up	TD	Curve	Reclosing Scheme	Directional Control	Harmonic Booking
POI Recloser [Askov BESS]	SEL-651R with NOVA-STS. 35 kV	SEL 651R 51P	**83**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**30**	**1.0**	**U3**			
POI Recloser [Kerrick BESS]	SEL-651R with NOVA-STS. 35 kV	SEL 651R 51P	**83**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**30**	**1.0**	**U3**			

X. Reliability Analysis

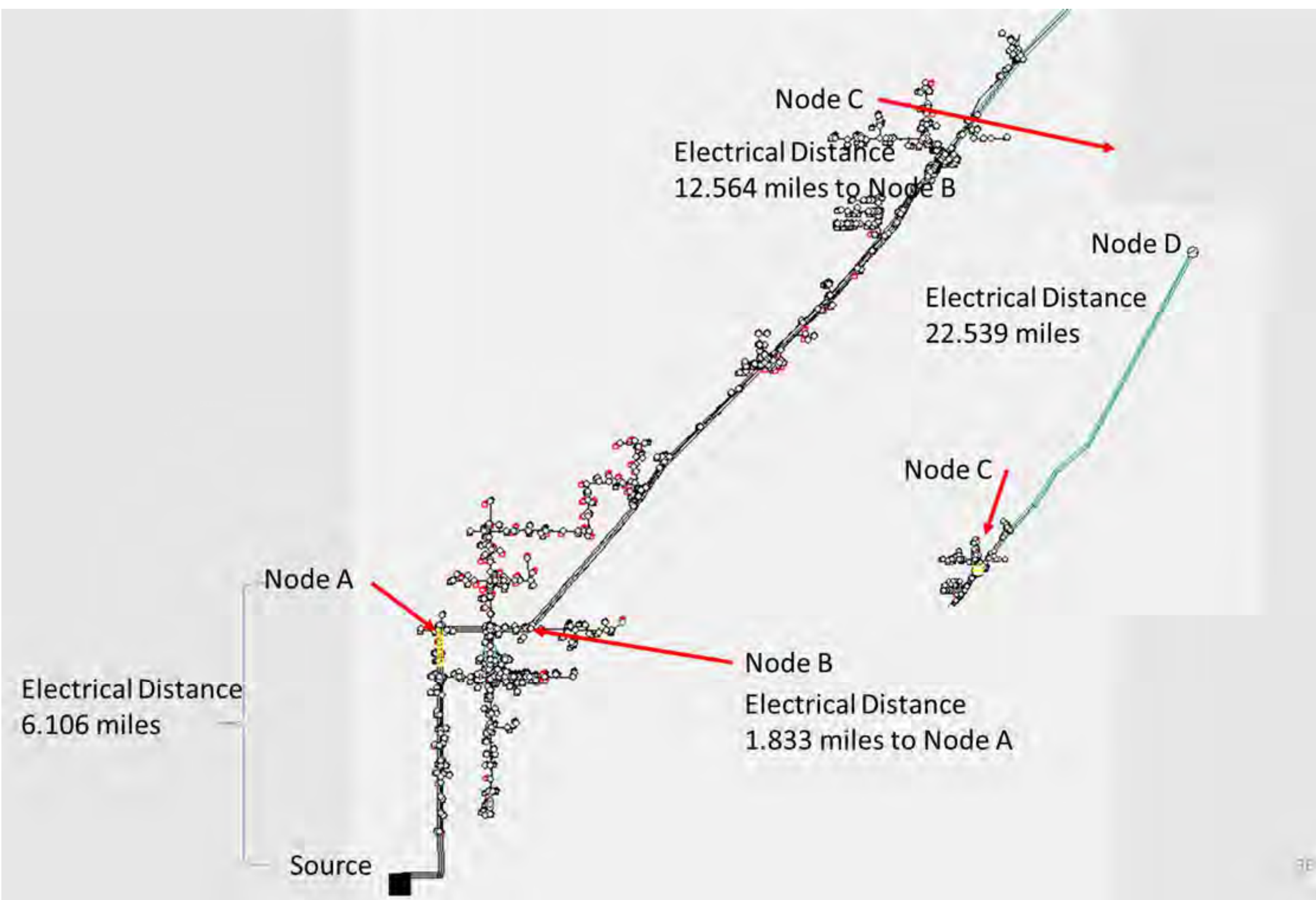

Figure 8. Kerrick Feeder Model

A. Reliability Improvement with Option 1

Based on Figure 3 & Figure 8, after the proposed NWA solution – BESS, the main goal that customers at Kerrick Feeder can have a backup source is achieved.

In order to isolate the fault, one 3P recloser (R1 in Figure 3) is required at PriOH1421668, one 3P recloser (R2 in Figure 3) is required at ASKOV 77 26860 to replace the existing switch. The recommended setting is given in Table 27 Also, switch (ASKOV 88 26859) will need to be remote controlled if the Askov stepper requires backup from the proposed BESS.

Table below summarizes the reliability improvement before and after the NWA.

Table 29. Reliability improvement with option 1

Fault Location	Kerrick Feeder Back up Ability		Askov Feeder Back up Ability	
	Before NWA	After NWA	Before NWA	After NWA
34 kV Source	No	Yes	No	Yes
Between Source and R1	No	Yes	No	Yes
Between R1 and R2	No	Yes	No	No

Sequence events example for a permanent fault at the 34 kV lines between Node A to Node C in Figure 8.

1. Recloser R2 senses the fault and opens;
2. BESS recloser R opens due to the loss of the source with anti-islanding feature;
3. Recloser R2 recloses and then open again;
4. Recloser R2 locks out and sends signal to Recloser R1 and Recloser R1 opens and locks out;
5. Remote control BESS recloser R to switch to islanding protection mode and close;
6. BESS feeding Kerrick Feeder
7. End of sequence.

B. Reliability Improvement with Option 2

Table 30. Reliability improvement with option 2

Fault Location	Kerrick Feeder Back up Ability		Askov Feeder Back up Ability	
	Before NWA	After NWA	Before NWA	After NWA
34 kV Source	No	Yes	No	Yes
Between Source and R1	No	Yes	No	Yes
Between R1 and R2	No	Yes	No	Yes

1. Sequence events example for a permanent fault at the 34 kV lines between source to Node A in Figure 8.

2. Recloser R2 senses the fault and opens;
3. Both BESS #1, #2 reclosers R open due to the loss of the source with anti-islanding feature;
4. Kerrick Feeder protection device opens to isolate the fault
5. Askov Feeder protection device opens to isolate the fault
6. Remote control BESS reclosers R to switch to islanding protection mode and close;
7. BESS#1 feeding Kerrick Feeder; BESS#2 feeding Askov Feeder;
8. End of sequence.

XI. Islanding Analysis

The islanding detection function for BESS inverter is activated by default according to UL 1741, US Rule 21.

The islanding detection function from BESS inverter detects the formation of unwanted electrical islands and disconnects the inverter from the utility grid. Unwanted islanding can occur when at the time of utility grid failure, the load in the shut-down sub-grid is roughly equivalent to the current feed-in power of the PV system or battery storage system. With active islanding detection, the inverter continuously checks the stability of the utility grid. If the utility grid is intact, this has no impact on the utility grid and the inverter continues to feed in. Only if an unwanted electrical island has formed will the inverter disconnect from the utility grid.

In order to allow BESS to support the local EPS while the grid is off-line, Minnesota Power will need to perform a time domain simulation in PSCAD, RSCAD or MATLAB with a provided inverter model from the manufacturer. Following simulations, tests would be required before allowing an intentional islanding:

- Load Rejection Overvoltage Analysis
- Ground Fault Overvoltage Analysis
- Islanding Evaluation in targe EPS
- Underfrequency Load Shed Impact Assessment
- Protection Coordination for Islanding Mode and Validating with Real Time Digital Simulator (RTDS)

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XII. FLISR Analysis

A FLISR (Fault Location, Isolation, and Service Restoration) Analysis was performed to improve the reliability of the circuit. Devices like FCI (Fault Current Indicator), Reclosers and Fuse-Saver are proposed for automatic detection of fault location, and rapid reconfiguration of the flow of electricity, to minimize the outage duration and number of customers experiencing the outage.

Total of 67 and 149 outage events are recorded for Kerrick and Askov feeder, respectively in past 5 years. Table 31 and 32 lists the outage data for Kerrick and Askov feeder.

Table 31. Outage Data for Kerrick Feeder

CIRCUIT_NAME	YEAR	DESCRIPTION	SAIDI	Feeder SAIDI	SAIFI	Feeder SAIFI	MAIFI	Feeder MAIFI	Total Events
Kerrick 6501	2004	Total	0.00	0.00	0.00	0.00	0.00	0.00	0
Kerrick 6501	2005	Total	0.33	167.32	0.00	2.04	0.01	5.32	12
Kerrick 6501	2006	Total	0.16	79.10	0.00	1.02	0.00	2.35	9
Kerrick 6501	2007	Total	0.77	419.30	0.01	3.56	0.01	6.00	15
Kerrick 6501	2008	Total	0.38	207.42	0.00	2.02	0.00	1.00	5
Kerrick 6501	2009	Total	0.50	252.99	0.00	2.00	0.01	3.00	16
Kerrick 6501	2010	Total	0.53	281.31	0.00	1.27	0.00	2.00	8
Kerrick 6501	2011	Total	2.55	1346.33	0.01	6.96	0.00	1.00	12
Kerrick 6501	2012	Total	1.40	719.62	0.04	4.27	0.01	6.00	19
Kerrick 6501	2013	Total	0.05	24.31	0.00	0.15	0.00	2.00	9
Kerrick 6501	2014	Total	0.62	331.58	0.01	3.05	0.00	2.00	11
Kerrick 6501	2015	Total	0.67	351.39	0.01	4.26	0.00	2.00	18
Kerrick 6501	2016	Total	0.32	169.17	0.00	1.17	0.00	2.00	11
Kerrick 6501	2017	Total	0.16	85.59	0.00	1.17	0.01	5.00	11
Kerrick 6501	2018	Total	0.39	211.56	0.00	2.20	0.01	5.00	1800
Kerrick 6501	2019	Total	0.01	4.37	0.00	0.04	0.01	5.00	12
Kerrick 6501	2020	Total	0.22	121.15	0.00	1.09	0.01	5.96	17
Kerrick 6501	2021	Total	0.40	219.97	0.01	3.02	0.00	2.00	9

Table 32. Outage Data for Feeder Askov

CIRCUIT _NAME	YEAR	DESCRIPTION	SAIDI	Feeder SAIDI	SAIFI	Feeder SAIFI	MAIFI	Feeder MAIFI	Total Event
Askov 6521	2004	Total	0.00	0.00	0.00	0.00	0.00	0.00	0
Askov 6521	2005	Total	1.01	292.72	0.01	2.24	0.02	5.47	40
Askov 6521	2006	Total	0.32	89.65	0.00	1.13	0.01	2.29	22
Askov 6521	2007	Total	0.63	183.91	0.01	2.33	0.02	6.00	27
Askov 6521	2008	Total	1.16	339.52	0.01	2.59	0.01	3.00	22
Askov 6521	2009	Total	0.55	159.25	0.01	1.83	0.01	3.00	23
Askov 6521	2010	Total	0.41	120.06	0.00	1.44	0.01	2.00	33
Askov 6521	2011	Total	4.18	1218.77	0.02	6.10	0.00	1.00	21
Askov 6521	2012	Total	3.70	1072.61	0.02	6.74	0.02	6.00	31
Askov 6521	2013	Total	0.30	86.03	0.00	0.26	0.01	2.00	24
Askov 6521	2014	Total	0.61	180.25	0.01	2.19	0.01	3.00	15
Askov 6521	2015	Total	0.77'	222.96	0.01	3.34	0.01	3.00	35
Askov 6521	2016	Total	0.69	206.46	0.01	1.83	0.01	2.00	27
Askov 6521	2017	Total	0.44	124.74	0.00	1.41	0.02	5.00	21
Askov 6521	2018	Total	0.69	199.15	0.01	2.44	0.02	5.00	26
Askov 6521	2019	Total	0.10	28.13	0.00	0.82	0.02	5.18	39
Askov 6521	2020	Total	1.36	389.61	0.01	1.54	0.03	9.82	38
Askov 6521	2021	Total	0.79	227.98	0.01	3.10	0.02	5.01	25

Following strategies are proposed to improve the reliability of Kerrick feeder.

Option 1:

Two (2) smart FCIs are proposed at locations shown in figure 9.

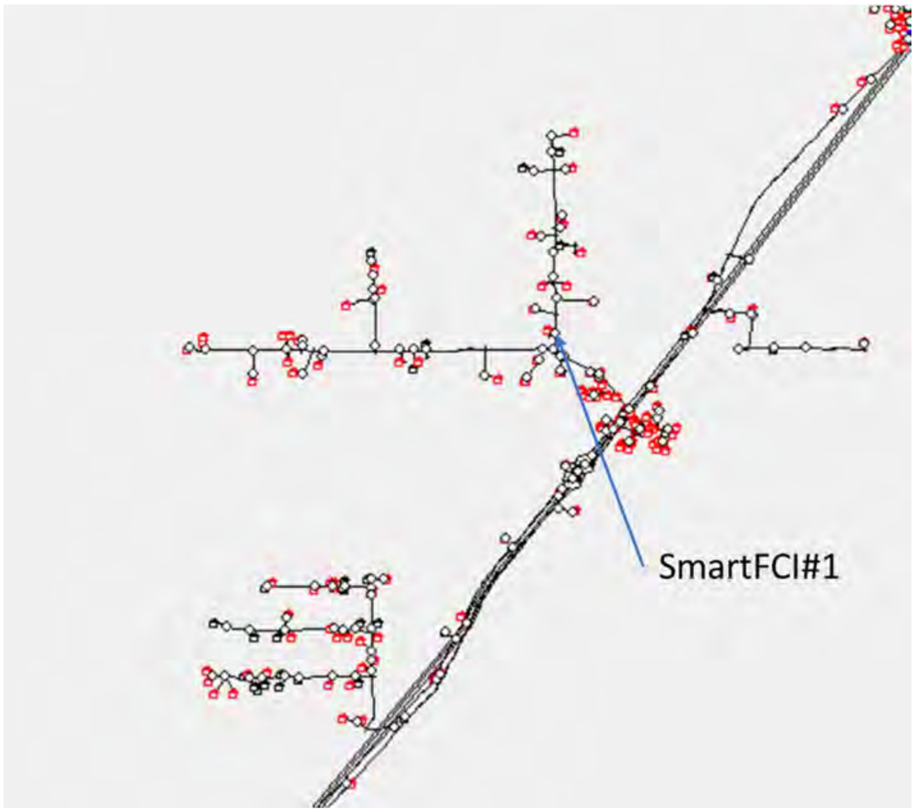

Figure 9: Proposed FCI location in Kerrick feeder (Option 1)

Option 2:

Two (2) smart FCIs need to be added to the Kerrick feeder, and one (1) existing fuse needs to be Siemens Fuse Saver. Figure 10 shows the locations of the proposed FCIs and fuse.

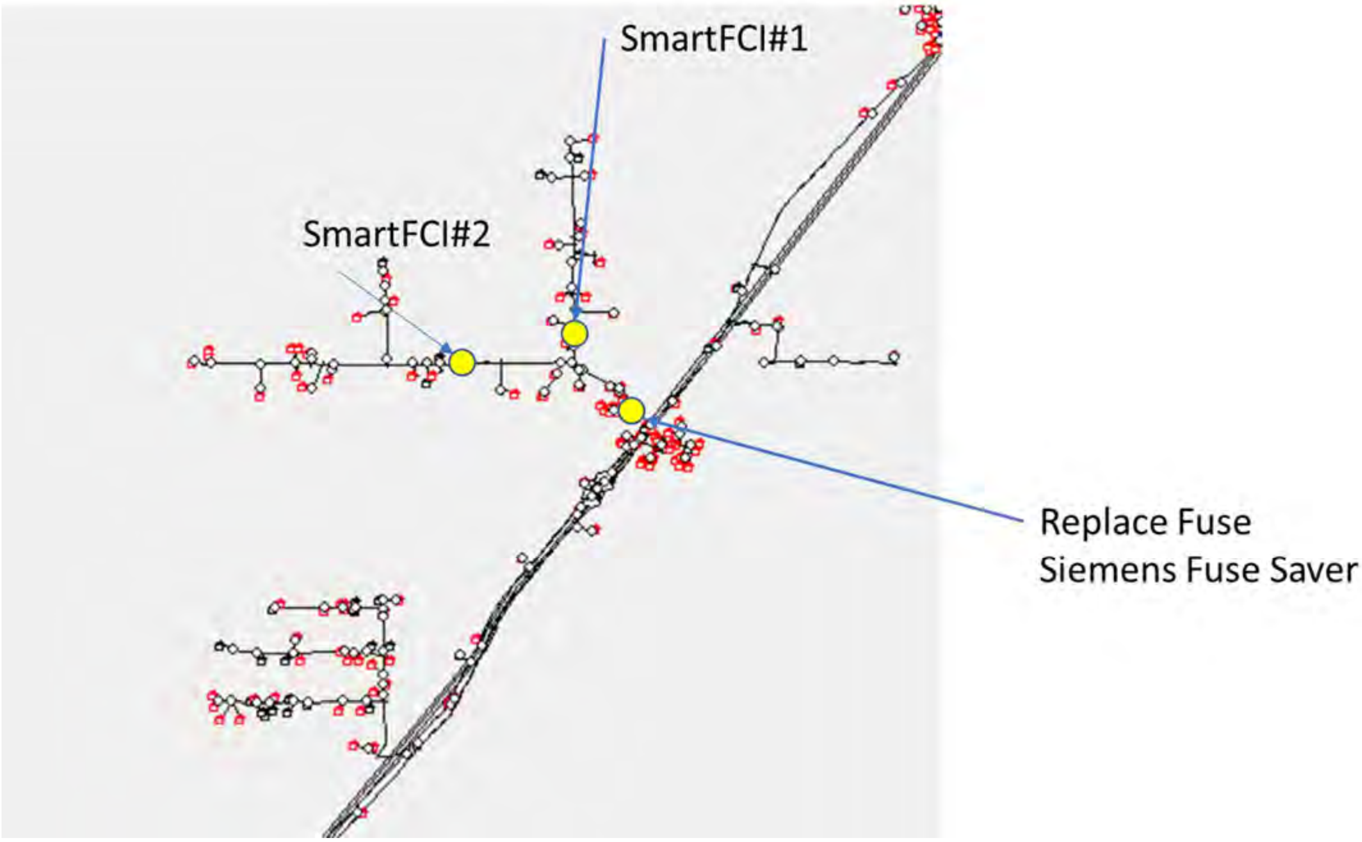

Figure 10: Proposed FCI and Fuse Savers Location in Kerrick feeder (Option 2)

Following strategies are proposed to improve the reliability of Askov feeder.

Option 1:

One (1) smart FCI, one (1) Siemens Fuse Saver and one (1) 3P reclosers needs to be added, locations shown in figure 11.

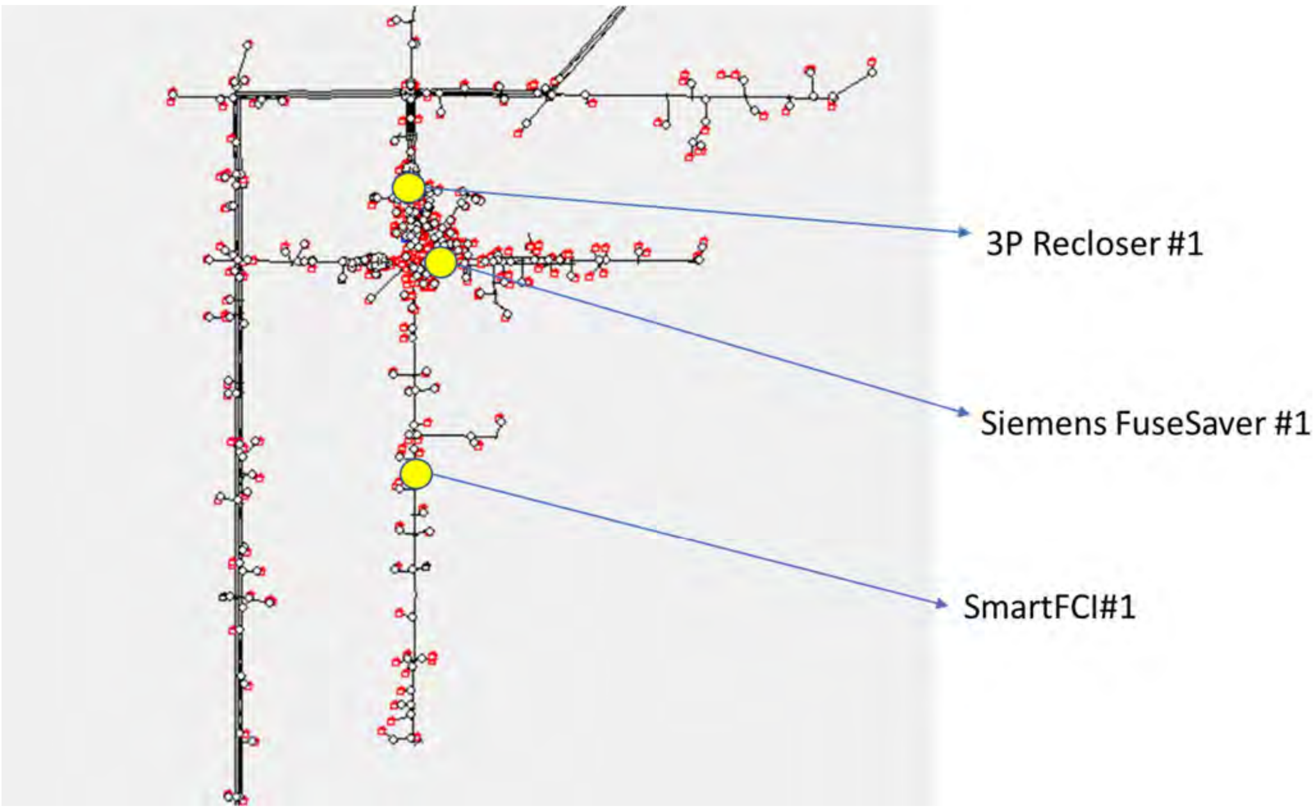

Figure 11. Proposed FCI, Fuse Saver and 3P recloser for Askov feeder

Table 33 shows the cost with the FCIs.

Table 33. Cost of one set of FLISR device

Part Number	Description	Sales Price	Quantity	Total Price
FLT-1000	SEL-FLT Fault and Load Transmitter	850	3	$ 2,550.00
FLR-1000	SEL-FLR Receiver	1200	1	$ 1,200.00
CA605#0101	SEL-CA605 Shielded Ethernet Cable with RJ45 Connectors, 3 Feet	32.99	1	$ 32.99
3505#B9JJ	SEL-3505-3	1111.5	1	$ 1,111.50
C602A-03	SEL-C602A Serial Cable for SEL-4388 (RS-232, DTE-DCE, DB9 F/DB9 M)	32.99	1	$ 32.99
3061#HCBG	SEL-3061 Cellular Router	1580	1	$ 1,580.00
######	3PH Solid Blade Disconnect Switch	1150	1	$ 1,150.00
######	3PH Fuse Cutout	5000	1	$ 5,000.00

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XIII. Appendix

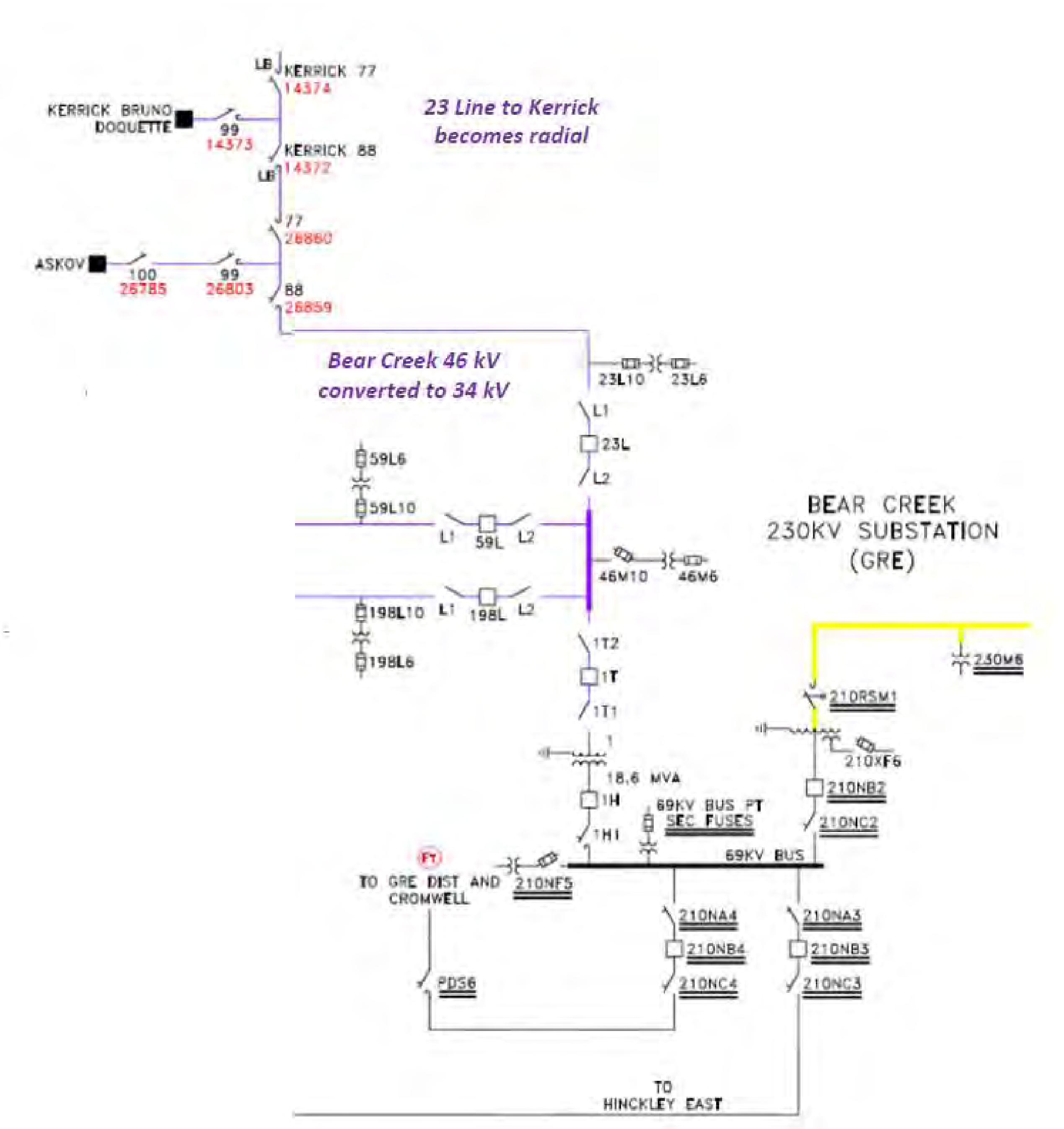

Figure 12. Substation SLD.

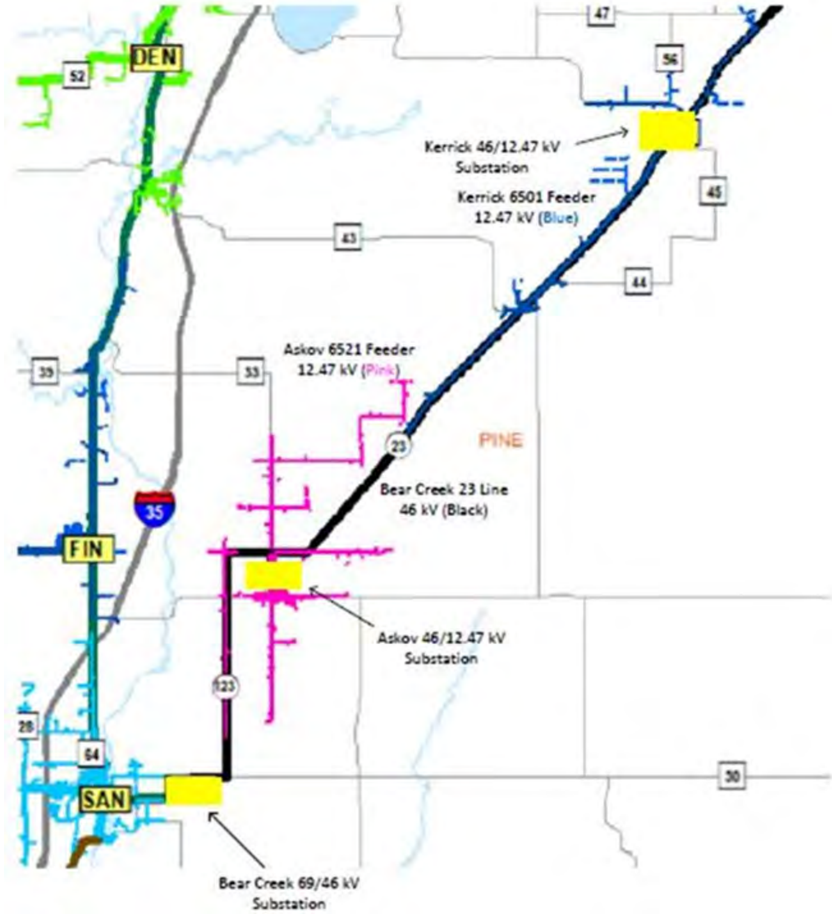

Figure 13. Existing Bear Creek Sub

Wrenshall Non-Wire Alternative (NWA) Solution Final Report

Prepared by:

Black & Veatch
and
K&A Engineering Consulting, P.C.

11/19/2021
BV Project #: 409724

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Revision History

Rev.	Date	Revised By	Updates
1	11/30/2021	G.C	Draft Release
2	03/16/2022	H.Z.	FINAL Release

Executive Summary

Two NWA solutions are offered to improve the reliability at Wrenshell-411 and Wrenshell 415 lines. Option 1 is 4 MW BESS at primary 13.8 kV side of Wrenshell-411 circuit and 3 MW BESS at primary 13.8 kV side of WRN-415, parameters are given in Table 3. Option 2 is two 2 MW BESS at primary 13.8 kV side of Wrenshell-411, and one 3 MW BESS at primary 13.8 kV side of WRN-415, parameters are given in Table 4. The proposed BESS would provide several layers of redundancy and flexibility for future expansion which is also cost effective.

Both options will back up the Wrenshell 411 and 415 feeders when it loses the source and supporting the local customers. There is no violation detected due to the interconnection of the proposed NWA solutions.

I. Introduction

The Wrenshall 115/13.8 kV Substation serves a small rural area south of Duluth, including just over 1,500 customers with peak load of 3.60 MW. While the majority of customers are rural residential and commercial, there are several aspects to the Wrenshall Substation that make the scenario unique:

- There is one backup source to the Wrenshall Substation, the Military Road 46/13.8 kV Substation. Military Road normally serves one customer, an industrial facility with demanding load requirements, with peak load of 2.81 MW.
- There is a 1.0 MW solar garden interconnected to the Wrenshall 14 kV feeder. Total daytime minimum loading for the feeder and substation is approximately 1.0 MW.
- Due to their age and condition, the Wrenshall and Military Road Substations are scheduled for a complete overhaul, modernization, and reconfiguration in the next 10 years.

This scenario will evaluate long-term considerations for the configuration and operation of the Wrenshall-area 13.8 kV system, given its varied characteristics and constraints. A holistic evaluation will include assessment of traditional solutions, including new and reconfigured sources, as well as non-wire alternatives such as volt-var optimization to manage voltage fluctuations from the solar garden and industrial facility, battery energy storage to provide backup capability and potentially optimize solar garden operation, and automated fault location, isolation and restoration. The goal of this scenario is to develop a holistic best-value long-term plan for the Wrenshall area.

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II. Scope of Study & Assumption

The study was conducted in accordance with Minnesota Power Technical Specifications Manual (TSM) [Ver 1.1 05-01-2020], standards, study guidelines, procedures, practices and IEEE 1547-2018, IEEE 1453-2015, UL 1741.

It is assumed that Minnesota Power will conduct further studies of the possible impact on the transmission level, to ensure adequacy of any equipment in conjunction with the proposed upgrades.

The following studies were performed to evaluate the base circuit and the impact from the proposed non-wire alternative to distribution equipment and performance of the circuit and the substation:

- Load-Flow
  - Peak Load + BESS Full Discharging
  - Peak Load + BESS Full Charging
  - Off-Peak Load + BESS Full Discharging
  - Off- Peak Load + BESS Full Charging
- Battery Energy Storage System (BESS) Control Mode
  - Volt Var (+/-0.99 power factor)
  - Fixed power factor at unity.
- Voltage Impact
  - Steady State Voltage Analysis
  - Voltage Change Analysis
- Short-Circuit Analysis
- Circuit Protection
  - Transformer Inrush
  - Circuit Protection Coordination
- Effective Grounding
- Reliability Analysis
- Islanding Analysis

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III. Feeder Overview

Table 1: Wrenshall 13.8 kV feeder load Information

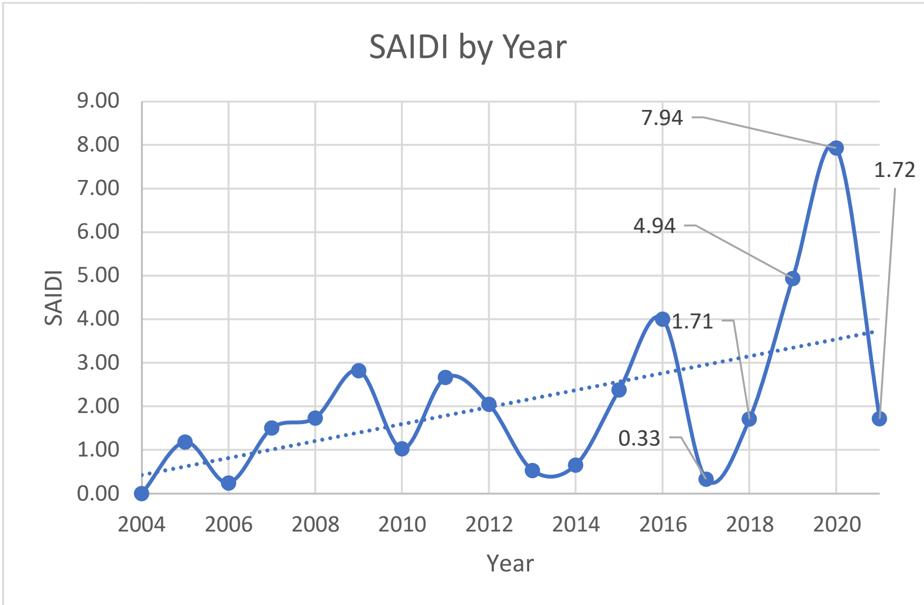
Wrenshall	Load	MW	MVAR	PF (%)	TIME
Peak	Winter – 2019	4.3426	0.2607	99.8	1/30/2019 12:00
	Summer – 2019	3.2232	0.2071	99.8	8/30/2019 16:00
	Winter – 2020	3.6668	0.3104	99.6	12/24/2020 9:00
	Summer– 2020	3.1633	0.6035	98.2	7/2/2020 3:00
	Study Case	**2.6253**	**0.2355**	**99.6**	**N/A**
Off-Peak	Daytime Min – 2019	0.911	0.0111	100	5/17/2019
	Absolute Min – 2019	0.9	-0.0958	99.4	5/29/2019 2:00
	Daytime Min – 2020	1.001	0.0092	100	6/16/2020 8:00
	Absolute Min – 2020	0.8	0.0891	99.2	5/22/2020 3:00
	Study Case	**0.8**	**0.0891**	**99.2**	**5/22/2020 3:00**

The given source impedance at the substation bus (WRN-411) is:

Z_1: 0.279 + j 3.988 [Ω]
Z_2: 0.279 + j 3.988 [Ω]
Z_0: 0.249 + j 3.850 [Ω]

The given source impedance at the substation bus (WRN-415) is:

Z_1: 0.279 + j 3.988 [Ω]
Z_2: 0.279 + j 3.988 [Ω]
Z_0: 0.249 + j 3.850 [Ω]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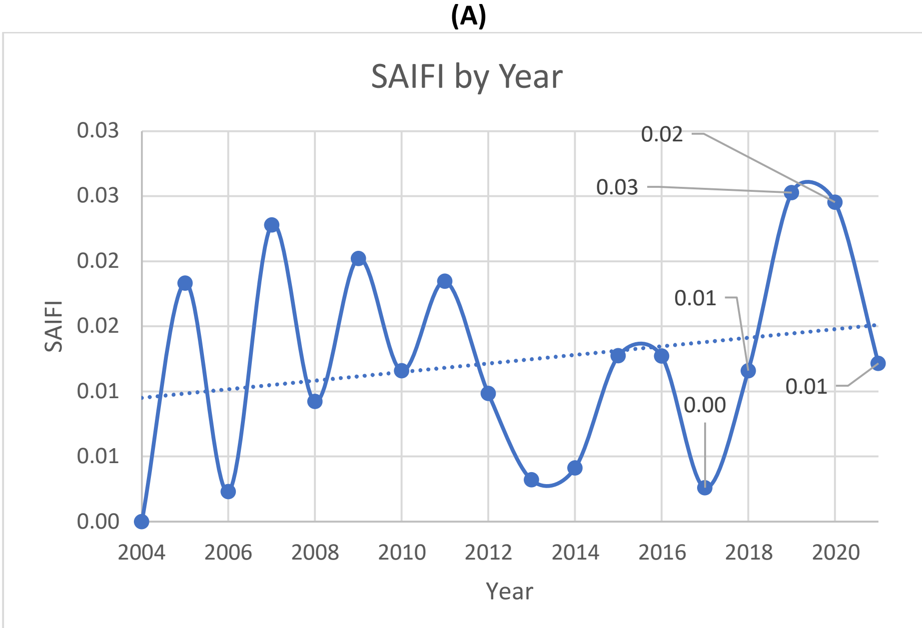
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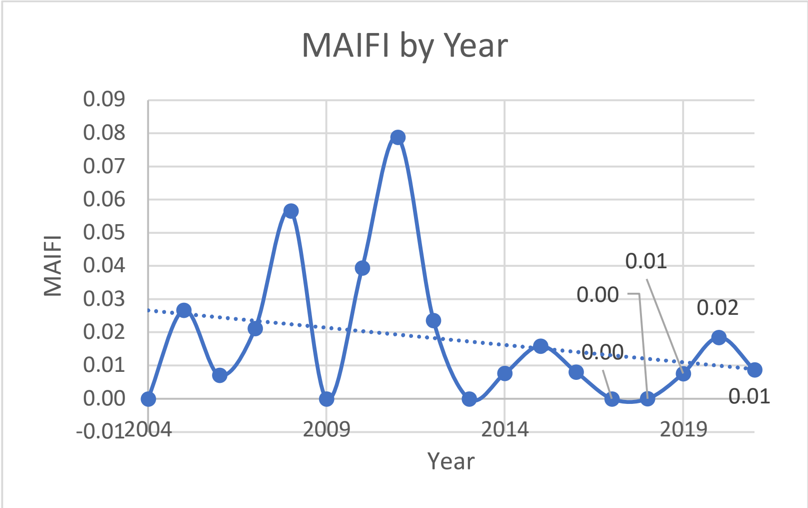

(C)

Figure 1. Historical Data- (A) SAIDI; (B) SAIFI; (C) MAIFI for WRN-411

Table 2: List of capacitor banks, regulators, DGs, and industrial loads

Element Name	Device	Settings	Rating/Output
CAPBANK 16323	3P Capacitor bank	Controlled by Ph A – 0.95pu to 1.05pu	900 kVAR
CAPBANK 537	3P Capacitor bank	Controlled by Ph A – 0.95pu to 1.05pu	450 kVAR
VR5124	3P Voltage Regulator	Voltage = 120 v BW = 2 v	1000 A
VR40	3P Voltage Regulator	Voltage = 120 v BW = 2 v	1000 A
VR38	1P Voltage Regulator	Voltage = 120 v BW = 2 v	1000 A
DG390123106			15.2 kW
DG680064277			7.6 kW
DG7790179028			10 kW
DG1050047235			8 kW
DG8220093151			2.53 kW
DG6520018216			9.9 kW
DG2930009374			5 kW
DG2600207319			17.5 kW
Wrenshall CSG	Solar		1000 kW
CONS7421 (WRN-411)	Northern Natural Gas LNG plant		2047.45 kW 88.7 % pf

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Northern Natural Gas (WRN-415)	Northern Natural Gas LNG plant		3047.493 kW 88.7 % pf

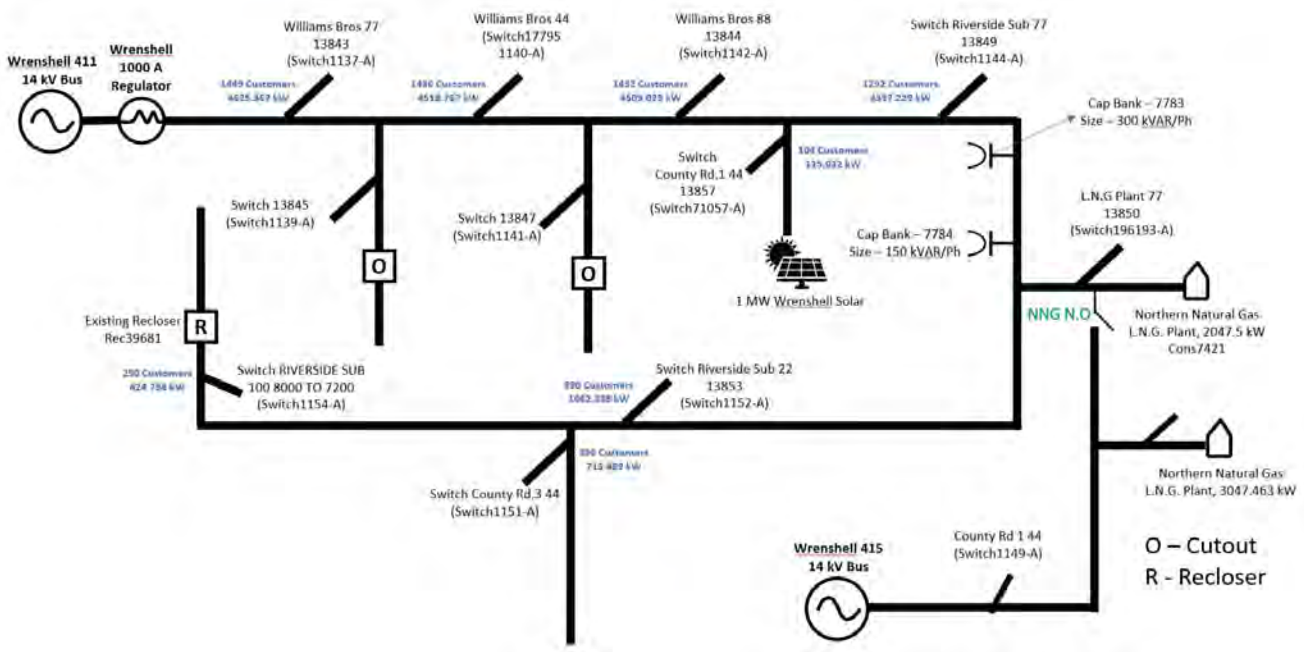

Figure 2. Wrenshall WRN 411 and WRN 415 One Line Diagram prior to the NWA

There are two exiting voltage-controlled cap banks as shown in Figure 2. The two cap banks are switched off during the given peak base case model. There are three-line regulators in the model on WRN-411 circuit. During off peak conditions, undervoltage is observed downstream of "Regulator-VR40" which is not the expected operation. However, as per suggestion from Minnesota power, no setting revision is proposed to any equipment. The following sections consider the given base model without any changes.

IV. Proposed Non-Wire Alternative Solution

Non-wires alternatives are defined as "an electricity grid investment or project that uses non-traditional transmission and distribution (T&D) solutions, such as distributed generation (DG), energy storage, energy efficiency (EE), demand response (DR), and grid software and controls, to defer or replace the need for specific equipment upgrades, such as T&D lines or transformers, by reducing load at a substation or circuit level. Several NWA solutions have been considered, based on the simulation result in the following sections, a new battery energy storage system (BESS) is determined as the best solution and is chosen for this report.

The proposed BESS would provide several layers of redundancy and flexibility for future expansion which is also cost effective.

No landscape or footprint has been considered as constraints for the location of the BESS, this report offers two options for the BESS in case there is any landscape acquisition.

Option 1: 4 MW, 8 MWH BESS at WRN-411 + 3 MW, 6 MWH BESS on WRN-415.

Tables below presents the parameters, required features and recommended operation window for the BESS.

Table 3: BESS parameters and required feature of Option 1

Size	4 MW, 8 MWh (WRN-411) + 3 MW, 6 MWh (WRN-415)
Location (POI)	PriOH1235089, 13.8 kV (WRN-411), PRIUG33797 (WRN-415)
Distance from Source	1.27 miles (WRN-411), 2.486 miles (WRN-415)
Impedance between Source and POI (WRN-411)	Z_1=0.865+ j 5.023; Z_0= 1.352 + j 6.368 [Ω]
Impedance between Source and POI (WRN-415)	Z_1=0.988+ j 5.497; Z_0= 2.114 + j 7.849 [Ω]
Upstream Capacity Limitation (WRN-411)	#4/0 ACSR 6/1 conductor with 357 A rating
Upstream Capacity Limitation (WRN-415)	350 Al 15 kV 1/3 N
Transformer (WRN-411)	One (1) 4000 kVA Grounded Wye – Grounded Wye, 13.8 kV/600 V, Z% = 6%, X/R = 10
Transformer (WRN-415)	One (1) 3000 kVA Grounded Wye – Grounded Wye, 13.8 kV/600 V, Z% = 6%, X/R = 10
Grounding Bank (WRN-411)	30 kVA Grounded Wye – Delta, 13.8 kV/480 V, Z% = 6%, X/R = 10
Primary Protection Device	3P Recloser, with SEL – 651R Recloser
Control Mode	Constant Unity Power Factor Mode with Volt-Var control mode stand by.
Emergency Power	The BESS is required to delay the recharging for 30 min after the restoration of the power outage.

Note: The Kyle Nova SEL-651 R is recommended in terms of small clearing tolerance, capability for harmonics blocking and reverse fault blocking. Also, the coordination is based on the Kyle Nova SEL-651R.

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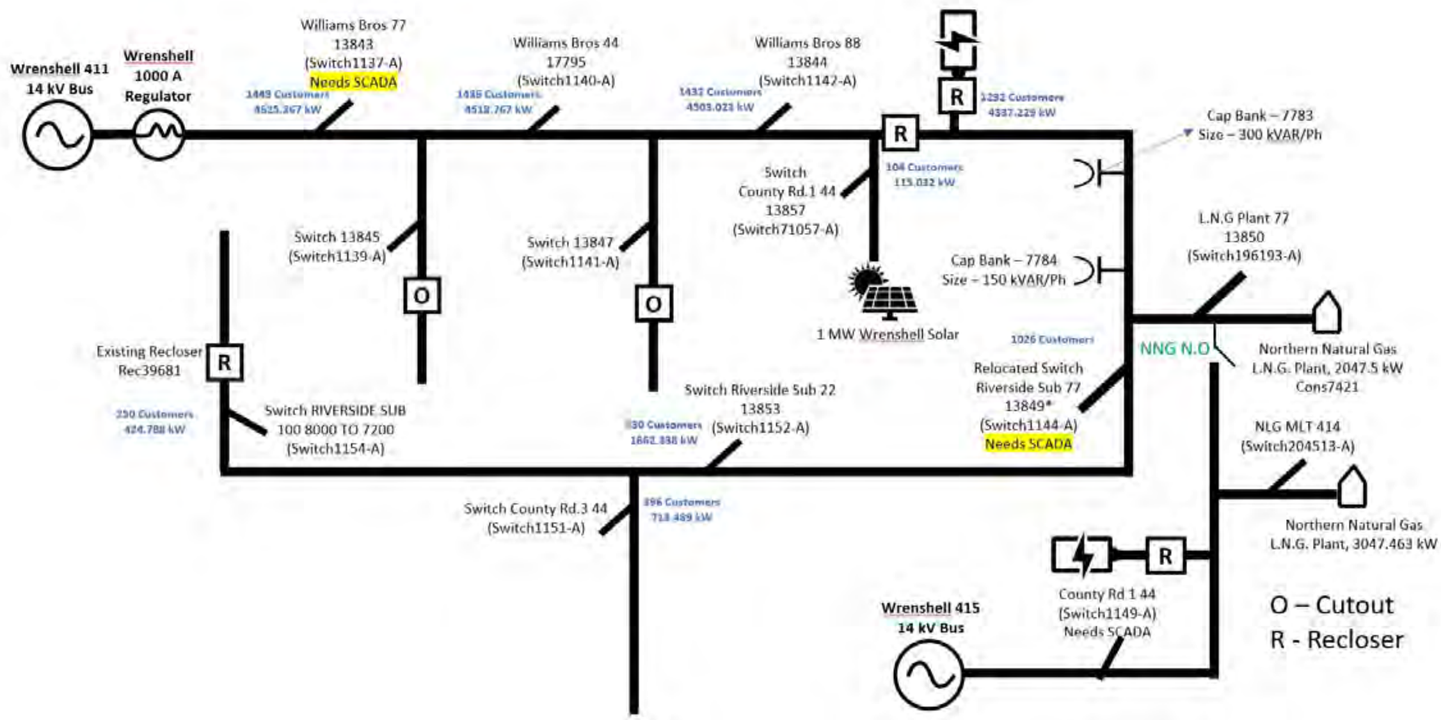

Figure 3. Wrenshall One Line Diagram with the NWA Option 1

Option 2: 2 MW, 4 MWH BESS at WRN-411 + 2 MW, 4 MWH BESS at WRN-411 + 3 MW, 6 MWH BESS on WRN-415.

Tables below presents the parameters, required features and recommended operation window for the BESS.

Table 4: BESS parameters and required feature of Option 2

Size	Two (2 MW, 4 MWH) on WRN-411 and One 3 MW, 6MWH (WRN-415)
Location (POI) WRN-411	POI 1: BESS#1 at PriOH1235089 (Wrenshall) (13 kV); POI 2: BESS#2 at PriOH443520
Location (POI) WRN-415	PRIUG33797 (WRN-415)
Impedance between Source and POI (PriOH1235089 (WRN 411))	Z_1= 0.865 + j 5.023; Z_0= 1.352 + j 6.368 [Ω]
Impedance between Source and POI (PriOH443520 (WRN 411))	Z_1= 1.379 + j 6.144; Z_0= 2.443 + j 9.237 [Ω]
Impedance between Source and POI (WRN-415)	Z_1=0.988+ j 5.497; Z_0= 2.114 + j 7.849 [Ω]
Upstream Capacity Limitation PriOH1235089 (WRN-411)	#4/0 ACSR 6/1 conductor with 357 A rating
Upstream Capacity Limitation (WRN-415)	350 Al 15 kV 1/3 N

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Upstream Capacity Limitation PriOH443520 (WRN-411)	336 MCM ACSR 18/1 conductor with 500 A rating
Transformer (WRN-411)	One (1) 2000 kVA Grounded Wye – Grounded Wye at each POI location on WRN-411, 13.8 kV/600 V, Z% = 6%, X/R = 10
Transformer (WRN-415)	One (1) 3000 kVA Grounded Wye – Grounded Wye, 13.8 kV/600 V, Z% = 6%, X/R = 10
Grounding Bank (WRN-411)	30 kVA Grounded Wye – Delta, 13.8 kV/480 V, Z% = 6%, X/R = 10
Primary Protection Device	3P Recloser, with SEL – 651R Recloser
Control Mode	Constant Unity Power Factor Mode with Volt-Var control mode stand by.
Emergency Power	The BESS is required to delay the recharging for 30 min after the restoration of the power outage.

Note: The Kyle Nova SEL-651 R is recommended in terms of small clearing tolerance, capability for harmonics blocking and reverse fault blocking. Also, the coordination is based on the Kyle Nova SEL-651R.

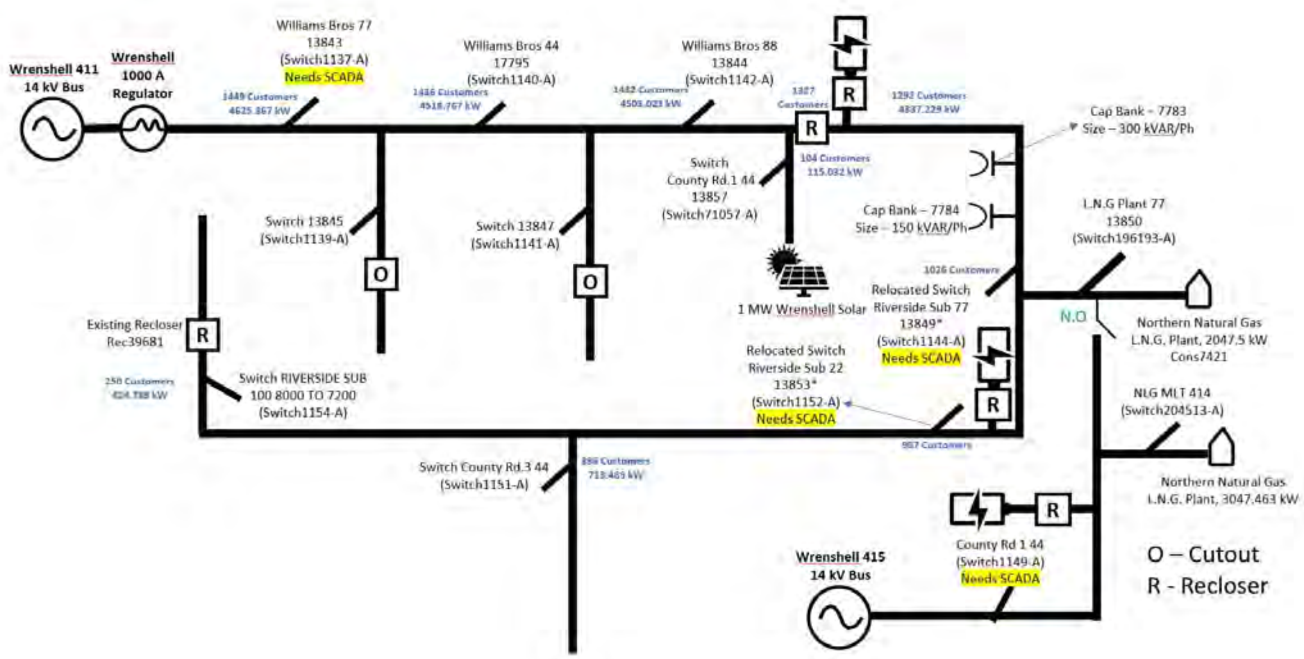

Figure 4. Wrenshall One Line Diagram with the NWA Option 2

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Table 5. Recommended Summer & Winter schedule for Charging and Discharging of BESS under normal operation.

Start Time	Mode	Power	Control Mode	Reference
12:00:00 AM	Idling	-	-	-
03:00:00 AM	Charging	100%	Volt Var Mode	Max Charging Power
6:00:00 AM	Idling	-	-	-
06:00:00 PM	Discharging	100%	Volt Var Mode	Max Discharging Power
09:30:00 PM	Idling	-		-

Note:
The BESS needs to synchronize with local EPS without causing any abnormal conditions while entering service.
The Charging start time is subject to change based on the local utility price.

V. Load Flow Analysis

A Steady State Voltage Analysis was conducted to determine the project's impact on the distribution circuit voltage. To ensure adequate service voltage to customers, 114 to 126 volts, the circuit voltage must remain within the range of 117 to 126 volts (120-volt base) during normal operation. In general, the circuit voltage at the substation must remain in the range of 123 to 126 volts to maintain an adequate voltage under all anticipated load conditions, regardless of project operation.

The peak and off-peak load case is using a 1.0458 pu (125.5 V) source operating voltage.

A. *Prior the non-wire alternative*

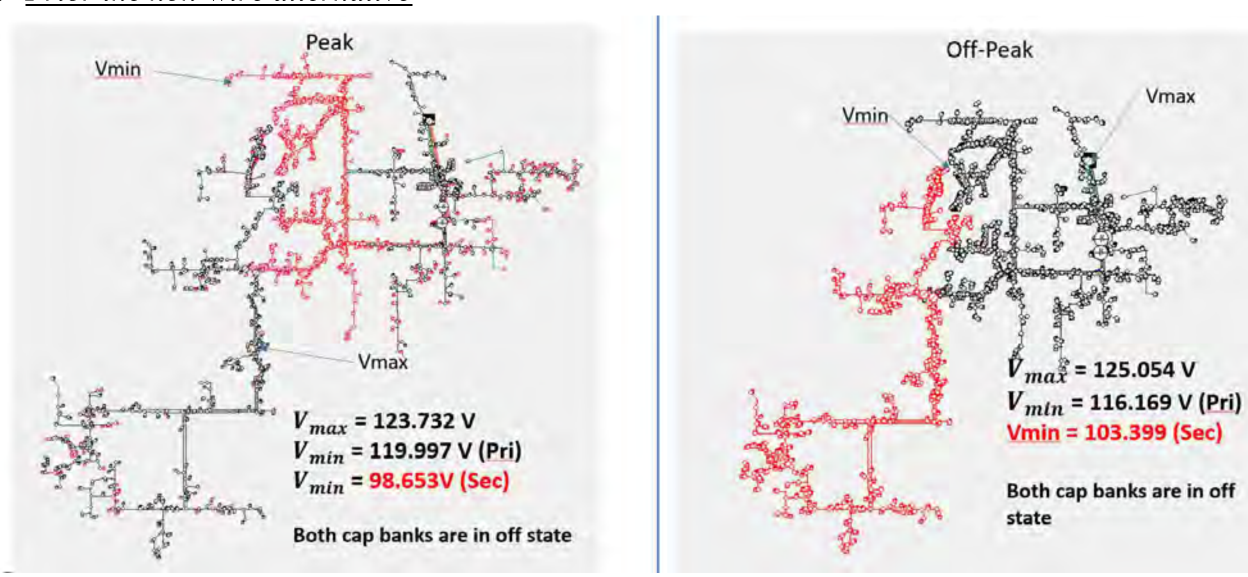

Figure 5. Load Flow Results – Prior to the NWA

From load flow results shown above, there are some pre-existing under-voltage violations detected at secondary voltage level. Load Balancing has been tried on several branches without any significant improvements on the secondary side voltage violations.

B. *After the non-wire alternative*

OPTION 1

❖ BESS in Constant unity PF operation mode with 4 MW Charging & Discharging Rate.

Table 6. Load Flow results for Discharging/Charging of BESS at PriOH1235089 (WRN-411) – Option 1

Scenario	Control Mode	Site Operation	Load Flow at POI	Load Flow at WRN-411 Substation
Peak	Constant Unity PF	Discharging at 4 MW	P = -3976.831 kW Q = 231.105 kVAR	P = 991.669 kW Q = 1415.758 kVAR
Peak	Constant Unity PF	Charging at 4 MW	P = 3951.069 kW Q = 238.922 kVAR	P = 9155.848 kW Q = 1865.51 kVAR
Off Peak	Constant Unity PF	Discharging at 4 MW	P = -3978.213 kW Q = 216.896 kVAR	P = -3841.287 kW Q = 461.287 kVAR
Off Peak	Constant Unity PF	Charging at 4 MW	P = 4037.818 kW Q = 238.931 kVAR	P = 4179.648 kW Q = 513.942 kVAR

Table 7: Load Flow results for Discharging/Charging of BESS at PriUG33797 (WRN-415) – Option 1

Scenario	Control Mode	Site Operation	Load Flow at POI	Load Flow at WRN-415 Substation
Peak	Constant Unity PF	Discharging at 3 MW	P = -2981.933 kW Q = 179.592 kVAR	P = 79.112 kW Q = 1779.13 kVAR
Peak	Constant Unity PF	Charging at 3 MW	P = 2833.08 kW Q = 178.926 kVAR	P = 5034.552 kW Q = 1312.621 kVAR
Off Peak	Constant Unity PF	Discharging at 3 MW	P = -2983.582 kW Q = 163.507 kVAR	P = -2350.072 kW Q = 510.636 kVAR
Off Peak	Constant Unity PF	Charging at 3 MW	P = 3019.761 kW Q = 179.228 kVAR	P = 3682.406 kW Q = 589.289 kVAR

Table 8: Voltage results for Discharging of BESS under unity pf operation at PriOH1235089 (WRN-411) – Option 1

Scenarios	BESS	Voltage at Substation [V]	Voltage at POI [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	120.731	120.212	123.452	117.258
	Charging	116.811	118.703	122.838	115.445
	Discharging	121.792	121.470	124.825	117.65
Off-peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	125.054	124.135	125.054	117.043
	Charging	123.099	121.344	123.099	120.142
	Discharging	124.691	125.376	125.622	118.249

Table 9: Voltage results for Discharging of BESS under unity pf operation at PriUG33797 (WRN-415) – Option 1

Scenarios	BESS	Voltage at Substation [V]	Voltage at POI [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	120.554	117.613	120.554	117.527
	Charging	118.151	113.542	118.151	113.453
	Discharging	121.039	119.339	121.039	119.254
Off-peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	124.637	124.094	124.637	124.078
	Charging	123.091	121.002	123.091	120.985
	Discharging	124.532	125.09	125.091	124.532

There are no overvoltage and overload violations detected during the discharging at off-peak scenarios which is the worst case.

- BESS in Constant 99% leading non unity PF operation mode (absorbing vars) with 4 MW Charging & Discharging Rate.

Table 10: Voltage results for Discharging of BESS under 99% leading pf operation (absorbing vars) at PriOH1235089 (WRN-411) – Option 1

Scenarios	BESS	Voltage at Substation [V]	Voltage at POI [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	120.731	120.212	123.452	117.258
	Charging	116.811	118.755	122.83	114.708
	Discharging	120.270	121.153	124.630	115.004
Off-peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	125.054	124.135	125.054	117.043
	Charging	123.131	121.403	123.131	119.374
	Discharging	123.233	123.953	124.029	115.973

There are no overvoltage and overload violations detected during the discharging at off-peak scenarios which is the worst case. There are no significant changes observed in voltage values between Unity PF and 99% leading PF (Absorbing Vars).

However, the volt-var operation mode from inverter is shown in the next section which could be used as a standby.

- BESS in Volt-Var operation mode.

"*The DER shall not cause the Area EPS primary circuit voltage at any location to go outside the requirements of ANSI C84.1 for primary service voltage.*"

----IEEE 1547-2018

IEEE 1547-2018 requires that the DER should have the ability of injecting and absorbing reactive power for DER voltage impact mitigation, and the reactive power magnitude needs to be controlled automatically. However, Minnesota Power TSM requires the settings for Volt-Var Power control to be disabled. This section will provide the setting for the reference.

This project shows over voltage violation under constant power factor mode; therefore, "Volt-Var mode" is provided. The suggested dead bandwidth is from 1.020 to 1.033 V p.u. (V_{Ref}=1.03) on 120V base.

The assumed inverter setting for BESS at PriOH1235089 (WRN-411) is as followed:
Rating: 4000 kVA
Rated Real Power Max: 4000 kW
PF capable: -99.0 - +99.0
Maximum reactive power absorbed = 564.27 kVAR

Maximum reactive power injected = 564.27 kVAR

By using the Volt-Var mode, the power factor of the BESS can vary from leading 99% to lagging 99 % based on the circuit voltage condition. However, based on the current feeder condition, the BESS will be constantly running a unity power factor during the normal operation.
If there is any voltage disturbance that within 0.88 p.u. to 1.1 p.u., by enabling the volt-var mode of the inverter, the BESS can give the voltage support.

Following tables presents the load flow results with a lagging 99% & a leading 99% pf range which would be determined based on the circuit conditions.

Table 11:Load Flow results for Discharging/Charging of BESS under Volt-Var mode at PriOH1235089 (WRN-411) – Option 1

Scenario	Control Mode	Site Operation	Load Flow at POI	Load Flow at WRN-411 Substation
Peak	Volt-Var Mode	Discharging at 4 MW	P = -3937.531 kW Q = -340.139 kVAR	P = 1026.351 kW Q = 838.482 kVAR
Peak	Volt-Var Mode	Charging at 4 MW	P = 3951.069 kW Q = 238.922 kVAR	P = 9155.848 kW Q = 1851.51 kVAR
Off Peak	Volt-Var	Discharging at 4 MW	P = -3937.303 kW Q = 789.978 kVAR	P = -3801.055 kW Q = 1047.886 kVAR
Off Peak	Volt-Var	Charging at 4 MW	P = 4037.818 kW Q = 238.931 kVAR	P = 4179.648 kW Q = 513.942 kVAR

Table 12: Voltage results for Discharging of BESS under Volt-Var mode at PriOH1235089 (WRN-411) – Option 1

Scenarios	BESS	Voltage at Substation [V]	Voltage at POI [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	120.709	120.212	123.452	116.338
	Charging	116.85	118.703	122.838	114.762
	Discharging	123.242	122.424	123.242	117.527
Off-peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	125.054	124.135	125.054	117.043
	Charging	123.099	121.353	123.099	120.14
	Discharging	123.233	123.953	124.211	116.858

By enabling the volt-var mode of the BESS, there is no over-voltage violation caused by the interconnection and there is no overloading issue detected with the interconnection.

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OPTION 2

- BESS in Constant unity PF operation mode with two 2 MW Charging & Discharging at PriOH1235089 and PriOH443520 and one 2 MW BESS charging & discharging, one at PriUG33797.

Table 13: Load Flow results for Discharging/Charging of BESS – Option 2

Scenario	Control Mode	Site Operation	Load Flow at POI (PriOH1235089 (Wrenshall))	Load Flow at POI (PriOH443520 (Wrenshall))	Load Flow at WRN-411 Substation
Peak	Constant Unity PF	Discharging at 4 MW (Gen 1 & 2)	P = -1988.431 kW Q = 115.38 kVAR	P = -1988.201 kW Q = 117.675 kVAR	P = 961.963 kW Q = 1354.784 kVAR
Peak	Constant Unity PF	Charging at 4 MW (Gen 1 & 2)	P = 1974.813 kW Q = 119.447 kVAR	P = 2017.982 kW Q = 200.639 kVAR	P = 9276.338 kW Q = 835.462 kVAR
Off Peak	Constant Unity PF	Discharging at 4 MW (Gen 1 & 2)	P = -1989.187 kW Q = 108.188 kVAR	P = -1994.596 kW Q = 54.021 kVAR	P = -3843.872 kW Q = 407.324 kVAR
Off Peak	Constant Unity PF	Charging at 4 MW (Gen 1 and 2)	P = 2019.62 kW Q = 119.449 kVAR	P = 2005.262 kW Q = 59.747 kVAR	P = 4185.107 kW Q = 499.222 kVAR

Table 14: Voltage results for Discharging of BESS under unity pf operation – Option 2.

Scenario	2.0 MVA PriOH1235089 (WRN-411)	2.0 MVA PriOH443520 (WRN-411)	Substation [V]	POI (PriOH1235089 (WRN-411)) [V]	POI (PriOH443520 (WRN-411)) [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	OFF	120.709	120.212	118.439	123.452	116.338
	Charging	Charging	116.451	118.214	115.642	122.458	113.475
	Discharging	Discharging	121.954	121.567	120.386	122.889	118.264
Off Peak (Base Volt	OFF	OFF	125.053	124.135	123.83	125.053	117.043

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= 125.5V, 1.0458 p.u.)	Charging	Charging	123.133	121.370	120.370	123.133	119.470
	Discharging	Discharging	124.825	125.556	125.823	125.830	118.969

There are no overvoltage and overload violations detected during the discharging at off-peak scenarios which is the worst case. However, the volt-var operation mode from inverter is shown in the next section which could be used as a standby.

❖ BESS in Volt-Var operation mode.

The suggested dead bandwidth is from 1.014 to 1.042 V p.u. (V_{Ref}=1.03) on 120V base for POI (PriOH1235089(WRN-411)), and from 1.006 to 1.043 V p.u. (V_{Ref}=1.03 p.u.) on 120V base for POI (PriOH443520 (WRN-411)).

The assumed inverter setting is as followed:
Rating: 2000 kVA
Rated Real Power Max: 2000 kW
PF capable: -99.0 - +99.0
Maximum reactive power absorbed = 282.13 kVAR
Maximum reactive power injected = 282.13 kVAR

Table 15: Load Flow results for Discharging/Charging of BESS under Volt-Var mode – Option 2

Scenario	Control Mode	Site Operation	POI (PriOH1235089 (WRN-411))	POI (PriOH443520 (WRN-411))	Load Flow at WRN-411 Substation
Peak	Volt Var Mode	Discharging at 4 W (Gen 1 & 2)	P = -1968.803 kW Q = -170.458 kVAR	P = -1968.623 kW Q = -168.656 kVAR	P = 999.657 kW Q = 776.842 kVAR
Peak	Volt Var Mode	Charging at 4 MW (Gen 1 & 2)	P = 1967.673 kW Q = 119.441 kVAR	P = 1923.916 kW Q = 119.439 kVAR	P = 9289.022 kW Q = 3944.457 kVAR
Off Peak	Volt Var Mode	Discharging at 4 MW (Gen 1 & 2)	P = -1968.706 kW Q = 394.513 kVAR	P = -1974.363 kW Q = 337.957 kVAR	P = -3804.00 kW Q = 991.73 kVAR
Off Peak	Volt Var Mode	Charging at 4 MW (Gen 1 and 2)	P = 2019.62 kW Q = 119.449 kVAR	P = 2005.262 kW Q = 57.747 kVAR	P = 4185.107 kW Q = 499.222kVAR

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Table 16: Voltage results for Discharging of BESS under Volt-Var mode – Option 2

Scenario	2.00 MVA PriOH1235089 (WRN-411)	2.00 MVA PriOH443520 (WRN-411)	Substation [V]	POI (PriOH1235089 (WRN-411)) [V]	POI (PriOH443520 (WRN-411) [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	OFF	120.709	120.212	118.439	124.106	116.338
	Charging	Charging	116.451	118.214	115.642	122.458	113.475
	Discharging	Discharging	123.402	122.602	121.617	123.402	118.963
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	OFF	125.053	124.135	123.83	125.053	117.043
	Charging	Charging	123.133	121.370	120.370	123.133	119.470
	Discharging	Discharging	123.374	124.13	124.202	125.091	117.402

By enabling the volt-var mode of the BESS, there is no over-voltage violation caused by the interconnection and there is no overloading issue detected with the interconnection.

VI. Voltage Change Analysis

A Voltage Change Analysis was performed to determine the instantaneous change in voltage (voltage change/flicker) that would occur in the distribution system upon sudden loss of the 4.0 MW project. IEEE 1547-2018 requires the voltage flicker at the POI given a 100% loss of the project must be "< / = 3%". Similarly, the voltage change at the line regulators and substation LTC must be less than or equal to half their bandwidths.

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OPTION 1:

Table 17: Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF (WRN 411) – Option 1

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriOH1235089)	121.584	117.754	3.15%	121.544	118.305	2.74%	121.284	118.05	2.74%
Substation Bus	121.736	120.439	1.297 V	121.864	120.722	1.142 V	121.776	120.634	1.142 V

Table 18: Voltage change assuming 100% BESS Drop at Peak Load Condition with 99% leading PF (WRN 411) – Option 1

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriOH1235089)	121.217	117.7	2.99%	121.18	118.257	2.47%	120.915	117.999	2.47%
Substation Bus	120.211	120.439	-0.228	120.347	120.722	-0.375	120.253	120.634	-0.381

Table 19: Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF (WRN 415) – Option 1

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriUG33797)	119.339	117.613	1.47%	119.339	117.613	1.47%	119.339	117.613	1.47%
Substation Bus	121.039	120.529	0.51 V	121.039	120.529	0.51 V	121.039	120.529	0.51 V

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Table 20: Voltage change assuming 100% BESS Drop at Off-peak Load Condition with Unity PF (WRN 411) – Option 1

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriOH1235089)	125.408	124.969	0.35%	125.376	124.986	0.31%	125.345	124.912	0.35%
Substation Bus	124.712	125.096	0.384 V	124.684	125.105	0.421 V	124.676	125.064	0.388 V

Table 21: Voltage change assuming 100% BESS Drop at Off-peak Load Condition with Unity PF (WRN 415) – Option 1

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriUG33797)	125.09	124.094	0.80%	125.09	124.094	0.80%	125.09	124.094	0.80%
Substation Bus	124.532	124.637	0.105 V	124.532	124.637	0.105 V	124.532	124.637	0.105 V

Maximum voltage change at POI (PriOH1235089) is greater than 3%. Hence, option 1 fails the voltage change analysis if operated at Unity power factor. However, the voltage change at POI is less than 3% if the BESS at PriOH1235089 is operated at 99% leading power factor (absorbing vars).

OPTION 2:

The distance between POIs **PriOH1235089 (Wrenshall WRN411) and PriOH443520 (Wrenshall WRN411)** is greater than 0.75 miles, so voltage change analysis is done independently.

Table 22: Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF at PriOH1235089 (WRN411) – Option 2

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI **(**PriOH1235089 (WRN411)**)**	121.422	119.462	1.641%	121.782	119.893	1.576%	121.5	119.676	1.524%

Substation Bus	121.901	121.411	0.49 V	122.033	121.601	0.432 V	121.929	121.54	0.389 V

Table 23: Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF at PriOH443520 (WRN411) – Option 2

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI **(**PriOH443520 (WRN411)**)**	120.276	117.417	2.435%	120.645	117.889	2.338%	120.242	117.549	2.291%
Substation Bus	121.901	121.218	0.683	122.033	121.423	0.61	121.929	121.349	0.58

Table 24: Voltage change assuming 100% BESS Drop at Off- Peak Load Condition with Unity PF at PriOH1235089 (WRN411) – Option 2

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriOH1235089 (WRN411)**)**	125.588	125.728	0.111%	125.553	125.729	0.140%	125.528	125.666	0.110%
Substation Bus	124.846	125.194	0.348 V	124.816	125.191	0.375 V	124.813	125.158	0.345 V

Table 25: Voltage change assuming 100% BESS Drop at Off- Peak Load Condition with Unity PF at PriOH443520 (WRN411) – Option 2

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriOH443520 (WRN411))	125.9	123.3	2.109%	125.809	125.257	0.441%	125.759	125.153	0.484%
Substation Bus	124.846	125.062	0.216 V	124.816	125.06	0.244 V	124.813	125.024	0.211 V

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VII. Short Current Analysis

A short circuit analysis was performed to determine the fault duty at various points and to identify any distribution protection equipment that exceeds its interrupting capability as a result of the project interconnection.

Below is a summary of the maximum fault levels on the 13.8 kV Wrenshall feeder. There is a limited ability for the simulation software windmill defining the short current contribution of the inverters. Therefore, a simplified CYME model is used to simulate the short current contribution impact due to the proposed BESS.

Option 1:

Table 26. Short Current Analysis at PriOH1235089 (WRN-411) – Option 1

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	1561	1520	1352	1428
ON	POI	1747	1635	1428	1487
Difference		11.92%	7.57%	5.62%	4.13%
OFF	Substation	1994	2009	1727	2017
ON	Substation	2177	2133	1804	2084
Difference		9.18%	6.17%	4.46%	3.32%

Table 27. Short Current Analysis at PriUG33797 (WRN-415) – Option 1

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	1957	2000	1694	1965
ON	POI	2035	2053	1721	1981
Difference		3.98%	2.65%	1.59%	0.81%
OFF	Substation	1993	2008	1726	2016
ON	Substation	2089	2072	1767	2049
Difference		4.81%	3.18%	2.37%	1.64%

There are significant short current contributions at the POI due to the interconnection of the BESS. However, the increase at the substation is still within the 10%, and the post interconnection short current levels are less than the short current interrupting ability of the protection devices.

Option 2:

Table 28. Short Current Analysis (POI: PriOH1235089 (WRN-411)) – Option 2

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	1561	1520	1352	1428
ON	POI	1746	1639	1429	1497
Difference		11.85%	7.83%	5.70%	4.83%
OFF	Substation	1994	2009	1727	2017
ON	Substation	2177	2137	1804	2092
Difference		9.18%	6.37%	4.46%	3.72%

Table 29. Short Current Analysis (POI: at PriOH443520 (WRN-411)) – Option 2

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	1331	1272	1153	1146
ON	POI	1491	1370	1219	1203
Difference		12.02%	7.70%	5.72%	4.97%
OFF	Substation	1994	2009	1727	2017
ON	Substation	2177	2137	1804	2092
Difference		9.18%	6.37%	4.46%	3.72%

There are significant short current contributions at the POI due to the interconnection of the BESS. However, the increase at the substation is still within the 10%, and the post interconnection short current levels are less than the short current interrupting ability of the protection devices.

There are significant short current contributions at the POI due to the interconnection of the BESS. However, the increase at the substation is still within the 10%, and the post interconnection short current levels are less than the short current interrupting ability of the protection devices.

VIII. Effective Grounding Analysis

Option 1:

Table 30. Effective grounding at POI (PriOH1235089 (WRN 411)) – Option 1

Status	POI		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.272	1.271	1.612	2.275
With Project	0.296	1.393	1.705	2.400

Table 31. Effective grounding at POI (PriUG33797 (WRN 415)) – Option 1

Status	POI		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.165	0.979	0.182	0.979
With Project	0.177	1.048	0.195	1.048

Option 2:

Table 32. Effective grounding at POI -1 (PriOH1235089 (WRN 411)) and POI -2 (PriOH443520 (WRN 411)) – Option 2

Status	POI (**PriOH1235089 (WRN 411)**)		POI (**PriOH443520 (WRN 411)**)		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.272	1.271	0.395	1.496	1.612	2.275
With Projects	0.290	1.368	0.420	1.609	1.719	2.407

There are no effective grounding issues at the POI with the interconnecting of the BESS.

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IX. Protection Coordination

The scope of this study is to provide detailed analysis for the protection coordination on the interconnected substation and all the distribution circuits from it.

Table 33. Proposed POI Protection Equipment for Both Option 1 & Option 2

POI Switch	Primary Breaker	Primary Relay
Lockable, Group-Operated Air Break (GOAB) Disconnect Switch Readily Accessible to the Utility at All Times Blade visibility not specified	KYLE NOVA	SEL-651R

Table 34. Shall Trip Abnormal Conditions (BESS) for Both Option 1 & Option 2

Shall Trip – Inverter Based DER – Abnormal Voltage			Shall Trip – Inverter Based DER – Abnormal Frequency		
Shall Trip Function	Clearing Time (s)	Volage Nominal	Shall Trip Function	Clearing Time (s)	Frequency (Hz)
UV2	0.16	0.50	UF1	0.16	59.3
UV1	2.0	0.88	OF1	0.16	61.2
OV1	1.0	1.10			
OV2	0.16	1.20			

Table 35. Required Settings for New Protection Devices on Option 1 – WRN-411

Device	Model	TYPE/Function	Pick Up	TD	Curve	Reclosing Scheme	Directional Control	Harmonic Blocking
POI Recloser [BESS]	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**200**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**100**	**1.0**	**U3**			
New Line Recloser, R	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**250**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**125**	**1.0**	**U3**			

Table 36. Required Settings for New Protection Devices on Option 1 – WRN-415

Device	Model	TYPE/Function	Pick Up	TD	Curve	Reclosing Scheme	Directional Control	Harmonic Blocking
POI Recloser [BESS]	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**150**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**75**	**1.0**	**U3**			

Note: The setting is recommended based on the BESS size, the final setting would be determined by Minnesota Power based on the upstream breaker setting and protections devices downstream.

Table 37. Required Settings for New Protection Devices on Option 2 – WRN-411

Device	Model	TYPE/Function	Pick Up	TD	Curve	Reclosing Scheme	Directional Control	Harmonic Booking
POI-1 Recloser	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**100**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**50**	**1.0**	**U3**			
POI -II Recloser	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**100**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**50**	**1.0**	**U3**			
New Line Recloser, R	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**250**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**125**	**1.0**	**U3**			

Table 38. Required Settings for New Protection Devices on Option 2 – WRN-415

Device	Model	TYPE/Function	Pick Up	TD	Curve	Reclosing Scheme	Directional Control	Harmonic Booking
POI Recloser [BESS]	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**150**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**75**	**1.0**	**U3**			

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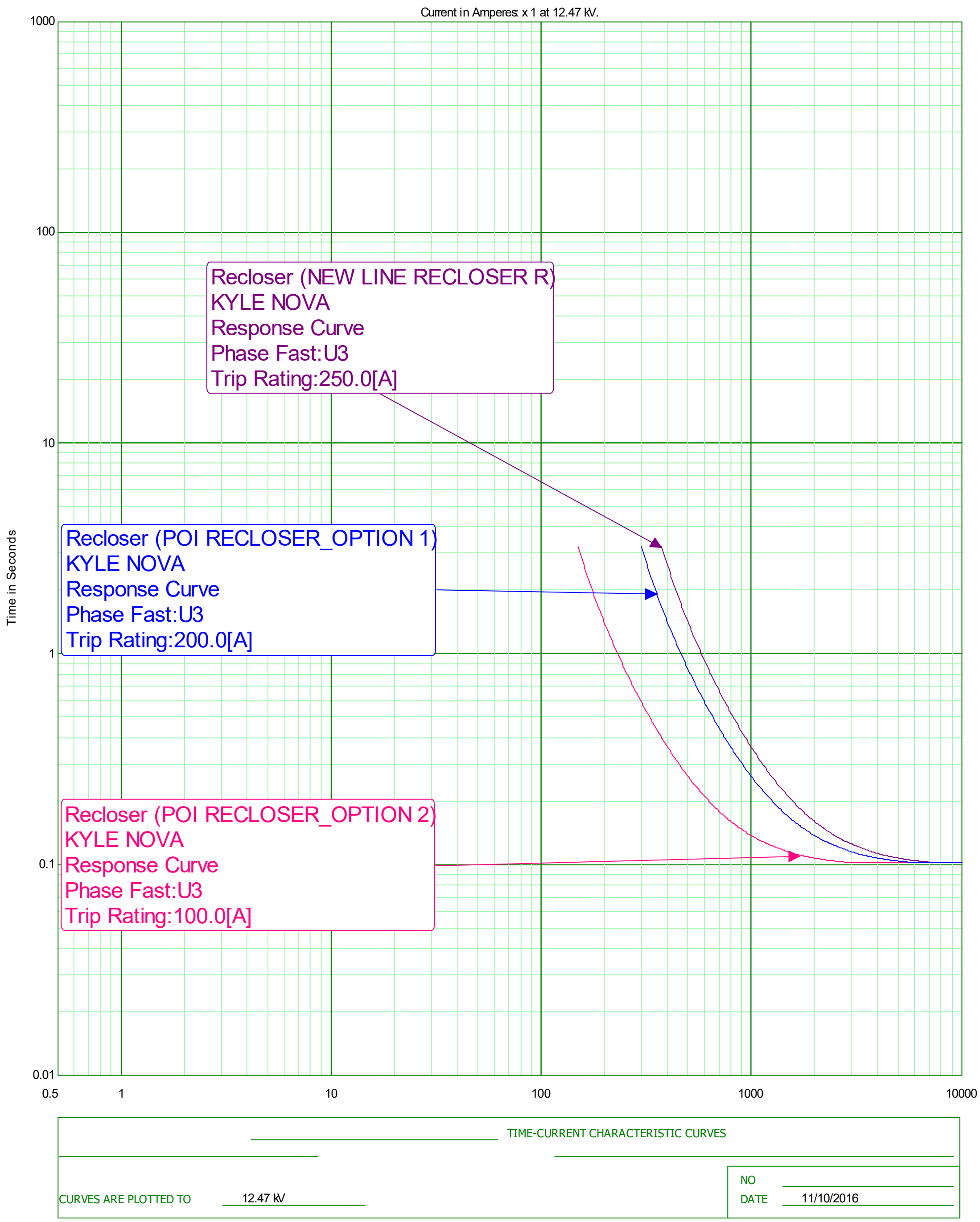

Figure 6. Branch Coordination among BESS Reclosers for Option 1 and Option 2, and new line recloser R.

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X. Reliability Analysis

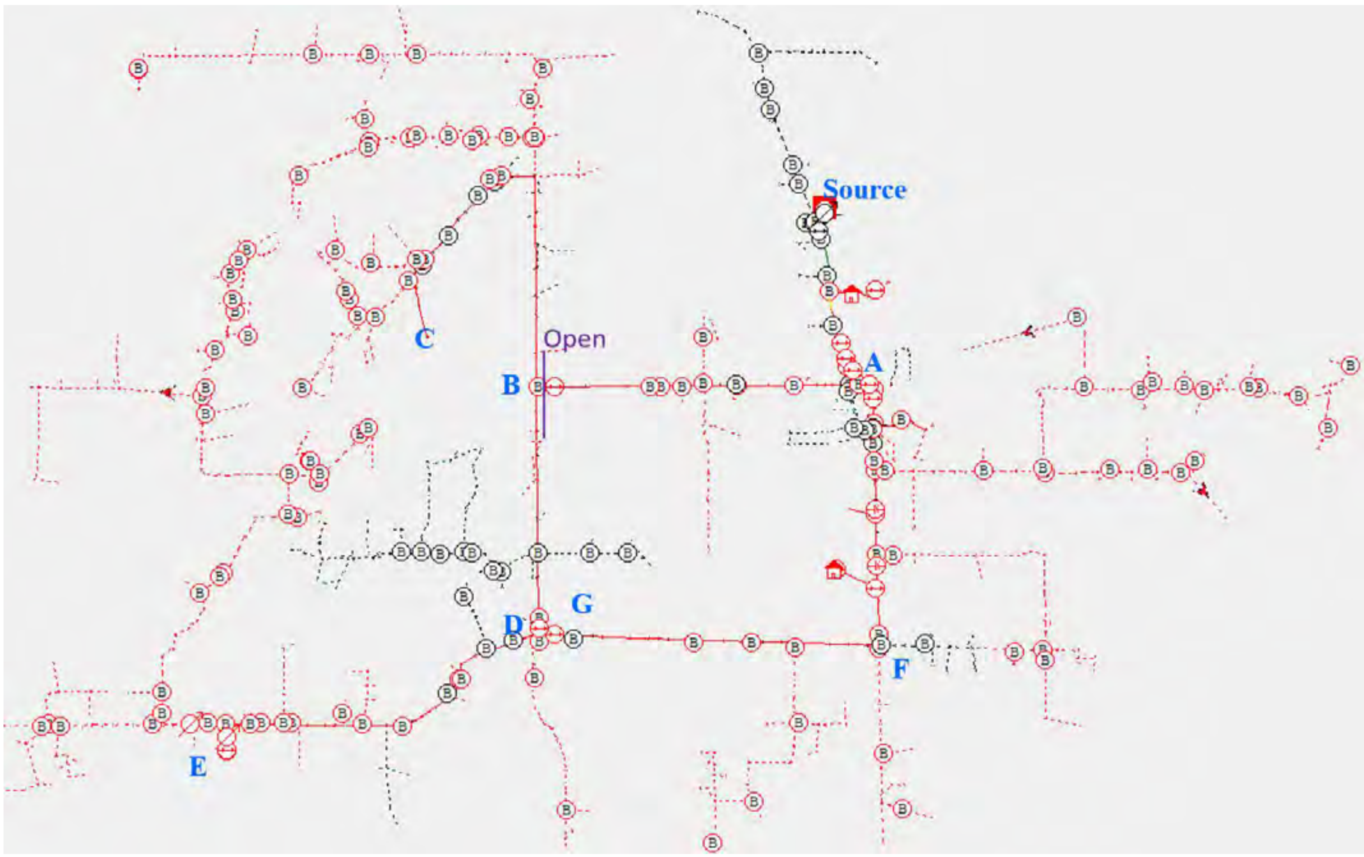

Figure 7. Wrenshell Feeder Model

A. Reliability Improvement with Option 1

Based on Figure 3 & Figure 7, after the proposed NWA solution – BESS, the main goal that customers at Wrenshell Feeder can have a backup source is achieved.

In order to isolate the fault, one 3P recloser (R in Figure 3) is required at PriOH443474. The recommended setting is given in Table 35. Also, switch (Riverside Sub 77 13849*) will need to be relocated to PriOH443340 for Option 1 or to PriOH443326 for Option 2 and remote controlled. Additionally for option 2, switch 13853 will also need to be relocated to PriOH443520 and remotely controlled.

Table below summarizes the reliability improvement before and after the NWA.

Table 39. Reliability improvement with option 1

Fault Location	WRN-411 feeder back up Ability	
	Before NWA	After NWA
13.8 kV Source	No	Yes
Between Source and line recloser R	No	Yes
Between new line recloser R and relocated switch 13849	No	No
Between existing line recloser Rec39681 and relocated switch 13849	No	Yes

Sequence events example for a permanent fault at the 13.8 kV source in Figure 8.

1. New Line recloser R senses the fault and opens
2. BESS recloser R opens due to the loss of the source with anti-islanding feature
3. New Line recloser R recloses and then open again
4. New Line recloser R locks out
5. Remote control BESS recloser R to switch to islanding protection mode and close
6. BESS feeding Wrenshell Feeder WRN-411
7. End of sequence

B. <u>Reliability Improvement with Option 2</u>

Table 40. Reliability improvement with option 2

Fault Location	WRN-411 feeder back up Ability	
	Before NWA	After NWA
13.8 kV Source	No	Yes
Between Source and line recloser R	No	Yes
Between new line recloser R and relocated switch 13849	No	Yes
Between new relocated switch 13849 and 13853	No	Yes
Between existing line recloser Rec39681 and relocated switch 13849	No	Yes

Sequence events example for a permanent fault at the 13.8 kV source in Figure 8.

1. New Line recloser R senses the fault and opens
2. Both BESS #1, #2 reclosers R open due to the loss of the source with anti-islanding feature
3. Remote control BESS reclosers R to switch to islanding protection mode and close
4. New Line recloser R recloses and then open again
5. New Line recloser R locks out
6. BESS#1 and BESS #2 feeding Wrenshell WRN-411 feeder
7. End of sequence

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XI. Islanding Analysis

The islanding detection function for BESS inverter is activated by default according to UL 1741, US Rule 21.

The islanding detection function from BESS inverter detects the formation of unwanted electrical islands and disconnects the inverter from the utility grid. Unwanted islanding can occur when at the time of utility grid failure, the load in the shut-down sub-grid is roughly equivalent to the current feed-in power of the PV system or battery storage system. With active islanding detection, the inverter continuously checks the stability of the utility grid. If the utility grid is intact, this has no impact on the utility grid and the inverter continues to feed in. Only if an unwanted electrical island has formed will the inverter disconnect from the utility grid.

In order to allow BESS to support the local EPS while the grid is off-line, Minnesota Power will need to perform a time domain simulation in PSCAD, RSCAD or MATLAB with a provided inverter model from the manufacturer. Following simulations, tests would be required before allowing an intentional islanding:

- Load Rejection Overvoltage Analysis
- Ground Fault Overvoltage Analysis
- Islanding Evaluation in targe EPS
- Underfrequency Load Shed Impact Assessment
- Protection Coordination for Islanding Mode and Validating with Real Time Digital Simulator (RTDS)

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XII. FLISR Analysis

A FLISR (Fault Location, Isolation, and Service Restoration) Analysis was performed to improve the reliability of the circuit. Devices like FCI (Fault Current Indicator), Reclosers and Fuse-Saver are proposed for automatic detection of fault location, and rapid reconfiguration of the flow of electricity, to minimize the outage duration and number of customers experiencing the outage.

Total of 277 outage events with net 1988.29 outage hours are recorded for Wrenshall 411 feeder in past 5 years. Table 41 lists the outage data for Wrenshall 411 feeder.

Table 411. Outage Data for Wrenshall Feeder

CIRCUIT NAME	YEAR	DESCIPTION	SAIDI	FEEDER SAIDI	SAIFI	Feeder SAIFI	MAIFI	Feeder MAIFI	Total Event
Wrenshall 411	2004	Total	0.00	0.00	0.00	0.00	0.00	0.00	0
Wrenshall 411	2005	Total	1.18	177.03	0.02	2.74	0.03	4.00	60
Wrenshall 411	2006	Total	0.25	34.70	0.00	0.33	0.01	1.00	43
Wrenshall 411	2007	Total	1.51	213.34	0.02	3.22	0.02	3.00	50
Wrenshall 411	2008	Total	1.74	245.60	0.01	1.30	0.06	8.00	48
Wrenshall 411	2009	Total	2.83	376.08	0.02	2.69	0.00	0.00	47
Wrenshall 411	2010	Total	1.03	130.37	0.01	1.47	0.04	5.00	48
Wrenshall 411	2011	Total	2.67	338.59	0.02	2.34	0.08	10.00	107
Wrenshall 411	2012	Total	2.05	260.41	0.01	1.25	0.02	3.00	52
Wrenshall 411	2013	Total	0.53	67.50	0.00	0.40	0.00	0.00	22
Wrenshall 411	2014	Total	0.66	85.65	0.00	0.54	0.01	1.00	37
Wrenshall 411	2015	Total	2.39	299.54	0.01	1.60	0.02	2.00	41
Wrenshall 411	2016	Total	4.01	497.04	0.01	1.58	0.01	1.00	66
Wrenshall 411	2017	Total	0.33	38.17	0.00	0.30	0.00	0.00	28
Wrenshall 411	2018	Total	1.71	196.71	0.01	1.33	0.00	0.00	59
Wrenshall 411	2019	Total	4.94	649.08	0.03	3.32	0.01	1.00	67
Wrenshall 411	2020	Total	7.94	906.86	0.02	2.80	0.02	2.12	88
Wrenshall 411	2021	Total	1.72	197.47	0.01	1.40	0.01	1.00	35

Following strategies are proposed to improve the reliability of Kerrick feeder.

Option 1:

Five (5) smart FCIs along with new air-break switch are proposed at locations shown in figure 8. Proposed FCI#3 can be replaced by a recloser.

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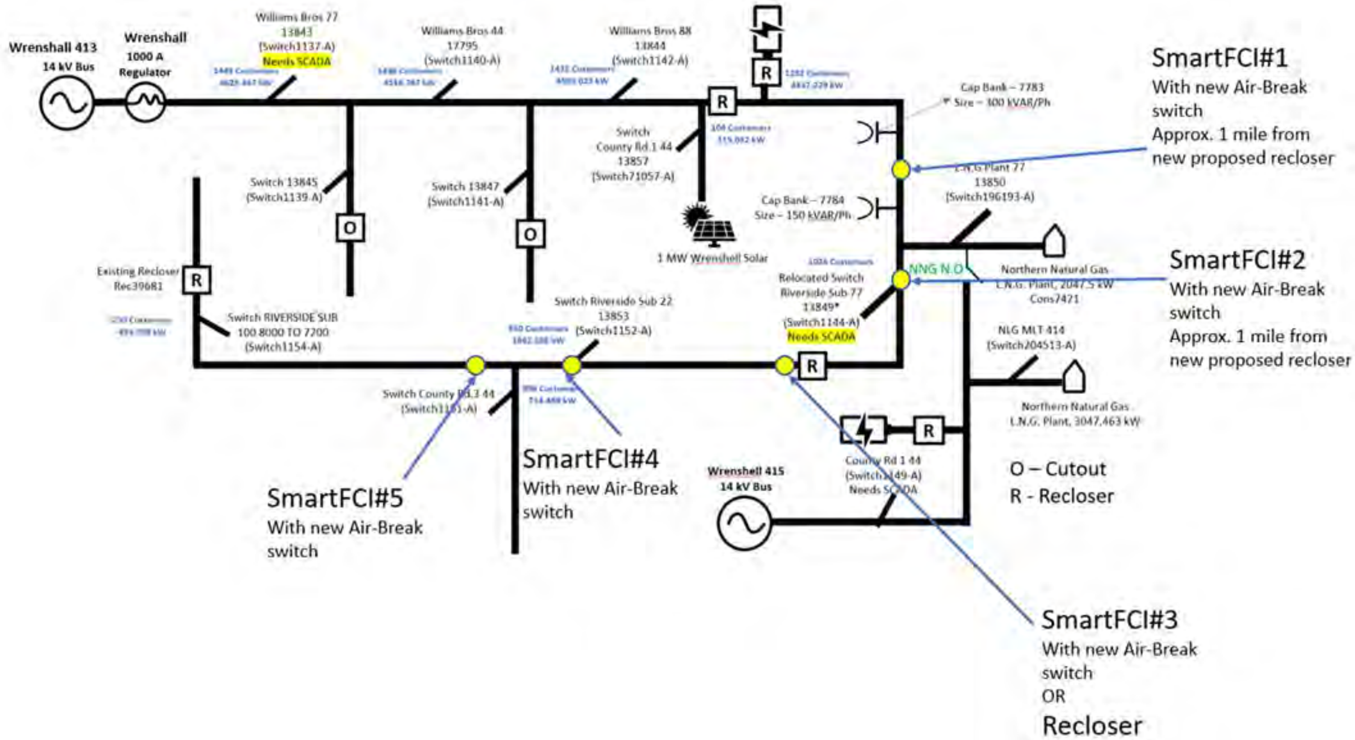

Figure 8. Proposed FCI location in Wrenshall 411 feeder (Option 1)

Option 2:
Five (5) smart FCIs along with new air-break switch are proposed at locations shown in figure 9.

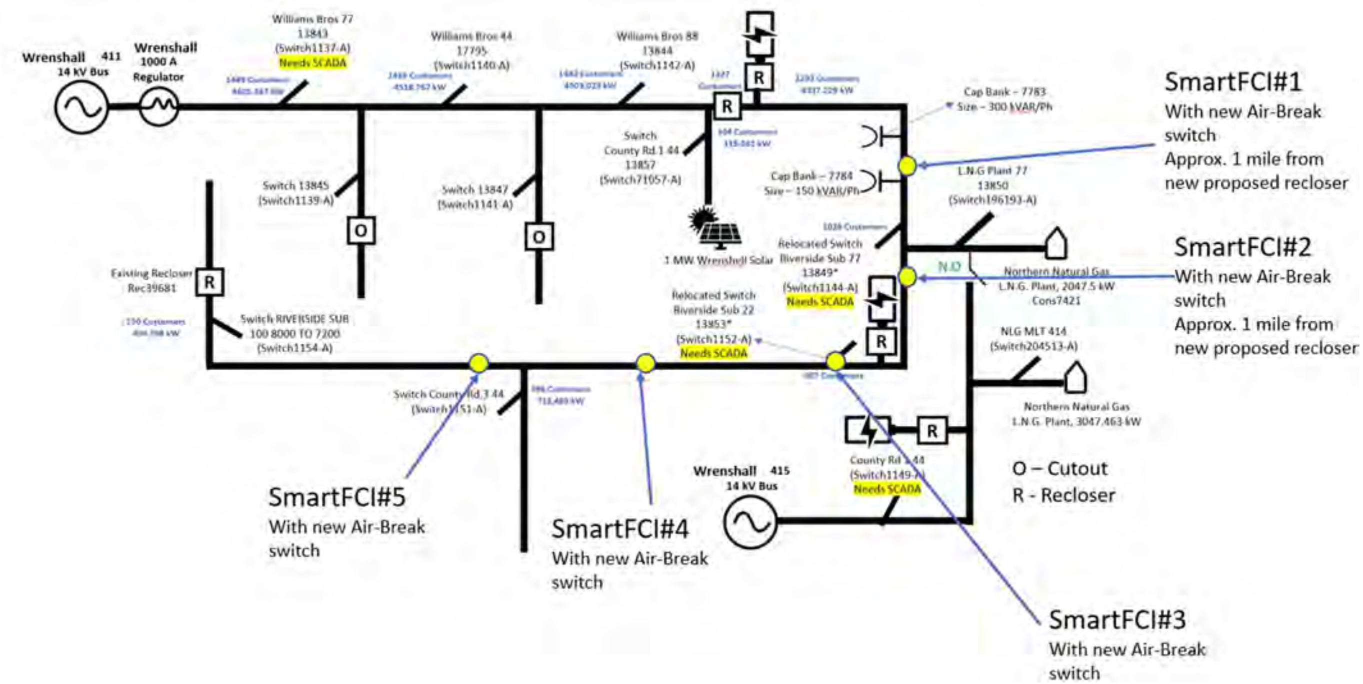

Figure 9. Proposed FCI location in Wrenshall 411 feeder (Option 2)

Table 42 shows the cost with the FCIs.

Table 42. *Cost of one set of FLISR devices*

Part Number	Description	Sales Price	Quantity	Total Price
FLT-1000	SEL-FLT Fault and Load Transmitter	850	3	$ 2,550.00
FLR-1000	SEL-FLR Receiver	1200	1	$ 1,200.00
CA605#0101	SEL-CA605 Shielded Ethernet Cable with RJ45 Connectors, 3 Feet	32.99	1	$ 32.99
3505#B9JJ	SEL-3505-3	1111.5	1	$ 1,111.50
C602A-03	SEL-C602A Serial Cable for SEL-4388 (RS-232, DTE-DCE, DB9 F/DB9 M)	32.99	1	$ 32.99
3061#HCBG	SEL-3061 Cellular Router	1580	1	$ 1,580.00
######	3PH Solid Blade Disconnect Switch	1150	1	$ 1,150.00
######	3PH Fuse Cutout	5000	1	$ 5,000.00

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XIII. Appendix

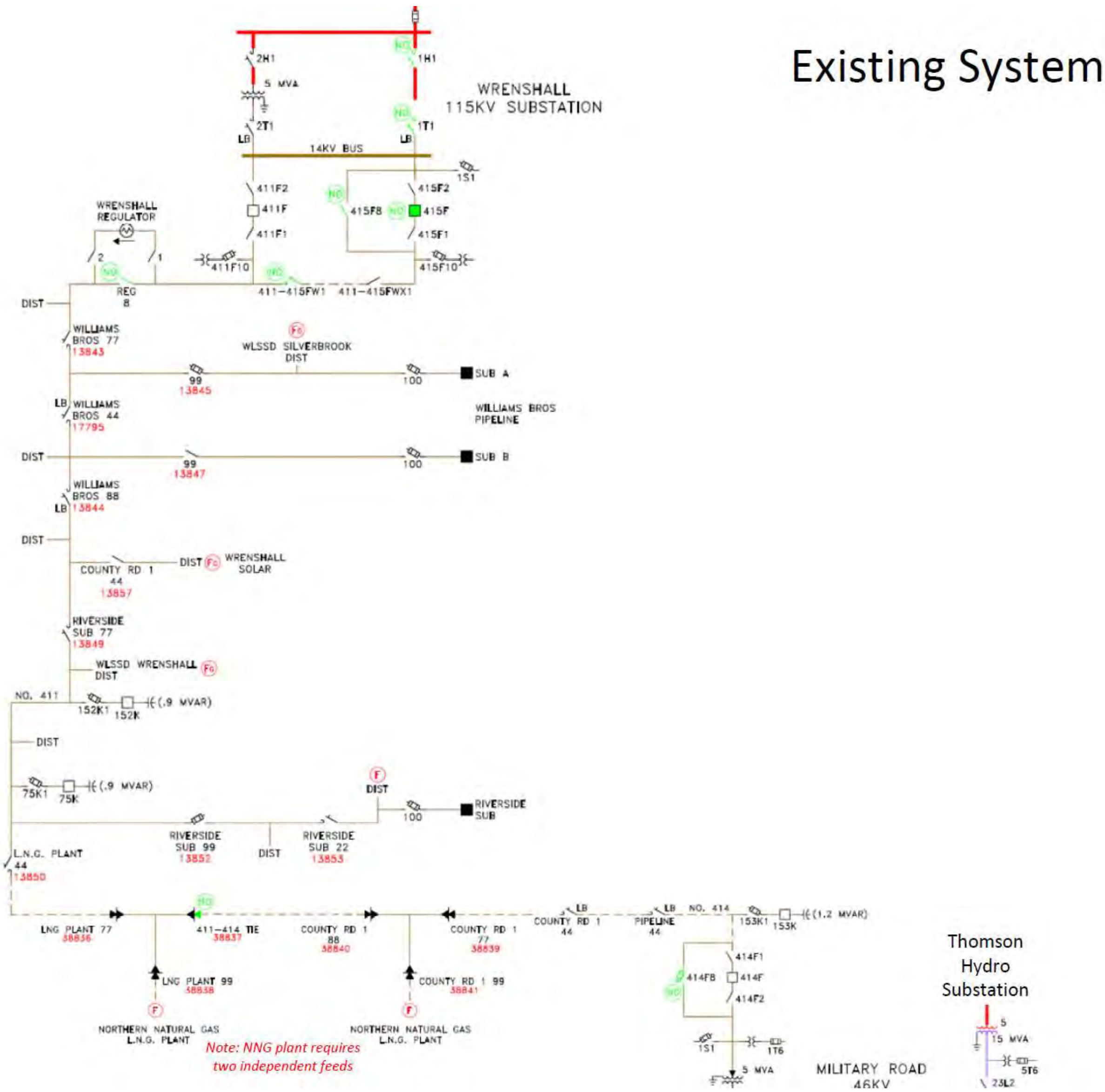

Figure 10. Substation SLD.

A. *Volt-Var Settings*

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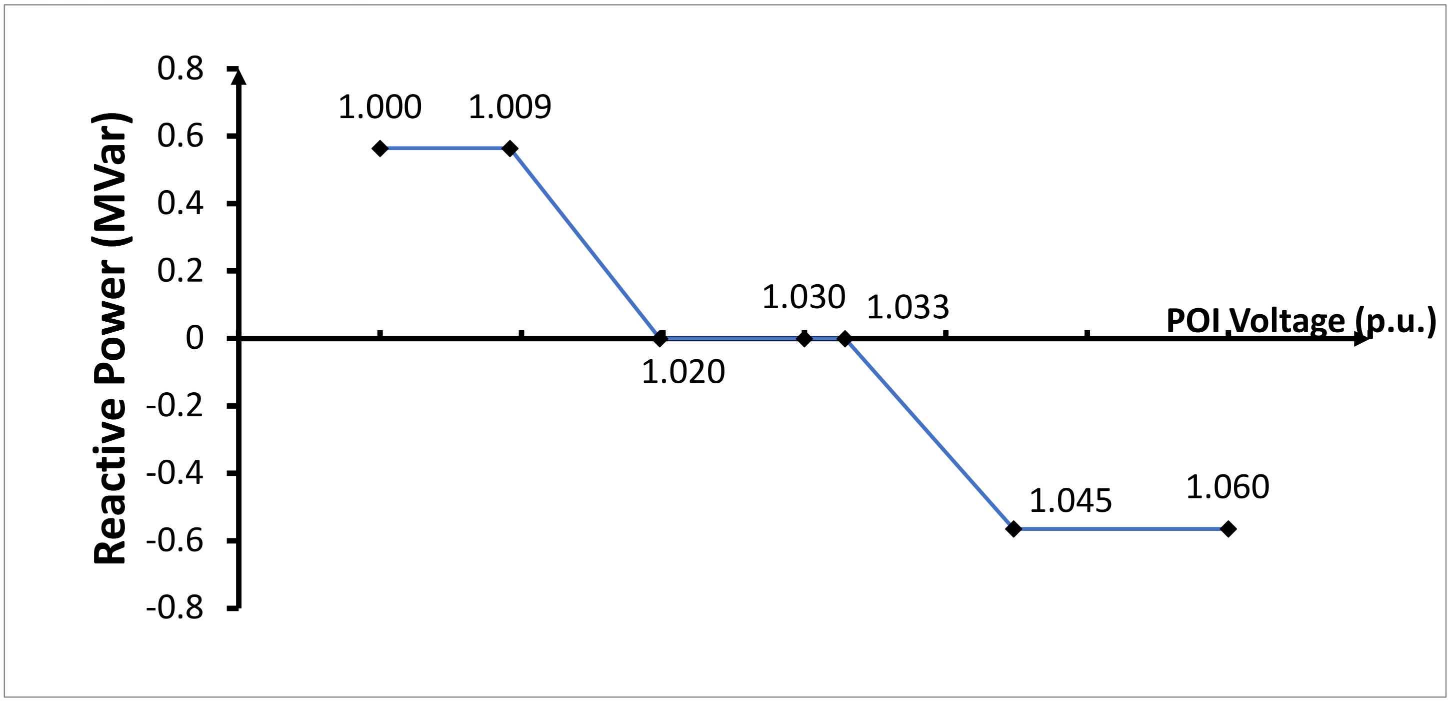

Figure 11. Volt-Var Settings for Option-1 BESS on WRN-411 Feeder (Plotted using Excel)

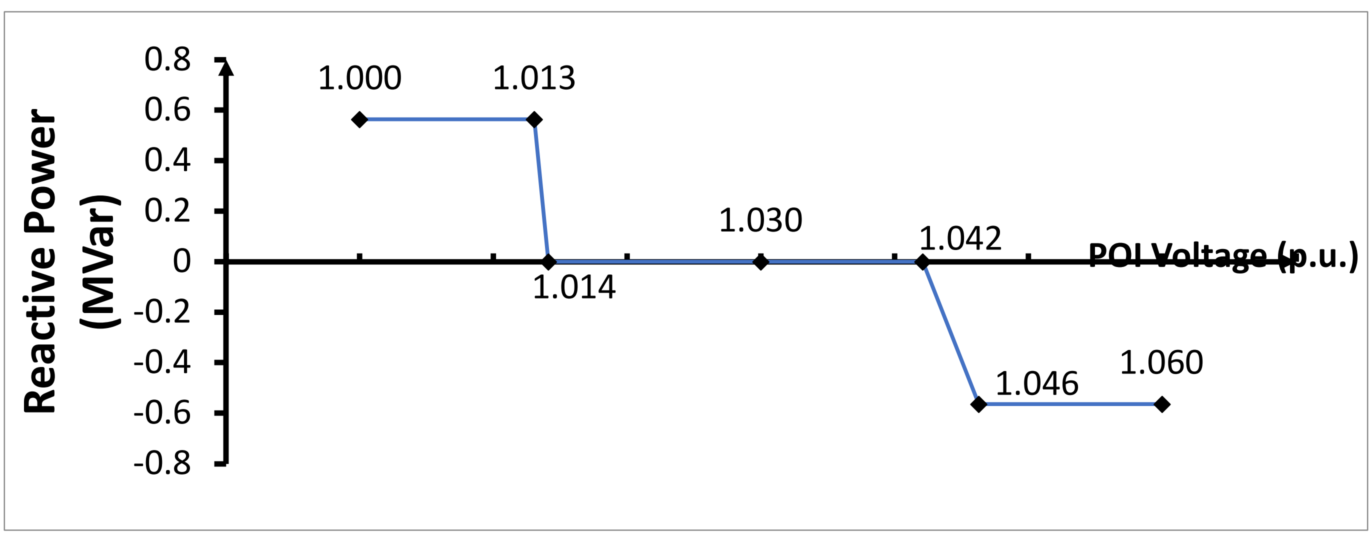

Figure 12. Volt-Var Settings for Option-2 BESS#1 on WRN-411 Feeder (Plotted using Excel)

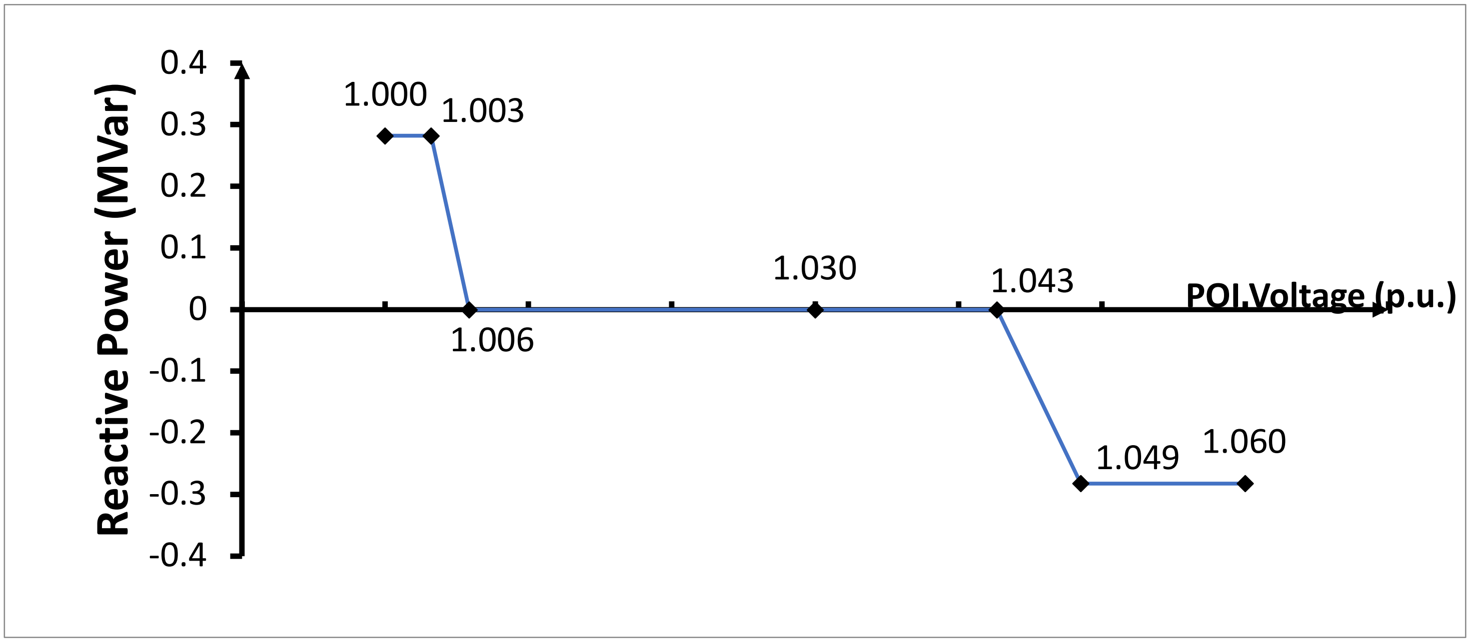

Figure 13. Volt-Var Settings for Option-2 BESS#2 on WRN-411 Feeder (Plotted using Excel).

B. <u>*Case Study - WRN-411 picks up load from WRN-415 with WRN-415 source disconnected*</u>

This case study considers the scenario where WRN-415 source is disconnected and the tie switch NNG N.O. is closed and WRN-411 picks up load from WRN-411. Two BESS each 3 MW and 6 MWH rated are proposed on WRN-411 feeder as Non-wire Alternative solution as shown in below figure.

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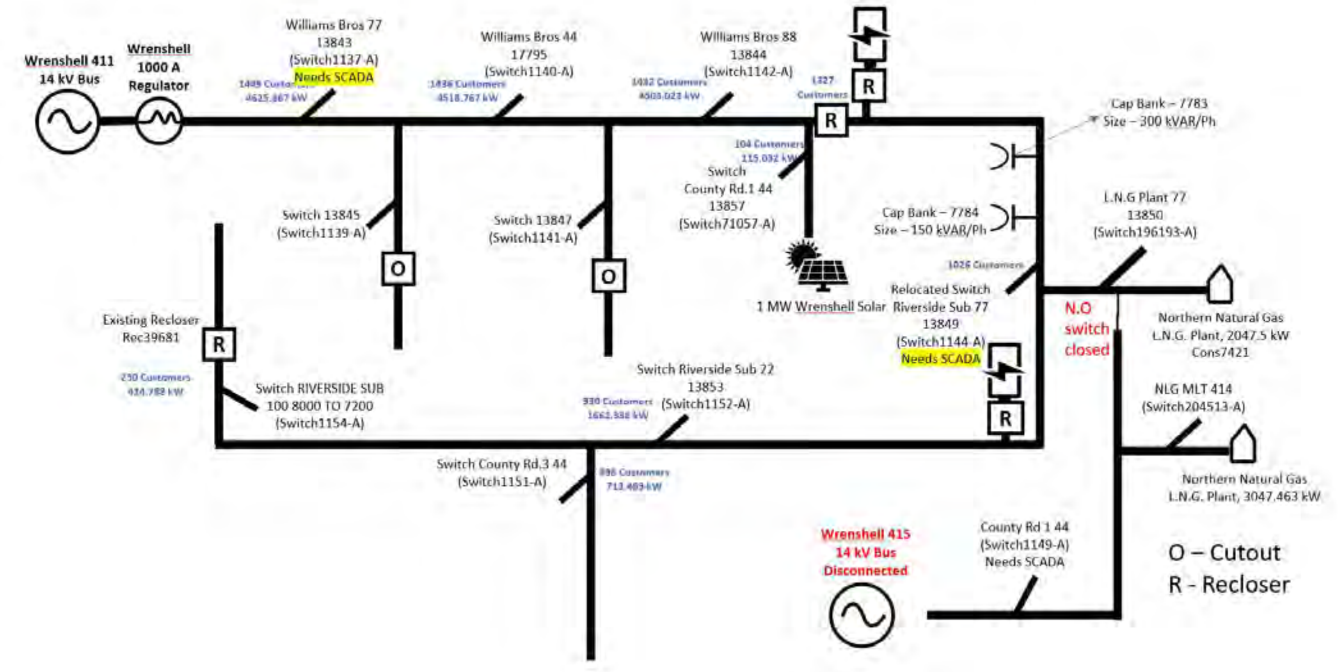

Figure 14. Wrenshell One Line Diagram for Case Study

Case Study: 3 MW, 6 MWH BESS at WRN-411 + 3 MW, 6 MWH BESS at WRN-411

Tables below presents the parameters, required features and recommended operation window for the BESS.

Table 43: BESS parameters and required feature of case study

Size	Two (3 MW, 6 MWH) on WRN-411
Location (POI) WRN-411	POI 1: BESS#1 at PriOH1235089 (Wrenshall) (13 kV) POI 2: BESS#2 at PriOH443520
Impedance between Source and POI (PriOH1235089 (WRN 411))	Z_1= 0.865 + j 5.023; Z_0= 1.352 + j 6.368 [Ω]
Impedance between Source and POI (PriOH443520 (WRN 411))	Z_1= 1.379 + j 6.144; Z_0= 2.443 + j 9.237 [Ω]
Upstream Capacity Limitation PriOH1235089 (WRN-411)	#4/0 ACSR 6/1 conductor with 357 A rating
Upstream Capacity Limitation PriOH443520 (WRN-411)	336 MCM ACSR 18/1 conductor with 500 A rating
Transformer	One (1) 3000 kVA Grounded Wye – Grounded Wye at each POI location on WRN-411, 13.8 kV/600 V, Z% = 6%, X/R = 10
Grounding Bank (WRN-411)	30 kVA Grounded Wye – Delta, 13.8 kV/480 V, Z% = 6%, X/R = 10
Primary Protection Device	3P Recloser, with SEL – 651R Recloser
Control Mode	Constant Unity Power Factor Mode with Volt-Var control mode stand by.

Emergency Power	The BESS is required to delay the recharging for 30 min after the restoration of the power outage.

Note: The Kyle Nova SEL-651 R is recommended in terms of small clearing tolerance, capability for harmonics blocking and reverse fault blocking. Also, the coordination is based on the Kyle Nova SEL-651R.

The following sections provides the load flow and voltage change results considering the Unity Power Factor operation of the two BESS.

Table 44: Load Flow results for Discharging/Charging of BESS - Case Study

Scenario	Control Mode	Site Operation	Load Flow at POI (PriOH1235089 (Wrenshall))	Load Flow at POI (PriOH443520 (Wrenshall))	Load Flow at WRN-411 Substation
Peak	Constant Unity PF	Discharging at 6 MW (Gen 1 & 2)	P = -2982.167 kW Q = 177.551 kVAR	P = -2981.37 kW Q = 185.472 kVAR	P = 2144.31 kW Q = 3573.618 kVAR
Peak	Constant Unity PF	Charging at 6 MW (Gen 1 & 2)	P = 2492.895 kW Q = 179.235 kVAR	P = 2359.903 kW Q = 179.243 kVAR	P = 11349.259 kW Q = 2844.782 kVAR
Off Peak	Constant Unity PF	Discharging at 6 MW (Gen 1 & 2)	P = -2983.301 kW Q = 164.721 kVAR	P = -2983.367 kW Q = 164.16 kVAR	P = -5173.228 kW Q = 960.319 kVAR
Off Peak	Constant Unity PF	Charging at 6 MW (Gen 1 and 2)	P = 2987.452 kW Q = 179.228 kVAR	P = 2943.13 kW Q = 179.196 kVAR	P = 6822.145 kW Q = 1205.351 kVAR

Table 45: Voltage results for Discharging of BESS under unity pf operation - Case Study

Scenario	2.0 MVA PriOH1235089 (WRN-411)	2.0 MVA PriOH443520 (WRN-411)	Substation [V]	POI (PriOH1235089 (WRN-411)) [V]	POI (PriOH443520 (WRN-411) [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	OFF	116.925	118.962	115.973	122.964	113.814
	Charging	Charging	102.883	99.836	94.64	108.061	91.833
	Discharging	Discharging	116.616	119.98	117.432	122.683	115.307

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Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	OFF	124.157	123.593	122.985	124.340	116.245
	Charging	Charging	120.131	119.675	117.944	123.755	117.283
	Discharging	Discharging	123.415	124.699	124.945	124.941	117.151

There are no overvoltage and overload violations detected during the discharging at off-peak scenarios which is the worst case. However, the volt-var operation mode from inverter is shown in the next section which could be used as a standby.

❖ BESS in Volt-Var operation mode.

The suggested dead bandwidth is from 1.002 to 1.030 V p.u. (V_{Ref}=1.025) on 120V base for POI (PriOH1235089(WRN-411)), and from 0.983 to 1.029 V p.u. (V_{Ref}=1.025 p.u.) on 120V base for POI (PriOH443520 (WRN-411)).

The assumed inverter setting is as followed:
Rating: 3000 kVA
Rated Real Power Max: 3000 kW
PF capable: -99.0 - +99.0
Maximum reactive power absorbed = 423.20 kVAR
Maximum reactive power injected = 423.20 kVAR

Table 46: Load Flow results for Discharging/Charging of BESS under Volt-Var mode - Case Study

Scenario	**Control Mode**	**Site Operation**	**POI (PriOH1235089 (WRN-411))**	**POI (PriOH443520 (WRN-411))**	**Load Flow at WRN-411 Substation**
Peak	Volt Var Mode	Discharging at 6 MW (Gen 1 & 2)	P = -2952.625 kW Q = -250.161 kVAR	P = -2951.961 kW Q = -243.547 kVAR	P = 2160.819 kW Q = 2341.31 kVAR
Peak	Volt Var Mode	Charging at 6 MW (Gen 1 & 2)	P = 2492.895 kW Q = 179.235 kVAR	P = 2359.903 kW Q = 179.243 kVAR	P = 11349.259 kW Q = 2844.782 kVAR
Off Peak	Volt Var Mode	Discharging at 6 MW (Gen 1 & 2)	P = -2952.605 kW Q = 594.095 kVAR	P = -2952.582 kW Q = 549.349 kVAR	P = -5107.286 kW Q = 1843.454 kVAR
Off Peak	Volt Var Mode	Charging at 6 MW (Gen 1 and 2)	P = 2987.452 kW Q = 179.228 kVAR	P = 2943.13 kW Q = 179.196 kVAR	P = 6855.145 kW Q = 1205.351 kVAR

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Table 47: Voltage results for Discharging of BESS under Volt-Var mode - Case Study

Scenario	2.00 MVA PriOH 1235089 (WRN -411)	2.00 MVA PriOH443520 (WRN-411)	Substation [V]	POI (PriOH1235089 (WRN-411)) [V]	POI (PriOH443520 (WRN-411) [V]	Vmax [V]	Vmin [V]
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	OFF	116.925	118.962	115.973	122.964	113.814
	Charging	Charging	102.883	99.836	94.64	108.045	91.831
	Discharging	Discharging	119.065	120.554	118.314	123.316	116.211
Peak (Base Volt = 125.5V, 1.0458 p.u.)	OFF	OFF	124.153	123.593	122.985	124.157	116.225
	Charging	Charging	120.104	119.719	117.95	123.755	117.006
	Discharging	Discharging	121.125	123.378	123.275	123.636	116.501

By enabling the volt-var mode of the BESS, there is no over-voltage violation caused by the interconnection and there is no overloading issue detected with the interconnection.

- Voltage-Change:

The distance between POIs **PriOH1235089 (Wrenshall WRN411) and PriOH443520 (Wrenshall WRN411)** is greater than 0.75 miles, so voltage change analysis is done independently.

Table 48: Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF at PriOH1235089 (WRN411) - Case Study

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	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI **(**PriOH1235089 (WRN411)**)**	119.754	115.463	3.72%	120.239	116.156	3.52%	119.950	115.860	3.53%
Substation Bus	116.508	118.709	2.201 V	116.728	119.084	2.356 V	116.614	118.968	2.354 V

Table 49: Voltage change assuming 100% BESS Drop at Peak Load Condition with Unity PF at PriOH443520 (WRN411) - Case Study

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI **(**PriOH443520 (WRN411)**)**	117.226	111.363	5.26%	117.736	112.207	4.93%	117.336	111.731	5.02%
Substation Bus	116.508	118.023	1.515 V	116.728	118.446	1.718 V	116.614	118.298	1.684 V

Table 50: Voltage change assuming 100% BESS Drop at Off- Peak Load Condition with Unity PF at PriOH1235089 (WRN411) - Case Study

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (PriOH1235089 (WRN411)**)**	124.699	124.527	0.137%	124.657	124.530	0.11%	124.638	124.469	0.136%
Substation Bus	123.415	124.135	0.72 V	123.379	124.132	0.753 V	123.380	124.100	0.72 V

Table 51: Voltage change assuming 100% BESS Drop at Off- Peak Load Condition with Unity PF at PriOH443520 (WRN411) - Case Study

	Off- Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV

POI (PriOH443520 (WRN411))	124.495	123.973	0.522%	124.849	123.934	0.915%	124.805	123.830	0.975%
Substation Bus	123.415	124.143.	0.728 V	123.379	124.142	0.763 V	123.380	124.105	0.725 V

The maximum voltage changes at the POI (PriOH1235089 (WRN411)) and POI (PriOH443520 (WRN411)) exceeds the threshold of 3% during peak load conditions. Therefore, case study fails for the voltage change. Therefore, it is not recommended to operate the BESS with the tie switch NNG N.O. closed with WRN-415 source disconnected and WRN-411 picks up load from WRN-415.

Silver Bay Non-Wire Alternative (NWA) Solution Final Report

Prepared by:

Black & Veatch
and
K&A Engineering Consulting, P.C.

06/23/2021
BV Project #: Sliver Bay

BLACK & VEATCH

K&A ENGINEERING CONSULTING, P.C.

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Revision History

Rev.	Date	Revised By	Updates
1	6/23/2022	H.L.	Draft Release
2	7/7/2022	H.L.	Draft Final Report Release

Executive Summary

Two NWA solutions are offered to improve the reliability at NSS-277 and NSS-271. NWA solution #1 is 3 MW BESS, 6 MWH at PriOH327740 primary 13.8 kV side of NSS-277 and NWA Solution #2 is 3 MW, 6 MWH BESS on NSS-271 at UG4676. The proposed BESS would provide several layers of redundancy and flexibility for future expansion which is also cost effective.

Reliability improvements:

1. NWA Solution #1 can be operated under normal NSS feeder conditions.
2. NWA Solution #1 can be operated with Industrial plant when NSS is open.
3. NWA Solution #1 can support feeder NSS-277 when it is disconnected from the source or industrial plant.
4. NWA Solution #1 can support both feeder NSS-277 & NSS-271 when it is disconnected from the source or industrial plant.
5. NWA Solution #2 can be operated under normal NSS feeder conditions.
6. NWA Solution #2 can be operated with Industrial plant when NSS is open.
7. NWA Solution #2 can support feeder NSS-271 when it is disconnected from the source or industrial plant.
8. NWA Solution #2 can support both feeder NSS-271 & NSS-277 when it is disconnected from the source or industrial plant.
9. NWA Solution #1 + #2 can be both operated under normal NSS feeder conditions.
10. NWA Solution #1 + #2 can be operated with Industrial plant when NSS is open.

I. Introduction

The City of Silver Bay is presently served by the Silver Bay Hillside 115/13.8 kV Substation, including approximately 1,348 customers with an estimated peak load of 4.50 MW. Due to the age and condition of the Silver Bay Hillside Substation, Minnesota Power's near-term asset renewal plans call for the decommissioning of this substation and replacement with a new 115/13.8 kV source from the relatively new North Shore Substation on the east side of Silver Bay in 2022. Subsequently, the Silver Bay Hillside Substation is planned to be converted to a mobile substation hook-up location. Outside of this future mobile substation site, the only potential source of immediate backup capability for the City of Silver Bay following loss of the primary North Shore source is a tie into the switchgear of a nearby large industrial plant. Historically, this tie was used for backup from Minnesota Power into the plant, and its reliability for use by Minnesota Power to back up the City from the industrial plant is questionable. This scenario will evaluate one or more non-wire alternatives involving battery energy storage and automated fault location, isolation, and restoration as a reliability backup solution for the City of Silver Bay.

This report will evaluate long-term considerations for the configuration and operation of the Silver Bay-area 13.8 kV system, given its varied characteristics and constraints. A holistic evaluation will include assessment of traditional solutions, including new and reconfigured sources, as well as non-wire alternatives such as volt-var optimization to manage voltage fluctuations from the solar garden and industrial facility, battery energy storage to provide backup capability and potentially optimize solar garden operation, and automated fault location, isolation and restoration. Following is the overall study scope:

1. Model and evaluate normal configuration with planned intellirupters, locations defined by MP.
    a) K&A to model and evaluate proposed scenario (as seen in the provided models).
    b) K&A to model and evaluate an additional scenario with improved reliability.
2. Model and evaluate Loss of NSS; Silver Bay served from Industrial Plant.
    a) Open IR-1 and IR-2
    b) Close 271-277 Tie Switch/IR-5 and Close Industrial Plant 44 Switch
3. Model and evaluate Loss of NSS; Silver Bay served from Silver Bay Hillside Battery.
    a) Normal configuration
    b) Industrial plant
4. Model and evaluate Loss of NSS; Silver Bay served from NSS Battery.

II. Scope of Study & Assumption

The study was conducted in accordance with Minnesota Power Technical Specifications Manual (TSM) [Ver 1.1 05-01-2020], standards, study guidelines, procedures, practices and IEEE 1547-2018, IEEE 1453-2015, UL 1741.

It is assumed that Minnesota Power will conduct further studies of the possible impact on the transmission level, to ensure adequacy of any equipment in conjunction with the proposed upgrades.

The following studies were performed to evaluate the base circuit and the impact from the proposed non-wire alternative to distribution equipment and performance of the circuit and the substation:

- Load-Flow (under various feeder configurations)
  - Peak Load + BESS Full Discharging
  - Peak Load + BESS Full Charging
  - Off-Peak Load + BESS Full Discharging
  - Off- Peak Load + BESS Full Charging
- Battery Energy Storage System (BESS) Control Mode
  - Volt Var (+/-0.99 power factor)
  - Fixed power factor at unity.
- Voltage Impact
  - Steady State Voltage Analysis
  - Voltage Change Analysis
- Short-Circuit Analysis
- Circuit Protection
  - Transformer Inrush Estimation
  - Protection Coordination
- Effective Grounding
- Reliability Analysis
- Islanding Analysis

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III. Feeder Overview

Table 1: Silver Bay 13.8 kV feeder load Information

Silver Bay	Feeder	kW	kVAR	kVA	PF
Peak	NSS-271	1082.387	232.012	1107.023	98%
	NSS-277	1525.657	323.767	1559.749	98%
	Total	2608.044	555.779	2666.772	98%
Off-Peak	NSS-271	486.673	123.039	502.034	97%
	NSS-277	677.063	169.472	697.948	97%
	Total	1163.736	292.511	1199.982	97%

The given source impedance at the substation bus (NSS-277 & NSS-271) is:

Z_1: 0.208 + j 1.887 [Ω]
Z_2: 0.208 + j 1.887 [Ω]
Z_0: 0.208 + j 1.887 [Ω]

Table 2: Historical total reliability index from 2017 to 2021

Circuit_Name	Year	Saidi	Feeder Saidi	Saifi	Feeder Saifi	Maifi	Feeder Maifi	Total Events
Silver Bay	2017	2.08	835.69	0.02	9.39	0.00	0.02	35
Silver Bay	2018	0.03	51.34	0.00	0.17	0.00	0.00	9
Silver Bay	2019	0.48	206.10	0.02	7.39	0.00	0.00	33
Silver Bay	2020	0.34	90.92	0.01	1.48	0.00	0.00	22
Silver Bay	2021	0.17	77.45	0.01	3.51	0.00	1.00	41

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Table 3: List of capacitor banks, regulators, DGs, and industrial loads

Element Name	Device	Settings (Status is "initially off" under base model)	Rating/Output
CAPBANK 368	3P Capacitor bank	voltage control under 0.95 pu to 1.05 pu	150 kVAR (50 kVAR /phase)
CAPBANK 369	3P Capacitor bank	voltage control under 0.95 pu to 1.05 pu	300 kVAR (150 kVAR /phase)
CAPBANK 370	3P Capacitor bank	voltage control under 0.95 pu to 1.05 pu	150 kVAR (50 kVAR /phase)

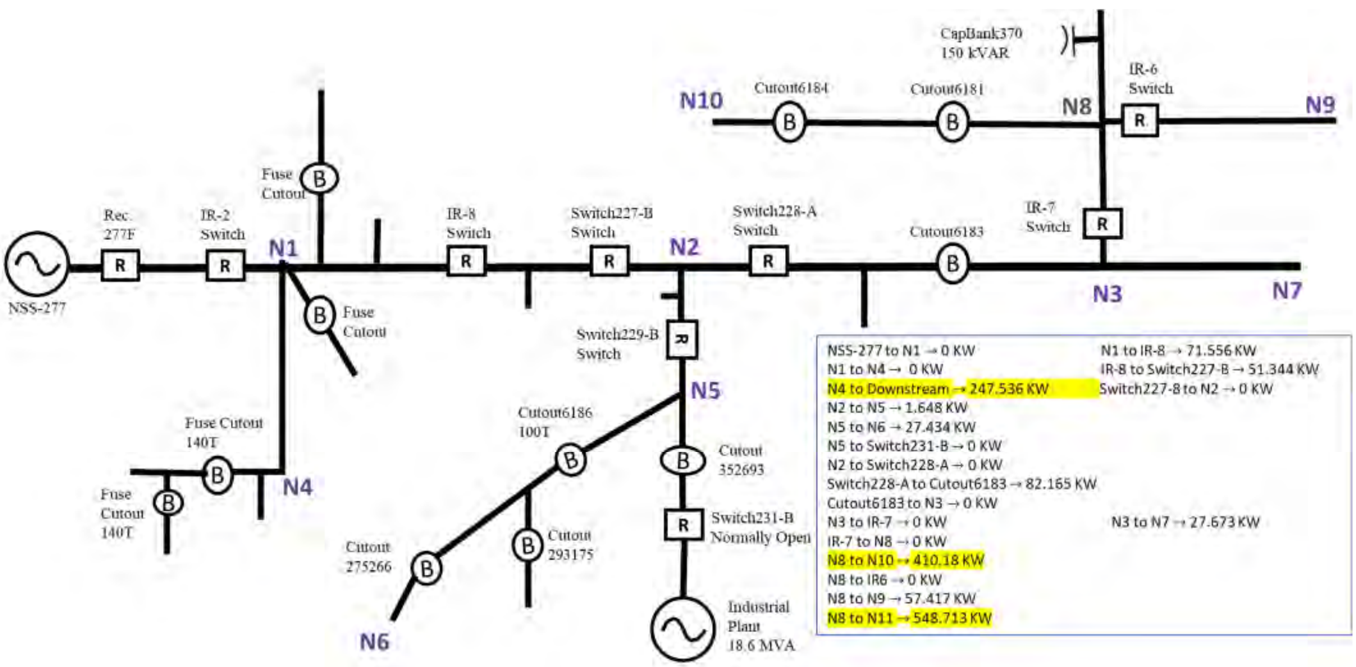

Figure 1. Silver Bay NSS-277 One Line Diagram prior to the NWA & Peak Load Allocation

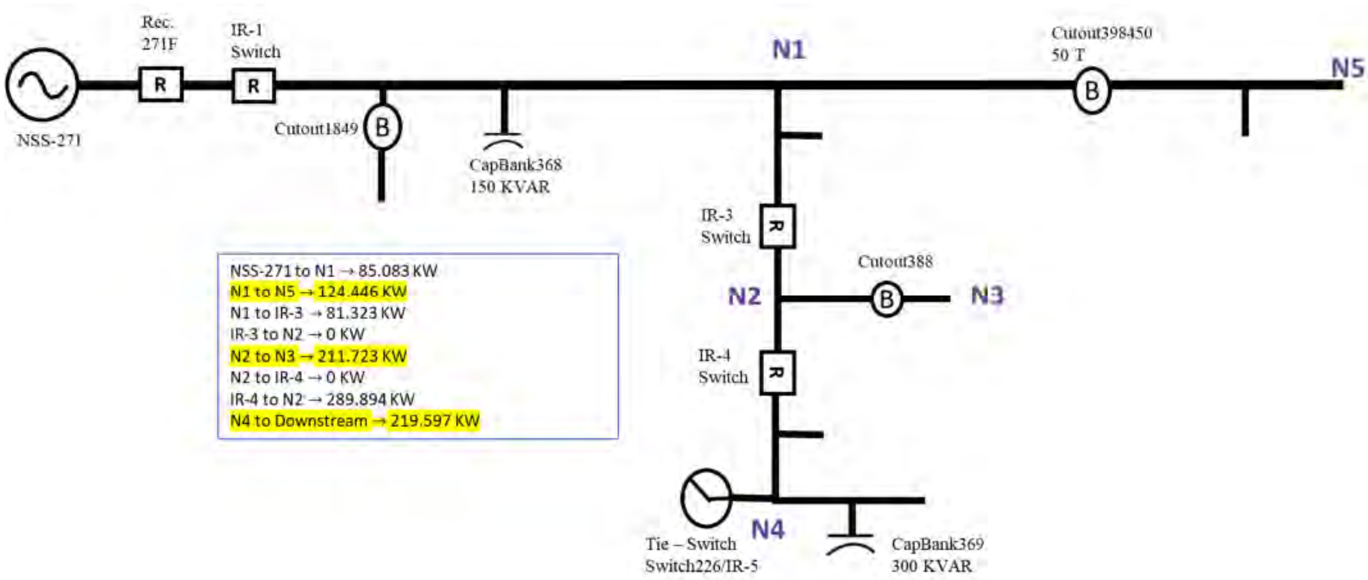

Figure 2. Silver Bay NSS-271 One Line Diagram prior to the NWA & Peak Load Allocation

Table 4: Voltage Condition prior to the NWA

Feeder	Criteria	Voltage	Location
NSS-277 (Peak)	Vmax	124.09 V	NSS-277 Source
	Vmin	112.75 V	CUST716623
NSS-271 (Peak)	Vmax	124.09 V	NSS-271 Source
	Vmin	114.77 V	CUST17180
NSS-277 (Off-Peak)	Vmax	124.09 V	NSS-277 Source
	Vmin	118.9 V	CUST716623
NSS-271 (Peak)	Vmax	124.09 V	NSS-271 Source
	Vmin	119.77 V	CUST17180

There are two exiting shunt cap banks in NSS-271, one shunt cap bank in NSS-277. There is no existing line voltage regulator. During peak conditions, minor undervoltage are observed around few secondary customer nodes. As per suggestion from Minnesota power, no mitigation is proposed for existing conditions. The following sections consider the given base model without any changes.

IV. Proposed Non-Wire Alternative Solution

Non-wires alternatives are defined as "an electricity grid investment or project that uses non-traditional transmission and distribution (T&D) solutions, such as distributed generation (DG), energy storage, energy efficiency (EE), demand response (DR), and grid software and controls, to defer or replace the need for specific equipment upgrades, such as T&D lines or transformers, by reducing load at a substation or circuit level. Several NWA solutions have been considered, based on the simulation result in the following sections, a new battery energy storage system (BESS) is determined as the best solution and is chosen for this report.

The proposed BESS would provide several layers of redundancy and flexibility for future expansion which is also cost effective.

NWA Solution #1: 3 MW, 6 MWH BESS on NSS-277 at PriOH327740

Tables below presents the parameters, required features and recommended operation window for the BESS.

Table 5: BESS #1 at NSS - 277 parameters and required feature

Size	3 MW, 6 MWh (NSS-277)
Location (POI)	PriOH327740, 13.8 kV (NSS-277)
Distance from Source	0.5 miles
Location Benefits	Land space available for construction; Can support most customers on 277 under various outage conditions.
Capacity Limitation (NSS-277)	#2 ACSR 6/1 conductor with 180A rating
BESS Transformer (NSS-277)	One (1) 3000 kVA Grounded Wye – Grounded Wye, 13.8 kV/600 V, Z% = 6%, X/R = 10
Grounding Bank (NSS-277)	30 kVA Grounded Wye – Delta, 13.8 kV/480 V, Z% = 6%, X/R = 10
Primary Protection Device	3P Recloser, with SEL – 651R Recloser
Control Mode	Constant Unity Power Factor Mode with Volt-Var control mode stand by.
Emergency Power	The BESS is required to delay the recharging for 30 min after the restoration of the power outage.

Note: The Kyle Nova SEL-651 R is recommended in terms of small clearing tolerance, capability for harmonics blocking and reverse fault blocking.

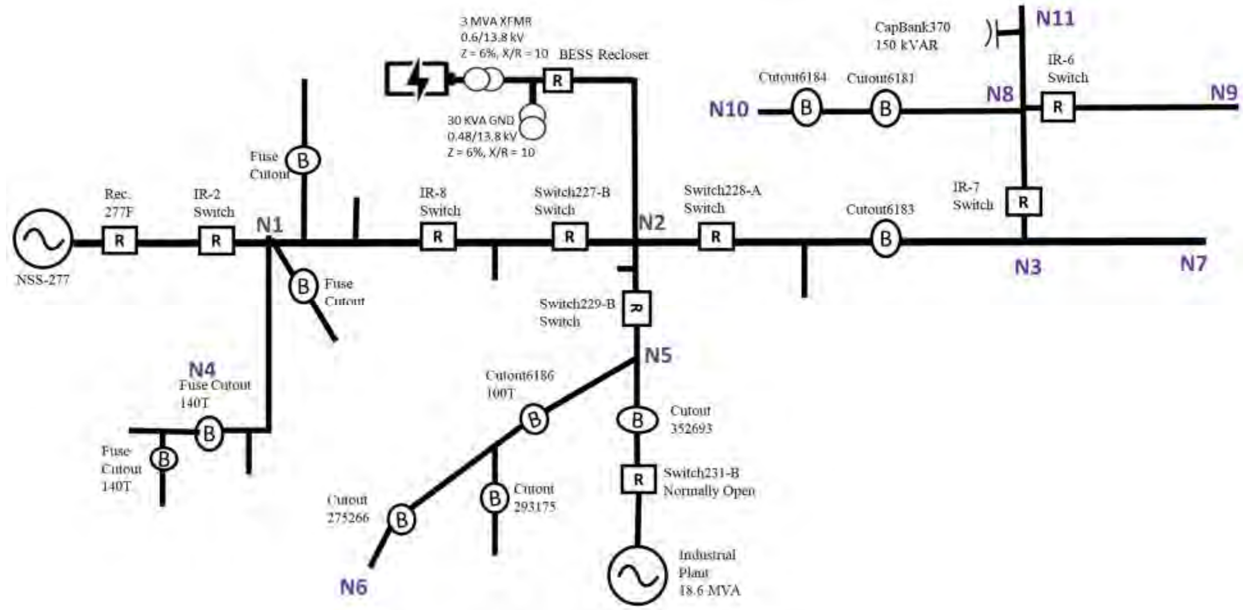

Figure 3. Silver Bay One Line Diagram with the BESS #1at NSS-277

NWA Solution #2: 3 MW, 6 MWH BESS on NSS-271 at UG4676

Tables below presents the parameters, required features and recommended operation window for the BESS.

Table 6: BESS #2 at NSS - 271 parameters and required feature

Size	3 MW, 6 MWh (NSS-271)
Location (POI)	NSS-271 Feeder Head UG4676, 13.8 kV (NSS-271)
Distance from Source	0 miles
Location Benefits	Land space available for construction; Can support most customers on 271 under various outage conditions.
Capacity Limitation (NSS-271)	#2 ACSR 6/1 conductor with 180A rating
BESS Transformer (NSS-271)	One (1) 3000 kVA Grounded Wye – Grounded Wye, 13.8 kV/600 V, Z% = 6%, X/R = 10
Grounding Bank (NSS-271)	30 kVA Grounded Wye – Delta, 13.8 kV/480 V, Z% = 6%, X/R = 10
Primary Protection Device	3P Recloser, with SEL – 651R Recloser
Control Mode	Constant Unity Power Factor Mode with Volt-Var control mode stand by.
Emergency Power	The BESS is required to delay the recharging for 30 min after the restoration of the power outage.

Note: The Kyle Nova SEL-651 R is recommended in terms of small clearing tolerance, capability for harmonics blocking and reverse fault blocking.

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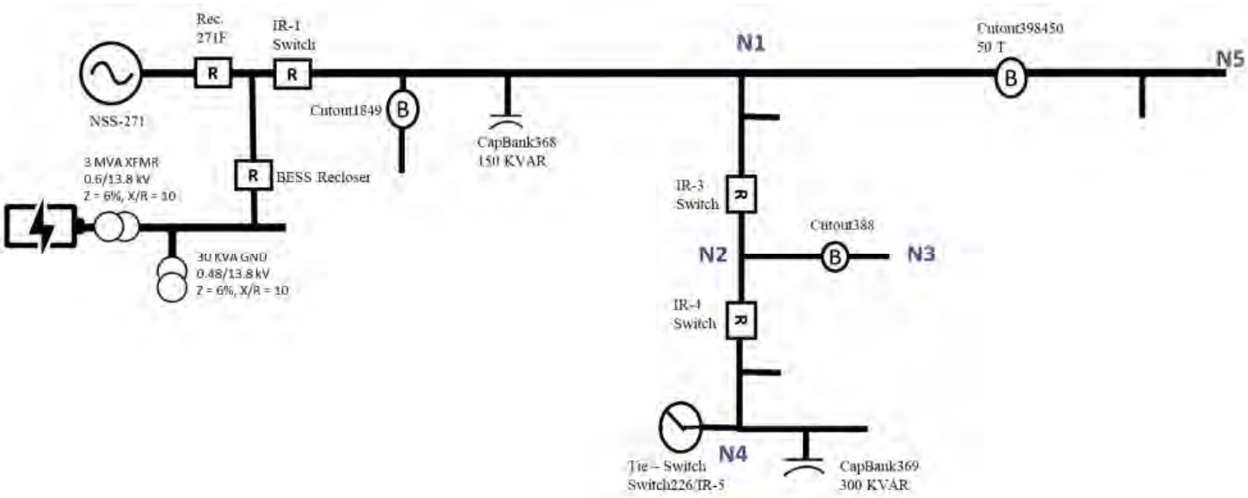


Figure 4. Silver Bay One Line Diagram with the BESS #2 at NSS-271

Table 7. Recommended Summer & Winter schedule for Charging and Discharging of BESS under normal operation.

Start Time	Mode	Power	Control Mode	Reference
12:00:00 AM	Idling	-	-	-
03:00:00 AM	Charging BESS #1	100%	Constant Unity Power Factor Mode	Max Charging Power
04:00:00 AM	Charging BESS #2	100%	Constant Unity Power Factor Mode	Max Charging Power
6:00:00 AM	Idling	-	-	-
06:00:00 PM	Discharging	100%	Constant Unity Power Factor Mode	Max Discharging Power
09:30:00 PM	Idling	-		-

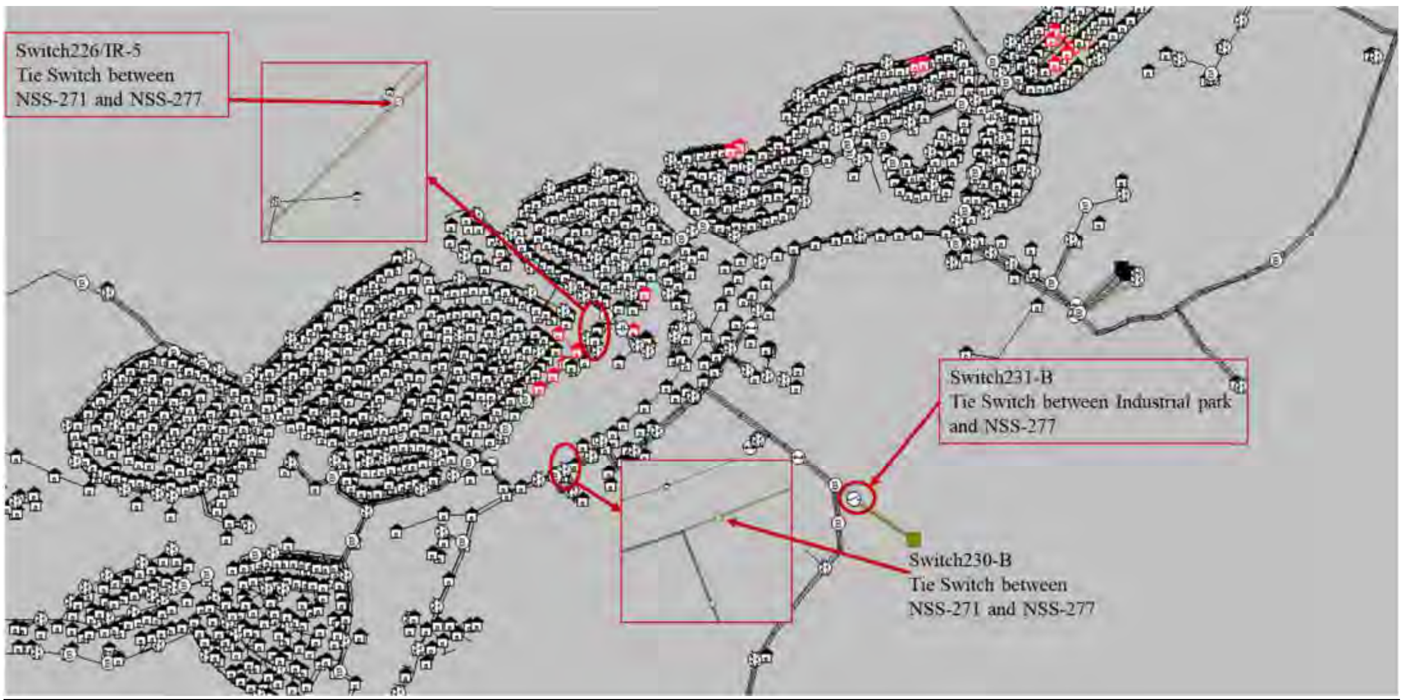
Note:
The BESS needs to synchronize with local EPS without causing any abnormal conditions while entering service.
The Charging start time is subject to change based on the local utility price.
The volt-var model can be stand by during normal feeder configuration condition but may be required during contingency scenarios to prevent possible overvoltage violations at POI.

V. Load Flow Analysis

A Steady State Voltage Analysis was conducted to determine the project's impact on the distribution circuit voltage. The adequate service voltage to customers is 117 to 126 volts (120-volt base) during normal operation.

The peak and off-peak load case is using the given operating voltage in the base model: 122.33 V for Industrial Plant; 124.09 V for NSS.

Scenario A: Normal NSS feeder configuration Prior to the NWA



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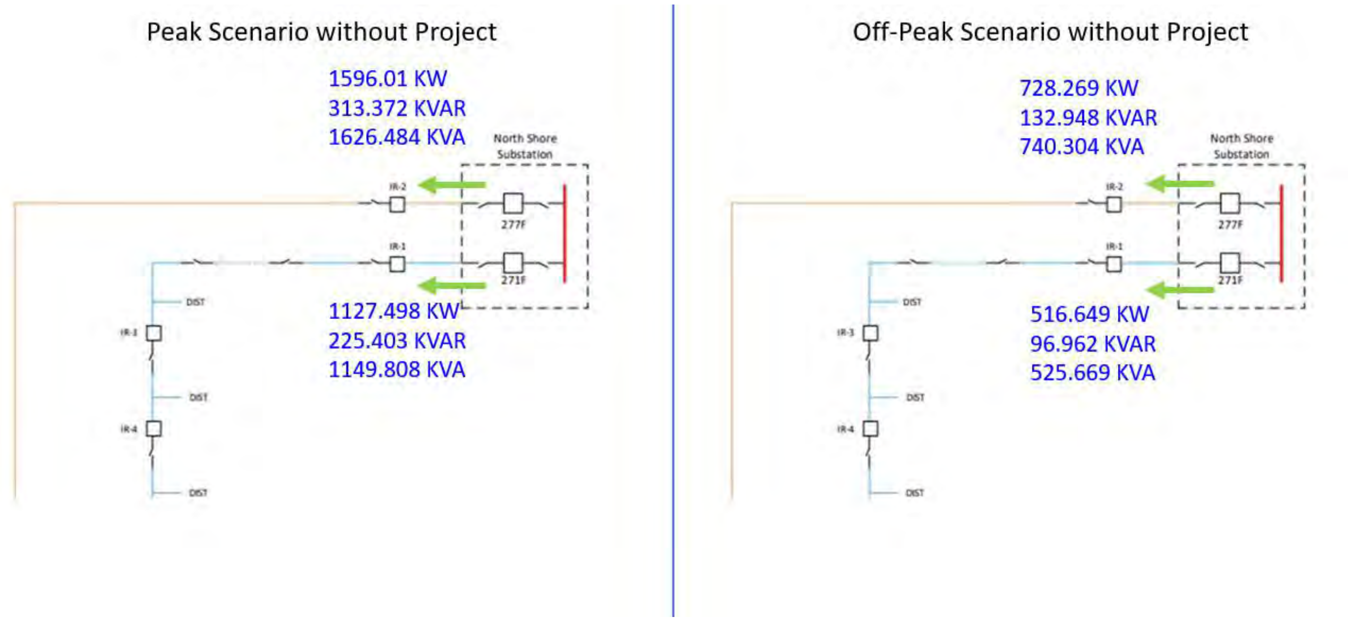

Figure 5. Load Flow Results under Scenario A – Prior to the NWA

From load flow results shown above, there are some pre-existing under-voltage violations detected at secondary voltage level. There is no existing reverse power flow detected.

The three capacitors are on the "OFF" status in the given based model under Scenario A.

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Scenario B: NSS open (IR-1 and IR-2 open, IR-5 close) with Industrial Plant prior to the NWA

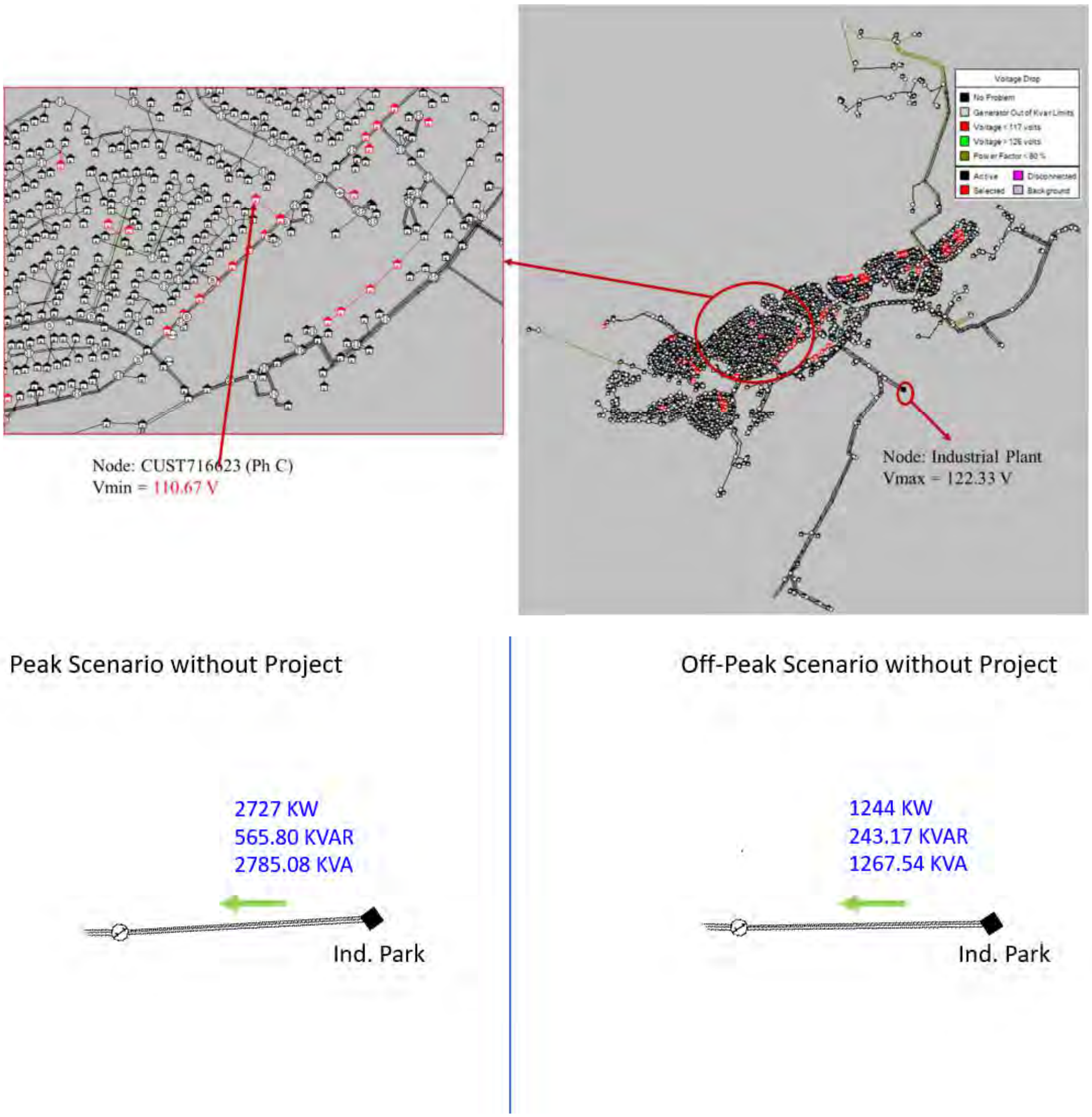

Figure 6. Load Flow Results under Scenario B – Prior to the NWA

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The three capacitors are on the "OFF" status in the given based model under Scenario B.

Note that in order to capture the worst-case scenarios, the study change the capacitor settings from "initially off" to "last status". This is because the most common violation caused by a DER interconnection is the overvoltage, and with existing Capacitor on give the worst voltage profile. Results with "initially off" settings are available in the Appendix C.

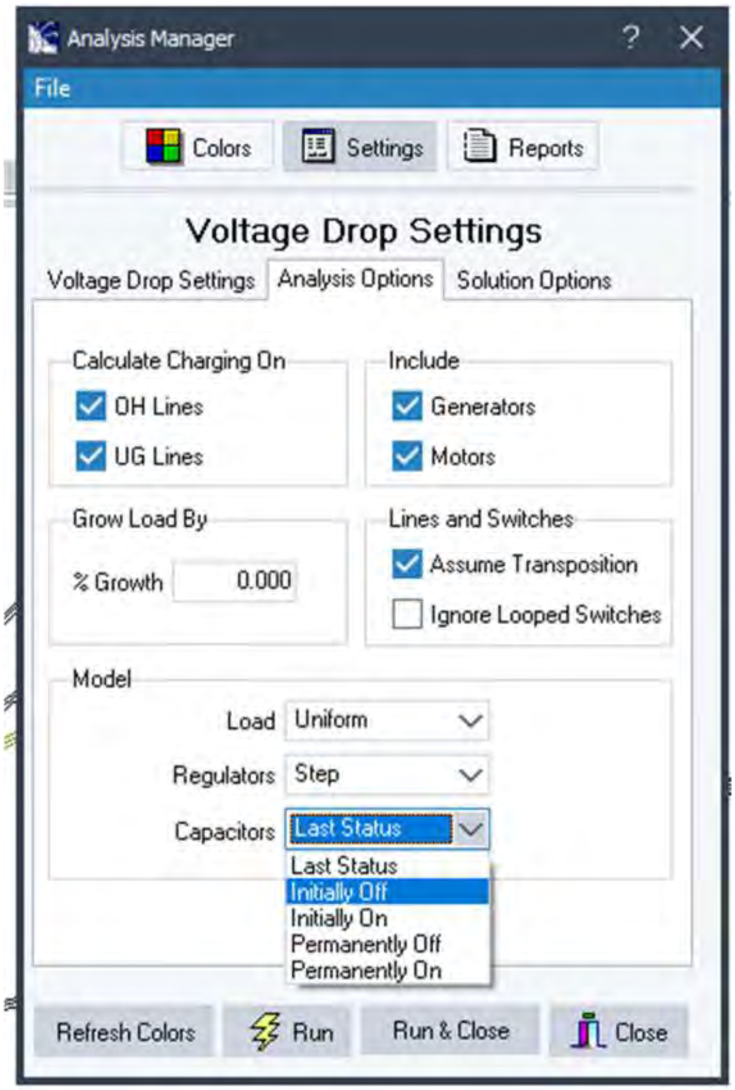

Figure 7. Voltage Drop Settings for Capacitors

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Scenario C: NWA Solution #1

❖ BESS #1(NSS-277) in Constant unity PF operation mode with 3 MW Charging & Discharging Rate.

Table 8. Load Flow results for Discharging/Charging of BESS at PriOH327740 (NSS-277)

BESS#1 Scenario C	Feeder Configuration	Site Operation	Load Flow at POI	Load Flow at NSS-277	Load Flow at NSS-271	Industrial Park
Peak	NSS normal, no Industrial Park	Discharging	-2983.35 kW 165.32 kVAR 124.43 V	-1384.72 kW 320.80 kVAR 124.09 V	1127.58 kW -253.04 kVAR 124.09 V	N/A
Peak		Charging	3064.38 kW 179.20 kVAR 122.79 V	4698.33 kW 394.70 kVAR 124.09 V	1127.58 kW -253.04 kVAR 124.09 V	N/A
Off Peak		Discharging	-2983.40 kW 164.85 kVAR 124.61 V	-2243.24 kW 152.75 kVAR 124.09 V	517.16 kW -383.31 kVAR 124.09 V	N/A
Off Peak		Charging	3070.75 kW 179.2 kVAR 122.98 V	3827.22 kW 198.54 kVAR 124.09 V	517.16 kW -383.31 kVAR 124.09 V	N/A
Peak	NSS IR-1 & IR-2 open, IR-5 close, Industrial Park close	Discharging	-2982.79 kW 171.01 kVAR 122.34 V	N/A	N/A	-261.66 kW 102.94 kVAR 122.33 V
Peak		Charging	3038.32 kW 179.19 kVAR 121.74 V	N/A	N/A	5785.17 kW 181.10 kVAR 122.33 V
Off Peak		Discharging	-2982.85 kW 170.43 kVAR 122.545 V	N/A	N/A	-1737.40 kW -208.68 kVAR 122.33 V
Off Peak		Charging	3043.77 kW 179.2 kVAR 121.962 V	N/A	N/A	4301.13 kW -164.22 kVAR 122.33 V

Conclusions:

- **There is no thermal or voltage violation during NSS normal with NWA solution #1.**
- **There is new reverse power flow back to transmission system (-2243.24 kW during off peak condition), reverse power handling capability need to be reviewed for upstream devices.**
- **Under NSS IR-1 & IR-2 open; IR-5 close & Industrial Park close with NWA solution #1 charging case, there will be 5785.17 kW running through 336 MCM ACSR 18/1 conductor from N2 to N5 with 53.6% capacity loading.**

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Scenario D: NWA Solution #2

- BESS #2(NSS-271) in Constant unity PF operation mode with 3 MW Charging & Discharging Rate.

Table 9: Load Flow results for Discharging/Charging of BESS at UG4676 (NSS-271)

BESS#2 Scenario D	Feeder Configuration	Site Operation	Load Flow at POI	Load Flow at NSS-271	Load Flow at NSS-277	Industrial Park
Peak	NSS normal, no Industrial Park	Discharging	-2983.29 kW 166.21 kVAR 124.1 V	-1855.63 kW -86.86 kVAR 124.09 V	1595.86 kW 154.13 kVAR 124.09 V	N/A
Peak		Charging	3096.57 kW 179.2 kVAR 124.07 V	4224.79 kW -72.97 kVAR 124.09 V	1595.86 kW 154.13 kVAR 124.09 V	N/A
Off Peak		Discharging	-2983.29 kW 166.2 kVAR 124.1 V	-2465.96 kW -217 kVAR 124.09 V	728.31 kW -27.03 kVAR 124.09 V	N/A
Off Peak		Charging	3096.78 kW 179.19 kVAR 124.08 V	3614.29 kW -203.62 kVAR 124.09 V	728.31 kW -27.03 kVAR 124.09 V	N/A
Peak	NSS IR-1 & IR-2 open, IR-5 close, Industrial Park close	Discharging	-2983.24 kW 165.4 kVAR 124.4 V	N/A	N/A	-226.399 kW 104.498 kVAR 122.33 V
Peak		Charging	2945.14 kW 179.19 kVAR 118.01 V	N/A	N/A	5797.23 kW 314.46 kVAR 122.33 V
Off Peak		Discharging	-2983.404 kW 163.7 kVAR 125.05 V	N/A	N/A	-1685.2 kW -183.67 kVAR 122.33 V
Off Peak		Charging	2962.62 kW 179.20 kVAR 118.72 V	N/A	N/A	4306.40 kW -59.16 kVAR 122.33 V

Conclusions:

- **There is no thermal or voltage violation during NSS normal with NWA solution #2.**
- **There is new reverse power flow back to transmission system (-2465.96 kW during off peak condition), reverse power handling capability need to be reviewed for upstream devices.**
- **Under NSS IR-1 & IR-2 open; IR-5 close & Industrial Park close with NWA solution #2 charging case, there is no thermal or voltage violation.**

Scenario E: NWA Solution #1 + NWA Solution #2

- BESS #1 (NSS-277) + BESS #2(NSS-271) in Constant unity PF operation mode with 3 MW Charging & Discharging Rate.

Table 10: Load Flow results for Discharging/Charging of with both BESS #1 & BESS #2

Scenario E	Feeder Configuration	Site Operation	Load Flow at POI 1	Load Flow at POI 2	Load Flow at NSS-271	Load Flow at NSS-277	Industrial Park
Peak	NSS normal, no Industrial Park	Discharging	-2983.35 kW 165.32 kVAR 124.43 V	-2983.28 kW 166.21 kVAR 124.096 V	-1855.68 kW -86.84 kVAR 124.09 V	-1384.72 kW 320.80 kVAR 124.09 V	-
Peak		Charging	3064.38 kW 179.2 kVAR 122.79 V	3096.76 kW 179.2 kVAR 124.08 V	4224.73kW -73.31 kVAR 124.09 V	4698.33kW 394.70kVAR 124.09 V	-
Off Peak		Discharging	-2983.41 kW 164.68 kVAR 124.675 V	-2983.28 kW 166.23 kVAR 124.09 V	-2466.12kW -217.07 kVAR 124.09 V	-2243.24 kW 152.75 kVAR 124.09 V	-
Off Peak		Charging	3070.75 kW 179.2 kVAR 123.04 V	3097.07 kW 179.19 kVAR 124.09 V	3614.23 kW -204.12 kVAR 124.09 V	3827.22 kW 198.54 kVAR 124.09 V	-
Peak	NSS IR-1 & IR-2 open, IR-5 close, Industrial Park close	Discharging	-2982.83 kW 170.35 kVAR 122.57 V	-2983.28 kW 164.78 kVAR 124.63 V	-	-	-3201.22 kW 290.7 kVAR 122.33 V
Peak		Charging	3028.9 kW 179.19 kVAR 121.37 V	2936.41kW 179.19kVAR 117.68 V	-	-	8852.44 kW 582.5 kVAR 122.33 V
Off Peak		Discharging	-2982.88 kW 169.79 kVAR 122.78 V	-2983.44 kW 163.07 kVAR 125.29 V	-	-	-4653.38 kW 18.08 kVAR 122.33 V
Off Peak		Charging	3034.59 kW 179.2 kVAR 121.6 V	2953.99 kW 179.21 kVAR 118.38 V	-	-	7359.85 kW 191.2 kVAR 122.33 V

Conclusions:

- **There is no thermal or voltage violation during Scenario E.**
- **There is new reverse power flow back to transmission system (2466 kW + 2243 kW) during off peak condition), reverse power handling capability need to be reviewed for upstream devices.**
- **The maximum loading is 364 A with both BESS charging with Industrial Park. All equipment is within their 80% rating.**

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- BESS in Volt-Var operation mode.

"*The DER shall not cause the Area EPS primary circuit voltage at any location to go outside the requirements of ANSI C84.1 for primary service voltage.*"

----IEEE 1547-2018

IEEE 1547-2018 requires that the DER should have the ability of injecting and absorbing reactive power for DER voltage impact mitigation, and the reactive power magnitude needs to be controlled automatically. However, Minnesota Power TSM requires the settings for Volt-Var Power control to be disabled. This section will provide the setting for the reference.

Scenario C, D ,E do not have any voltage violations; therefore, "Volt-Var mode" is provided only as future reference. The suggested dead bandwidth is from 1.020 to 1.05 V p.u. (V_{Ref}=1.03) on 120V base.

The assumed inverter setting for both BESS solution is as followed:
Rating: 3000 kVA
Rated Real Power Max: 3000 kW
PF capable: -99.0 - +99.0
Maximum reactive power absorbed = 423 kVAR
Maximum reactive power injected = 423 kVAR

By using the Volt-Var mode, the power factor of the BESS can vary from leading 99% to lagging 99 % based on the circuit voltage condition. However, based on the current feeder condition, the BESS will be constantly running a unity power factor during the normal operation.

If there is any voltage disturbance that within 0.88 p.u. to 1.1 p.u., by enabling the volt-var mode of the inverter, the BESS can give the voltage support.

Following tables presents the load flow results with a lagging 99% & a leading 99% pf range which would be determined based on the circuit conditions.

VI. Voltage Change Analysis

A Voltage Change Analysis was performed to determine the instantaneous change in voltage (voltage change/flicker) that would occur in the distribution system upon sudden loss of the 4.0 MW project. IEEE 1547-2018 requires the voltage flicker at the POI given a 100% loss of the project must be "< / = 3%". Similarly, the voltage change at the line regulators and substation LTC must be less than or equal to half their bandwidths.

Assumption #1: BESS has a sudden output drop from 100% discharging to 0% discharging (3MW drop).

Table 11: Voltage change under assumption #1at Peak Load Condition with Unity PF for BESS #1 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	124.35	123.61	0.59%	124.55	123.82	0.59%	124.4	123.67	0.59%
Substation Bus (NSS)	124.1	124.06	0.04	124.11	124.07	0.038	124.11	124.07	0.04

Table 12: Voltage change under assumption #1at Peak Load Condition with Unity PF for BESS #1 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	122.31	122.06	0.20%	122.35	122.1	0.20%	122.34	122.09	0.20%
Substation Bus (Ind. Park)	122.32	122.21	0.11	122.34	122.23	0.11	122.33	122.22	0.11

Table 13: Voltage change under assumption #1at Peak Load Condition with Unity PF for BESS #2 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #2)	124.1	124.09	0.01%	124.1	124.09	0.01%	124.1	124.09	0.01%
Substation Bus (NSS)	124.1	124.09	0.01	124.1	124.09	0.01	124.1	124.09	0.01

Table 14: Voltage change under assumption #1at Peak Load Condition with Unity PF for BESS #2 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #2)	124.33	121.47	2.35%	124.34	121.47	2.36%	124.5	121.65	2.34%
Substation Bus (Ind. Park)	122.32	122.21	0.11	122.34	122.23	0.11	122.33	122.22	0.11

Table 15: Voltage change under assumption #1at Peak Load Condition with Unity PF for both BESS #1 & #2

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	124.35	123.61	0.59%	124.6	123.82	0.59%	124.4	123.7	0.59%
POI (BESS #2)	124.1	124.09	0.01%	124.1	124.09	0.01%	124.1	124.09	0.01%
Substation Bus (NSS)	124.1	124.09	0.001	124.1	124.09	0.01	124.1	124.09	0.01

Table 16: Voltage change under assumption #1at Peak Load Condition with Unity PF for both BESS #1 & #2

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	122.55	122.06	0.4%	122.59	122.1	0.4%	122.58	122.1	0.4%
POI (BESS #2)	124.57	121.47	2.6%	124.58	121.47	2.56%	124.74	121.7	2.54%
Substation Bus (Ind. Park)	122.43	122.21	0.2	122.45	122.23	0.22	122.4	122.2	0.22

Conclusion:

- **There is no voltage change violation detected under assumption #1 with various feeder configuration conditions.**
- **BESS # 2 under Industrial Plant case shows a max 2.6% flicker due to its distance from the source. The value can be mitigated with ramp rate limitation setting within the BESS inverter. No system upgrade is required.**

Assumption #2: BESS has a sudden output drop from 100% discharging to 100% charging.

Table 17: Voltage change under assumption #2 at Peak Load Condition with Unity PF for BESS #1 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	124.35	122.7	1.35%	124.6	122.91	1.33%	124.4	122.75	1.34%
Substation Bus (NSS)	124.1	124.01	0.08	124.11	124.024	0.08	124.11	124.02	0.08

Table 18: Voltage change under assumption #2 at Peak Load Condition with Unity PF for BESS #1 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	122.31	122.06	0.2%	122.35	122.1	0.2%	122.34	122.09	0.20%
Substation Bus (Ind. Park)	122.32	122.21	0.11	122.34	122.27	0.11	122.33	122.22	0.11

Table 19: Voltage change under assumption #2 at Peak Load Condition with Unity PF for BESS #2 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #2)	124.1	124.08	0.02%	124.1	124.08	0.02%	124.1	124.08	0.02%
Substation Bus (NSS)	124.1	124.08	0.02	124.1	124.08	0.02	124.1	124.08	0.02

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Table 20: Voltage change under assumption #2 at Peak Load Condition with Unity PF for BESS #2 only

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #2)	124.33	117.97	5.39%	124.3	117.95	5.4%	124.33	118.15	5.23%
Substation Bus (Ind. Park)	122.32	122.04	0.28	122.34	122.06	0.28	122.33	122.05	0.28

Table 21: Voltage change under assumption #2 at Peak Load Condition with Unity PF for both BESS #1 & #2

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	124.35	122.7	1.35%	124.6	122.91	1.3%	124.4	122.8	1.34%
POI (BESS #2)	124.1	124.08	0.02%	124.1	124.08	0.02%	124.1	124.08	0.02%
Substation Bus (NSS)	124.1	124.08	0.02	124.1	124.08	0.02	124.1	124.08	0.02

Table 22: Voltage change under assumption #2 at Peak Load Condition with Unity PF for both BESS #1 & #2

	Peak								
	Phase A [V]			Phase B [V]			Phase C [V]		
	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV	W/ BESS	W/o BESS	ΔV
POI (BESS #1)	122.55	121.34	0.99%	122.6	121.38	1.0%	122.6	121.4	1.0%
POI (BESS #2)	124.57	117.6	5.91%	124.58	117.6	5.94%	124.74	117.81	5.89%
Substation Bus (Ind. Park)	122.43	121.88	0.55	122.45	121.9	0.55	122.4	121.9	0.54

Conclusion:

There is voltage change violation detected (max 5.94%) at BESS #2 POI with Industrial Park feeder conditions under assumption #2 due to its distance from the source.

Mitigation: Limit the BESS #2 charging/discharging ramp rate to 1 MW/s.

VII. Short Current Analysis

A short circuit analysis was performed to determine the fault duty at various points and to identify any distribution protection equipment that exceeds its interrupting capability as a result of the project interconnection.

Below is a summary of the maximum fault levels on the 13.8 kV Silver Bay feeder.

Table 23. Short Current Analysis with BESS #1 only (Circuit fed from NSS)

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	2812	2782	2435	2642
ON	POI	2958	2928	2561	2789
Difference		5.20%	5.24%	5.20%	5.56%
OFF	Substation	3801	4113	3292	4197
ON	Substation	3944	4258	3416	4342
Difference		3.76%	3.53%	3.76%	3.46%

Table 24. Short Current Analysis with BESS #1 only (Circuit fed from Ind. Park, NSS disconnected)

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	3197	3200	2769	3164
ON	POI	3343	3346	2895	3310
Difference		4.55%	4.56%	4.55%	4.61%
OFF	Substation	3795	4107	3286	4191
ON	Substation	3939	4253	3411	4337
Difference		3.80%	3.56%	3.79%	3.49%

Table 25. Short Current Analysis with BESS #2 only (Circuit fed from NSS)

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	3791.042	4092.985	3282.957	4184.28
ON	POI	3936	4240.263	3408.534	4331.994
Difference		3.82%	3.60%	3.83%	3.53%
OFF	Substation	3802.159	4114.232	3292.572	4197.727
ON	Substation	3947.132	4261.695	3418.134	4345.489
Difference		3.81%	3.58%	3.81%	3.52%

Table 26. Short Current Analysis BESS #2 only (Circuit fed from Ind. Park, NSS disconnected)

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI	1784	1668	1544	1475
ON	POI	1927	1815	1669	1626
Difference		8.04%	8.80%	8.03%	10.25%
OFF	Substation	3795	4107	3286	4191
ON	Substation	3933	4247	3406	4331
Difference		3.66%	3.41%	3.66%	3.33%

Table 27. Short Current Analysis with BESS #1 & BESS #2 only (Circuit fed from NSS)

Project (Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI 1	2812	2782	2435	2642
ON	POI 1	2958	2928	2561	2789
Difference		5.19%	5.25%	5.17%	5.56%
OFF	Substation (NSS-277)	3801	4113	3292	4197
ON	Substation (NSS-277)	3944	4258	3416	4342
Difference		3.76%	3.53%	3.77%	3.45%
OFF	POI 2	3791	4093	3283	4184
ON	POI 2	3936	4240	3409	4332
Difference		3.82%	3.59%	3.84%	3.54%
OFF	Substation (NSS-271)	3802	4114	3293	4198
ON	Substation (NSS-271)	3947	4262	3418	4345
Difference		3.81%	3.60%	3.80%	3.50%

Table 28. Short Current Analysis BESS #1 & BESS #2 (Circuit fed from Ind. Park, NSS disconnected)

Project (BESS #1 and BESS #2 Status)		LLL (A)	LLG (A)	LL (A)	LG (A)
OFF	POI (BESS 1)	3197	3200	2769	3164
ON	POI (BESS 1)	3484	3485	3016	3448
Difference		8.96%	8.92%	8.95%	8.98%
OFF	POI (BESS 2)	1784	1668	1545	1475
ON	POI (BESS 2)	1969	1854	1705	1655
Difference		10.36%	11.15%	10.35%	12.23%
OFF	Substation	3795	4107	3286	4191
ON	Substation	4075	4391	3529	4474
Difference		7.40%	6.91%	7.40%	6.75%

Conclusion:

There are insignificant short current contributions at the BESS #1 POI due to the. There are significant short current contributions at the BESS # 2 POI due to the interconnection. However, the increase at the substation is still within the 10%, and the post interconnection short current levels are less than the short current interrupting ability of the protection devices. Therefore, no mitigation is proposed.

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VIII. Effective Grounding Analysis

Table 29. Effective grounding at POI BESS #1 only (Circuit fed from NSS)

Status	POI		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.379	1.173	1.019	1.71
With Project	0.371	1.163	1.035	1.72

Note: max value at PriOH426443

Table 30. Effective grounding at POI BESS #1 only (Circuit fed from Ind. Park, NSS disconnected)

Status	POI		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.198	1.028	1.149	1.9
With Project	0.201	1.027	1.17	1.95

Note: max value at PriOH1553526

Table 31. Effective grounding at POI BESS #2 only (Circuit fed from NSS)

Status	POI		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.051	0.724	1.132	1.617
With Project	0.056	0.731	1.132	1.617

Note: max value at PriOH1553526

Table 32. Effective grounding at POI BESS #2 only (Circuit fed from Ind. Park, NSS disconnected)

Status	POI		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.793	1.629	1.136	1.878
With Project	0.715	1.562	1.136	1.878

Note: max value at PriOH1553526

Table 33. Effective grounding at POI BESS #1 & BESS #2 (Circuit fed from NSS)

Status	POI (BESS #1 **NSS-277**)		POI (BESS #1 **NSS-271**)		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.379	1.173	0.051	0.724	1.11	1.59
With Projects	0.371	1.163	0.056	0.731	1.13	1.62

Note: max value at PriOH1553526

Table 34. Effective grounding at POI BESS #1 & BESS #2 (Circuit fed from Ind. Park, NSS disconnected)

Status	POI (BESS #1 **NSS-277**)		POI (BESS #1 **NSS-271**)		Maximum Values	
	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{R_0}{X_1}$	$\frac{X_0}{X_1}$
Without Project	0.198	1.028	0.793	1.629	1.149	1.9
With Projects	0.205	1.027	0.732	1.578	1.156	1.89

Note: max value at PriOH1553526

Conclusion:

- **There are no effective grounding issues at the POI with the interconnecting of the BESS.**
- **There are existing effective grounding issues around primary overhead** *PriOH1553526* **area which the R_0/X_1 is slightly over the IEEE limit (R_0/X_1 <1). Future mitigation may be required to improve the grounding conditions.**

IX. Protection Coordination

The scope of this study is to provide detailed analysis for the protection coordination on the interconnected substation and all the distribution circuits from it.

Table 35. Proposed POI Protection Equipment for Both Option 1 & Option 2

POI Switch	Primary Breaker	Primary Relay
Lockable, Group-Operated Air Break (GOAB) Disconnect Switch Readily Accessible to the Utility at All Times Blade visibility not specified	KYLE NOVA	SEL-651R

Table 36. Shall Trip Abnormal Conditions (BESS) for Both Option 1 & Option 2

Shall Trip – Inverter Based DER – Abnormal Voltage			Shall Trip – Inverter Based DER – Abnormal Frequency		
Shall Trip Function	Clearing Time (s)	Volage Nominal	Shall Trip Function	Clearing Time (s)	Frequency (Hz)
UV2	0.16	0.50	UF1	0.16	59.3
UV1	2.0	0.88	OF1	0.16	61.2
OV1	1.0	1.10			
OV2	0.16	1.20			

Table 37. Required Settings of the POI recloser for both BESS

Device	Model	TYPE/Function	Pick Up	TD	Curve	Reclosing Scheme	Directional Control	Harmonic Blocking
POI Recloser [BESS]	SEL-651R with NOVA-STS. 13.8 kV	SEL 651R 51P	**170**	**1.0**	**U3**	Enabled	Disabled	Enabled
		SEL 651R 51G	**120**	**1.0**	**U3**			

Note: The setting is recommended based on the BESS size, the final setting would be determined by Minnesota Power based on the upstream breaker setting and protections devices downstream.

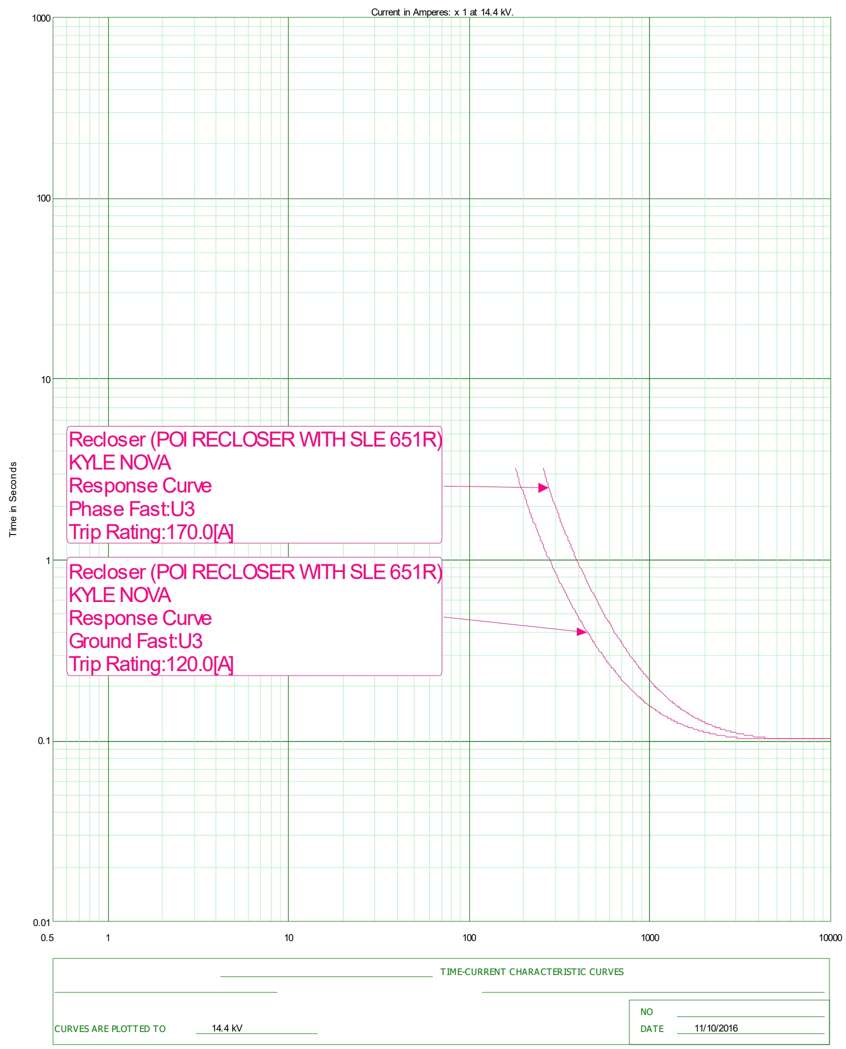

Figure 8. POI recloser TCC curves

X. Reliability Analysis

Reliability Improvement with NWA Solution #1 (BESS #1 on NSS – 277)

Based on Figure 3, after the proposed NWA solution – BESS, the main goal that customers at Silver Bay Feeder can have a backup source is achieved.

Table below summarizes the reliability improvement before and after the NWA solution #1.

Table 38. Reliability improvement with NWA solution #1

Fault Location	NSS feeder back up Ability	
	Before NWA	After NWA
13.8 kV Source (NSS – 277)	1. NSS – 271 2. Industrial Plant	1. NSS – 271 2. Industrial Plant 3. BESS #1
Between IR – 2 & IR - 8	1. NSS – 271 2. Industrial Plant	1. NSS – 271 2. Industrial Plant 3. BESS #1

Sequence events example for a permanent fault at the node N1 in Figure 3.

1. Recloser 277F senses the fault and opens
2. BESS recloser R opens due to the loss of the source with anti-islanding feature
3. Recloser 277F reclose and re-open due to the permanent fault and Feeder NSS 277 experiences the outage.
4. System operator can disconnect the switch IR-8 to isolate the fault
5. System operator remote control BESS recloser R to switch to islanding protection mode and close
6. BESS feeding Silver Bay Feeder NSS - 277
7. End of sequence

Reliability Improvement with NWA Solution #2 (BESS #2 on NSS – 271)

Table 39. Reliability improvement with NWA solution #2

Fault Location	NSS feeder back up Ability	
	Before NWA	After NWA
13.8 kV Source (NSS – 271)	1. NSS – 277 2. Industrial Plant	1. NSS – 277 2. Industrial Plant 3. BESS #2

Sequence events example for a permanent fault at the 13.8 kV source in Figure 4.

1. Recloser 271F open

2. BESS #2 recloser R open due to the loss of the source with anti-islanding feature
3. Remote control BESS reclosers R to switch to islanding protection mode and close
4. BESS #2 feeding Silver Bay NSS - 271
5. End of sequence

XI. Islanding Analysis

The islanding detection function for BESS inverter is activated by default according to UL 1741, US Rule 21.

The islanding detection function from BESS inverter detects the formation of unwanted electrical islands and disconnects the inverter from the utility grid. Unwanted islanding can occur when at the time of utility grid failure, the load in the shut-down sub-grid is roughly equivalent to the current feed-in power of the PV system or battery storage system. With active islanding detection, the inverter continuously checks the stability of the utility grid. If the utility grid is intact, this has no impact on the utility grid and the inverter continues to feed in. Only if an unwanted electrical island has formed will the inverter disconnect from the utility grid.

In order to allow BESS to support the local EPS while the grid is off-line, Minnesota Power may need to perform a time domain simulation in PSCAD, RSCAD or MATLAB with a provided inverter model from the manufacturer. Following simulations, tests would be required before allowing an intentional islanding:

- Load Rejection Overvoltage Analysis
- Ground Fault Overvoltage Analysis
- Islanding Evaluation in targe EPS
- Underfrequency Load Shed Impact Assessment
- Protection Coordination for Islanding Mode and Validating with Real Time Digital Simulator (RTDS)

XII. Appendix

A. NSS Feeder SLD

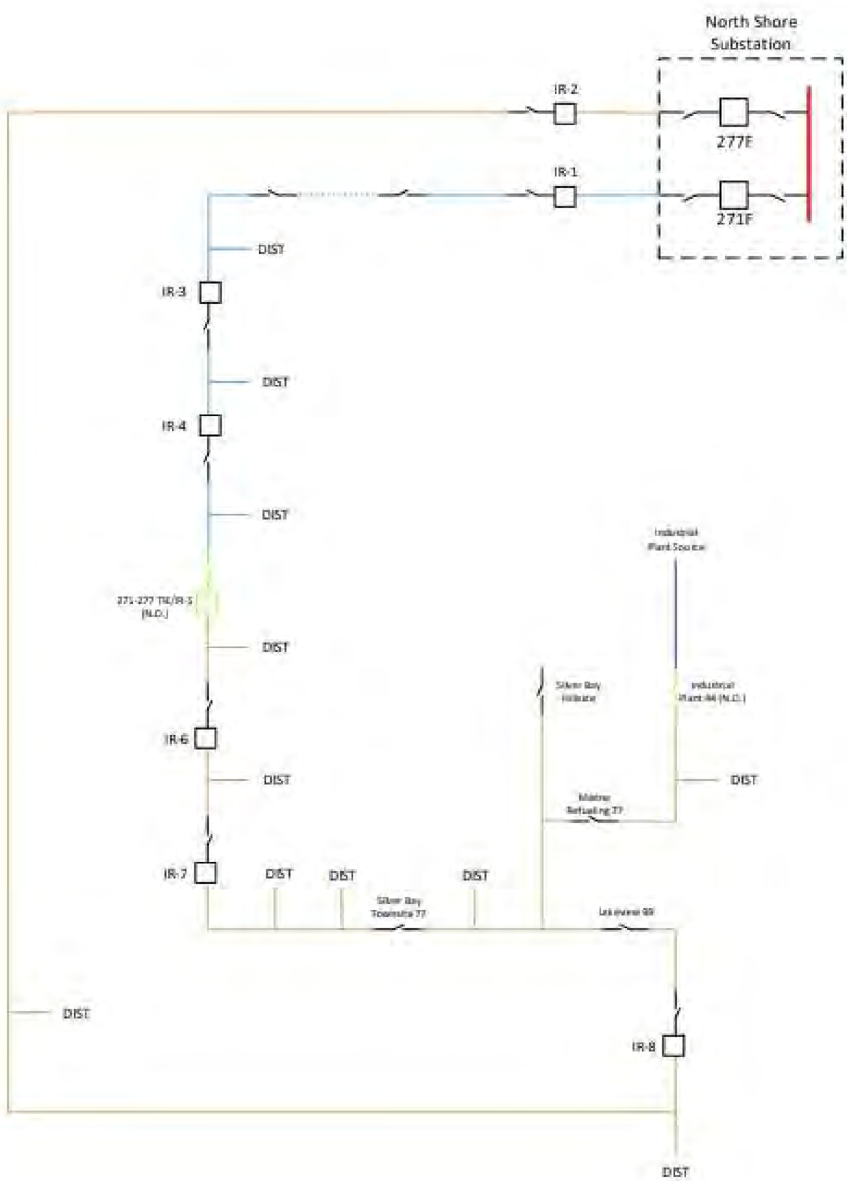

Figure 9. NSS SLD.

B. Volt-Var Settings

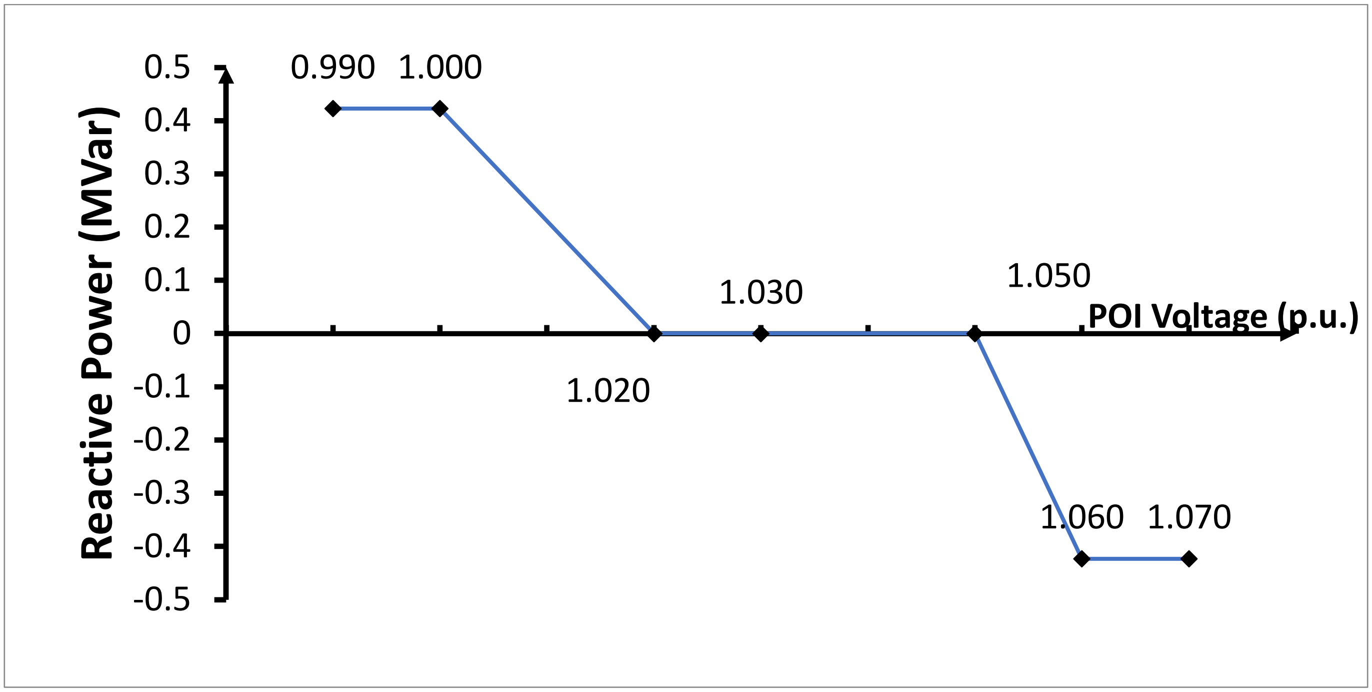

Figure 10. Volt-Var Settings for BESS#1 & BESS #2 Feeder

C. Load flow results with Capacitors as "Initially Off"

Note: The load flow results in this section are for reference only as they are not the worst-case scenario.

Table 40. Load Flow results for Discharging/Charging of BESS at PriOH327740 (NSS-277) with reference to Table 8

BESS#1 Scenario C'	Feeder Configuration	Site Operation	Load Flow at POI	Load Flow at NSS-277	Load Flow at NSS-271	Industrial Park
Peak	NSS normal, no Industrial Park	Discharging	-2983 kW 165 kVAR 124.3 V	-1384 kW 482 kVAR 124.1 V	1119 kW 225 kVAR 124.1 V	N/A

Peak		Charging	3063 kW 179 kVAR 122.7 V	4697 kW 552 kVAR 124.09 V	1119 kW 225 kVAR 124.1 V	N/A
Off Peak		Discharging	-2983 kW 165 kVAR 124.6 V	-2243 kW 153 kVAR 124.1 V	517 kW 97 kVAR 124.1 V	N/A
Off Peak		Charging	3069 kW 179 kVAR 122.98 V	3826 kW 356 kVAR 124.1 V	517 kW 97 kVAR 124.1 V	N/A
Peak	NSS IR-1 & IR-2 open, IR-5 lose, Industrial Park close	Discharging	-2982 kW 171 kVAR 122.2 V	N/A	N/A	-269 kW 725 kVAR 122.33 V
Peak		Charging	3035 kW 179 kVAR 121.6 V	N/A	N/A	5774 kW 796 kVAR 122.3 V
Off Peak		Discharging	-2983 kW 171 kVAR 122.4 V	N/A	N/A	-1737 kW 417 kVAR 122.3 V
Off Peak		Charging	3040 kW 179 kVAR 121.8 V	N/A	N/A	4279 kW 455 kVAR 122.3 V

Table 41. Load Flow results for Discharging/Charging of BESS at UG4676 (NSS-271) with reference to Table 9

BESS#1 Scenario D'	Feeder Configuration	Site Operation	Load Flow at POI	Load Flow at NSS-277	Load Flow at NSS-271	Industrial Park
Peak	NSS normal, no Industrial Park	Discharging	-2983 kW 166 kVAR 124.1 V	-1856 kW -87 kVAR 124.1 V	1596 kW 154 kVAR 124.1 V	N/A
Peak		Charging	3097 kW 179 kVAR 124.1 V	4225 kW -73 kVAR 124.1 V	1596 kW 154 kVAR 124.09 V	N/A
Off Peak		Discharging	-2983 kW 166 kVAR 124.09 V	-2467 kW 263 kVAR 124.09 V	728 kW 133 kVAR 124.09 V	N/A
Off Peak		Charging	3097 kW 179 kVAR 124.08 V	3614 kW 276 kVAR 124.09 V	728 kW 133 kVAR 124.09 V	N/A
Peak	NSS IR-1 & IR-2 open, IR-5 lose,	Discharging	-2983 kW 165 kVAR 124.4 V	N/A	N/A	-233 kW 738 kVAR 122.3 V

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Peak	Industrial Park close	Charging	2935 kW 179 kVAR 117.6 V	N/A	N/A	5797 kW 314 kVAR 122.3 V
Off Peak		Discharging	-2983 kW 165 kVAR 124.6 V	N/A	N/A	-1685 kW 453 kVAR 122.3 V
Off Peak		Charging	2952 kW 179 kVAR 118.3 V	N/A	N/A	4296 kW 550 kVAR 122.3 V

Table 42: Load Flow results for Discharging/Charging of with both BESS #1 & BESS #2 with reference to Table 10

Scenario E'	Feeder Configuration	Site Operation	Load Flow at POI 1	Load Flow at POI 2	Load Flow at NSS-271	Load Flow at NSS-277	Industrial Park
Peak	NSS normal, no Industrial Park	Discharging	-2983 kW 165 kVAR 124 V	-2983 kW 166 kVAR 124.1 V	-1864 kW 392 kVAR 124.09 V	-1384 kW 482 kVAR 124.1 V	N/A
Peak		Charging	3063 kW 179 kVAR 122.7 V	3097 kW 179.195 kVAR 124.076 V	4216 kW 405 kVAR 124.09 V	4697 kW 552 kVAR 124.09 V	N/A
Off Peak		Discharging	-2983 kW 164.9 kVAR 124.61 V	-2983 kW 166 kVAR 124.1 V	-2467 kW 263 kVAR 124.1 V	-2243 kW 315 kVAR 124.09 V	N/A
Off Peak		Charging	3069 kW 179 kVAR 123 V	3097 kW 179 kVAR 124.09 V	3614 kW 276 kVAR 124.09 V	3826 kW 356 kVAR 124.09 V	N/A
Peak	NSS IR-1 & IR-2 open, IR-5 close, Industrial Park close	Discharging	-2983 kW 171 kVAR 122.4 V	-2983 kW 166 kVAR 124.2 V	N/A	N/A	-3207 kW 927 kVAR 122.3 V
Peak		Charging	3025 kW 179 kVAR 121.2 V	2926 kW 179 kVAR 117.3 V	N/A	N/A	8832 kW 1184 kVAR 122.3 V
Off Peak		Discharging	-2983 kW 170 kVAR 122.6 V	-2983 kW 164 kVAR 124.8 V	N/A	N/A	-4653 kW 658 kVAR 122.3 V
Off Peak		Charging	3031 kW 179 kVAR 121.6 V	2943 kW 179 kVAR 117.95 V	N/A	N/A	7346 kW 797 kVAR 122.3 V

D. Base Model Loading Status

Table 43: Loading condition for NSS – 277 Base model before NWA

From	To	Cables	Overhead Lines	Max Loading under normal configuration				Min. Conductor Ampacity
				Amps	KW	KVAR	KVA	
NSS-277	N1	500 Cu 15 kv 1/3 N (One Section)		65	1596.01	313.372	1626.48	518 Amps
N1	N4	1/0 Al 15 kv 1/3 N (Three sections)	#1/0 ACSR 6/1 (Seventeen Sections, #3/0 ACSR 6/1 (Two Sections)	10.509	254.819	50.074	259.69	228 Amps
N4	Downstream	1/0 Al 15 kv 1/3 N (Three Sections), 750 Al 15 kv 1/3 N (One Section)	#1/0 ACSR 6/1 (Twenty-Six Sections), #2 ACSR 6/1 (One Section), #2/0 QUAD (Two Section)	10.48	253.846	50.611	258.84	228 Amps
N1	N2	1/0 Al 15 kv 1/3 N (Two Sections)	#1/0 ACSR 6/1 (Five Sections), #2/0 QUAD (Four Sections), #3/0 ACSR 6/1 (Twenty-One Sections), #4/0 QUAD (One Section), 336 MCM ACSR 18/1 (Three Sections)	55.342	1340.709	269.478	1367.52	228 Amps
N2	N5		336 MCM ACSR 18/1 (Ten Sections)	1.249	30.53	-2.597	30.64	500 Amps
N5	N6	1/0 Al 15 kv 1/3 N (Five Sections)	#2 ACSR 6/1 (Twenty-Nine Sections)	1.179	28.834	-2.488	28.94	180 Amps
N2	N3	3/0 Al 15 kv 1/3 N (Two Sections)	#1/0 ACSR 6/1 (One Section), #3/0 ACSR 6/1 (Three Sections), 336	48.916	1179.967	241.459	1204.42	230 Amps

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			MCM ACSR 18/1 (Fifteen Sections)					
N3	N8		#3/0 ACSR 6/1 (Three Sections)	44.188	1064.889	215.918	1086.56	300 Amps
N8	N9		#3/0 ACSR 6/1 (Ten Sections)	2.493	60.186	11.206	61.22	300 Amps
N8	N10		#1/0 ACSR 6/1 (Four Sections), #4 ACSR 6/1 (Eighteen Sections)	17.815	430.369	81.22	437.97	230 Amps
N8	N11		#1/0 ACSR 6/1 (Thirteen Sections), #3/0 ACSR 6/1 (Nineteen Sections)	23.885	574.057	123.183	587.12	230 Amps
N3	N7		Two Phase Lines Downstream	1.858	29.942	5.451	30.43	

Table 44: Loading condition for NSS – 271 Base model before NWA

From	To	Cables	Overhead Lines	Max Loading under normal configuration				Min. Conductor Ampacity
NSS-271	N1	500 Cu 15 kv 1/3 N (Two Sections Near to SS)	#2 ACSR 6/1 (Nine Sections)	46.522	1127.5	225.403	1149.81	180 Amps
N1	N2		#2 ACSR 6/1 (Ten Sections)	23.811	906.002	202.771	928.42	180 Amps
N2	N3	750 Al 15 kv 1/3 N (One Section), 500 Cu 15 kv 1/3 N (One Section), 1/0 Al 15 kv 1/3 N (Three Sections)		5.713	137.381	29.474	140.51	228 Amps
N2	N4		#1/0 ACSR 6/1 (Twenty-Four Sections), #2 ACSR 6/1 (Four Section), #3/0 ACSR 6/1 (Fifteen Sections), #2/0	10.576	253.419	58.42	260.07	230 Amps

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			QUAD (Two Sections)					
N4	Downstream		#1/0 ACSR 6/1 (Six Sections), #4/0 QUAD (One Section), 636 MCM ACSR 26/7 (Two Sections)	9.561	229.199	52.245	235.08	230 Amps
N1	N5		#1/0 ACSR 6/1 (One Section), #2 ACSR 6/1 (Thirty-Five Sections)	5.378	131.001	14.397	131.79	180 Amps

Cloquet Area Analysis

Final Report

Prepared by:

Black & Veatch
and
K&A Engineering Consulting, P.C.

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Revision History

Rev.	Date	Revised By	Updates
1	8/15/2023	G.C.	Final Report Submitted

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Abbreviations

MNP	:	Minnesota Power
BESS	:	Battery Energy Storage System
CLQ	:	Cloquet 115/13.8 kV Substation
CQN	:	Cloquet North 34.5/13.8 kV Stepdown
CQS	:	Cloquet South 34.5/13.8 kV Stepdown
CQE	:	Cloquet East 34.5/13.8 kV Stepdown
CNA	:	Canosia Road 115/13.8 kV Substation
TMS	:	Thompson 115/13.8 kV Substation
MAT	:	Mahtowa 115/13.8 kV Substation
FDR	:	Feeder
IEEE	:	Institute of Electrical and Electronics Engineers
UL	:	Underwriters Laboratories
SW	:	Switch
Al	:	Aluminum
ACSR	:	Aluminum Conductor Steel Reinforced
MCM	:	Thousand Circular Mils
kV	:	Kilovolt
V	:	Volt
Ph	:	Phase
kVAR	:	Kilo-Volt-Amperes Reactive Power
SUB	:	Substation
N.O.	:	Normally Open
FLISR	:	Fault Location, Isolation, and Service Restoration

1. Executive Summary

This study performed Load Flow and Voltage Analysis on the area supplied from Cloquet, Canosia Road Mahtowa, and Thompson Substations. The study identified thermal violations and voltage violations considering the existing normal and contingency conditions. Accordingly, suitable mitigation methods including reconductoring, rephasing, and installation or relocation of capacitor banks or regulators were considered to resolve the violations. Several combinations were tried and finally, the most cost-effective mitigation method was chosen.

Following the normal conditions, a similar analysis was conducted for loss of source conditions. In this loss of source scenarios, the source of the feeder is disconnected, and adjacent feeder as selected by Minnesota Power (MNP) is chosen to supply customers of the disconnected feeder. This analysis is performed considering the mitigation proposed in contingency scenario analysis. Similar to the normal scenario, thermal violations and voltage violations were identified. Mitigations proposed include various combinations of reconductoring, rephasing, and installation or relocation of capacitor banks or regulators.

Finally, a FLISR analysis is performed to identify the areas where a bulk number of customers are not protected and where there are more customers being affected due to faults happening on the feeder. Based on the customer count, the Reclosers and Sectionalizers at various locations of the feeder are suggested to further enhance the reliability of the system under both normal and contingency scenarios.

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2. Introduction

The purpose of this study is to evaluate the performance of the Cloquet area distribution system under system normal and loss of source conditions. This assessment will evaluate the 13.8 kV system supplied by Cloquet substation, as well as adjacent feeders, and step-downs, connected to the Canosia Road, Mahtowa, and Thompson Substation.

The Cloquet Area Substation consists of ten feeders, having feeders out the Canosia Road, Mahtowa, and Thompson Substations acting as the *contingency feeders*.

Future peak feeder loading will be considered for voltage and power flow performance in all scenarios of this study, where viable and optimum solutions to maintain the sound and safe operation of the system will be identified.

The study will assess traditional solutions, such as addition of new Capacitor Banks, Bi-Directional voltage-Regulators, rephasing, and reconductoring of existing conductors. *Note: Per suggestion from MNP, Non-Wire Alternatives solutions such as installation of BESS Units, were not considered.*

The scope of this study is as follows:

1. Evaluate normal configuration with models provided by MNP.
    a) Evaluate the voltage and thermal violations (as seen in the provided models).
    b) Propose mitigations for voltage and thermal violation, to enhance the power quality and reliability.
2. Model and evaluate loss of CLQ-404 Source; Served from CQN feeder.
    a) Evaluate the voltage and thermal violations.
    b) Propose mitigations for voltage and thermal violations.
3. Model and evaluate loss of CLQ-406 Source; Served from CQS-416 FDR
    a) Close 406-416 Tie Switch
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violations.
4. Model and evaluate loss of CLQ-409 Source; Served from CNA-403 FDR
    a) Close 403-409 Tie Switch
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violation.
5. Model and evaluate loss of CLQ-410 Source; Served from CNA-405 FDR
    a) Close 405-410 Tie Switch
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violations.
6. Model and evaluate loss of CLQ-412 Source; Served from CQE-417 FDR
    a) Close 412-417 Tie Switch
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violations.
7. Model and evaluate loss of CNA-403 FDR; Served from CLQ-409 FDR
    a) Close 403-409 Tie Switch
    b) Evaluate the voltage and thermal violations.

c) Propose mitigations for voltage and thermal violations.

8. Model and evaluate loss of CNA-405 FDR; Served from CLQ-410 FDR
    a) Close 405-410 Tie Switch
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violations.
9. Model and evaluate loss of TMS-412 FDR; Served from CQE-417 FDR
    a) Close 412-417 Switch Carlton Switch
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violations.
10. Model and evaluate loss of Cloquet East 34.5/13.8 kV Stepdown; CQE-417 FDR Served from CLQ-412 FDR
    a) Open 417 Recloser; Close 412-417 FDR
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violations.
11. Model and evaluate loss of Cloquet South 34.5/13.8 kV Stepdown; CQS-416 FDR served from CLQ-406 FDR
    a) Open CQS-416 Recloser; Close 412-417 FDR
    b) Evaluate the voltage and thermal violations.
    c) Propose mitigations for voltage and thermal violations.
12. Model and evaluate loss of CNA-421 Source; Served from MAT-420 FDR
    a) Evaluate the voltage and thermal violations.
    b) Propose mitigations for voltage and thermal violations.
13. Model and evaluate loss of MAT-420 Source; Served from CNA-421 FDR
    a) Evaluate the voltage and thermal violations.
    b) Propose mitigations for voltage and thermal violations.

The study area and approximate substation locations are shown in the figure below.

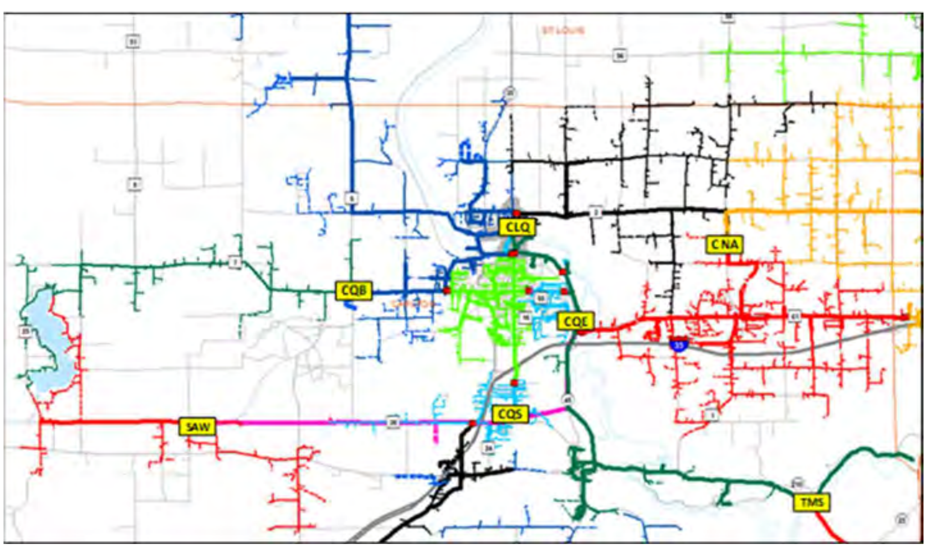

Figure 2-1: Cloquet Area Overview

3. Assumptions

The study was conducted in accordance with the Minnesota Power Technical Specifications Manual (TSM) [Ver 1.1 05-01-2020], standards, study guidelines, procedures, and practices, as well as IEEE 1547-2018, IEEE 1453-2015, UL 1741.

It is assumed that Minnesota Power will conduct further studies investigating the possible impacts of the identified and applied upgrades and updates at the transmission level, to ensure adequate operation of the system.

Also, it is assumed that the regulators and reclosers existing in the circuit are capable of bidirectional power flow, which might occur during contingency scenarios. Additionally, as per the MNP direction, the circuit voltage must remain between 114 V and 126 V on the primary side of the feeder. Therefore, any undervoltage or over-voltage seen on the secondary side of the feeder is ignored.

4. Analysis

The following analyses were performed in this study:

- Load-Flow (under various feeder configurations) for the following loading conditions:
  - Peak Load
  - Off-Peak Load
- Voltage Impact during the following:
  - Steady State Voltage Analysis

5. Voltage Drop Analysis – Normal Configuration

Voltage Drop Analysis was performed to assess the status of voltage and thermal loading on the provided circuit. According to Minnesota Power directions, the circuit voltage at the substation must remain in the range of 114 to 126 volts to maintain an adequate voltage on circuit under all anticipated load conditions regardless of generation operation. All provided feeders were analyzed and evaluated for any pre-existing undervoltage and thermal overloading. Sections below discuss the voltage values for Peak and off-peak conditions.

a. Feeder CBCLQ-404

The analysis found that there are no pre-existing undervoltage and thermal violations present in feeder CBCLQ-404. Figure 5-1 shows the simulation results of the voltage drop analysis.

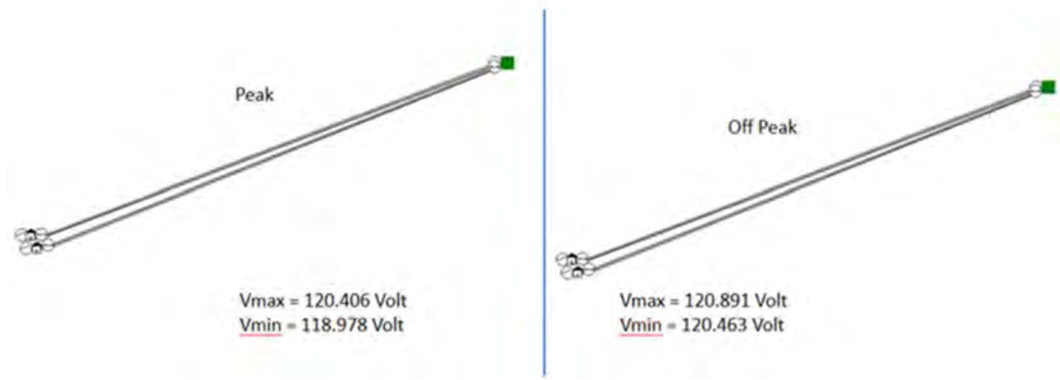

Figure 5-1: Load flow Analysis of feeder CBCLQ-404, existing condition

b. Feeder CBCLQ-406

The analysis found that there are pre-existing undervoltage present in feeder CBCLQ-406 (Vmin = 109.76 V at section PriUG1087698). Figure 5-2 shows the simulation results of the voltage drop analysis.

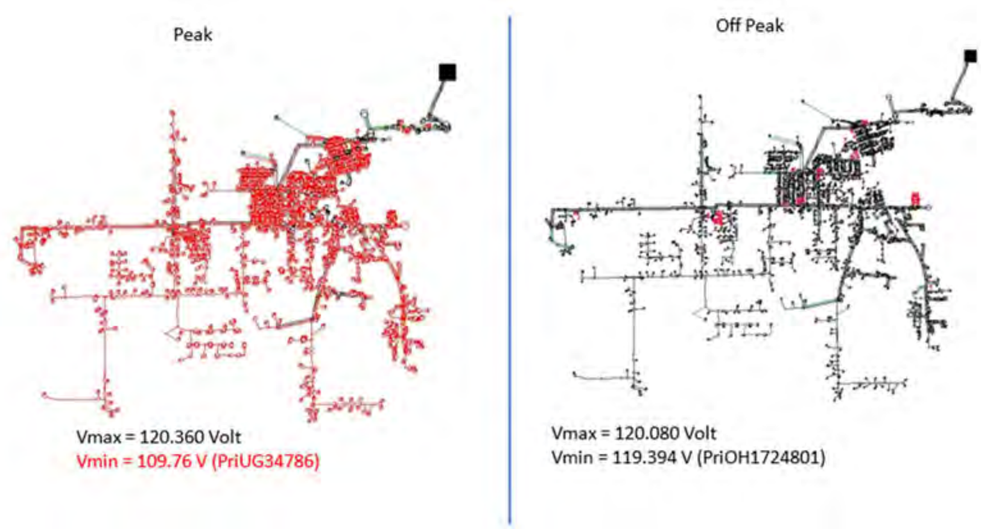

Figure 5-2: Load flow Analysis of feeder CBCLQ-406, existing condition

Different mitigation methods were tried and the below-mentioned mitigation was found to be the most effective one.

- Change PriOH1458470 and downstream from phase B to phase C.
- Add 900 kVAR 3 ph Capbank (On Set; 117 V, Off Set: 126 V, Control phase: A) downstream of PriOH332214.

The below results show with the above mitigation applied.

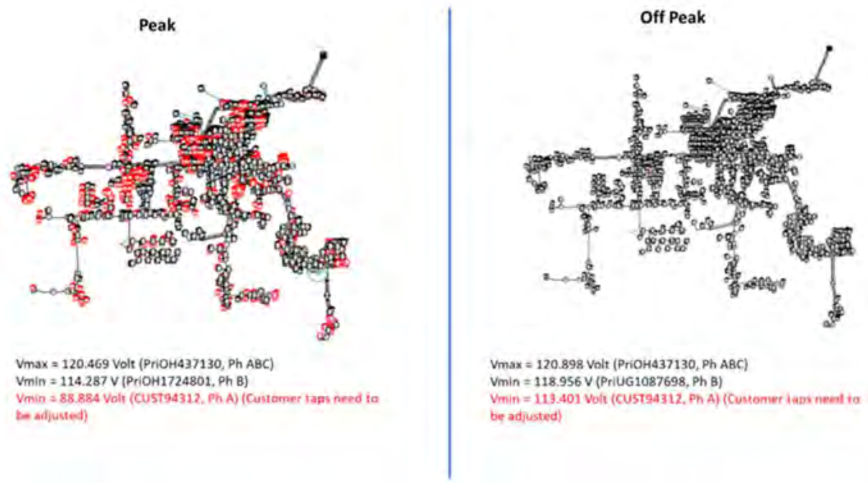

Figure 5-3: Load flow Analysis of feeder CBCLQ-406, after mitigation

Figure 5-3 (above) shows that, with the above mitigation applied, the voltage values are within the limits.

c. Feeder CBCLQ-409

The analysis found that there are pre-existing undervoltage present in feeder CBCLQ-409 (Vmin = 110.075 V at section PriUG41718). Figure 5-4 shows the simulation results of the voltage drop analysis.

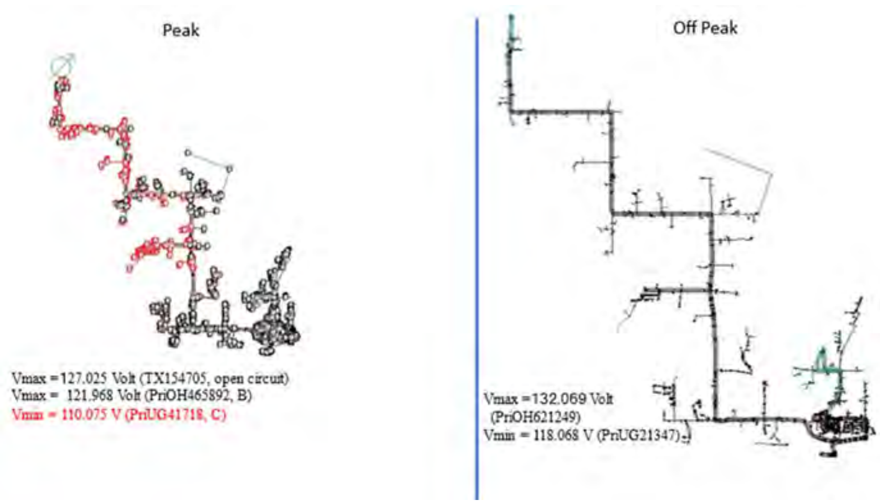

Figure 5-4: Load flow Analysis of feeder CBCLQ-409, existing condition

Different mitigation methods were tried and the below-mentioned mitigation was found to be the most effective one.

- Rephase the existing 1Ph A overhead conductor from downstream of PriOH320872 to Ph B
- Rephase the existing 1Ph C Underground conductor from downstream of PriUG40299 to Ph B

Figure 5-5 (below) shows results considering the above mitigation applied.

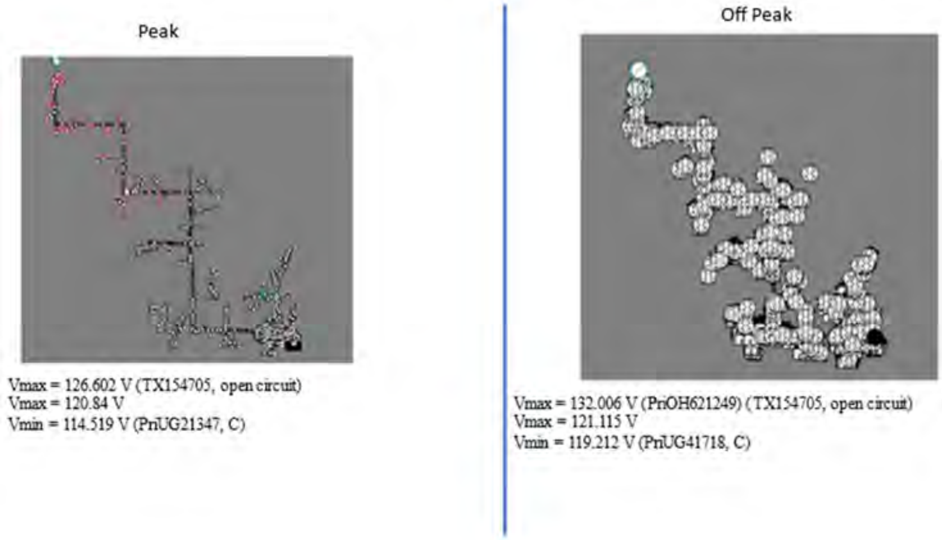

Figure 5-5: Load flow Analysis of feeder CBCLQ-409, after mitigation

Figure 5-5 shows that the voltage values are within the limits.

d. Feeder CBCLQ-410

The analysis found that there are no pre-existing undervoltage and thermal violations present in feeder CBCLQ-410. Figure 5-6 shows the simulation results of the voltage drop analysis.

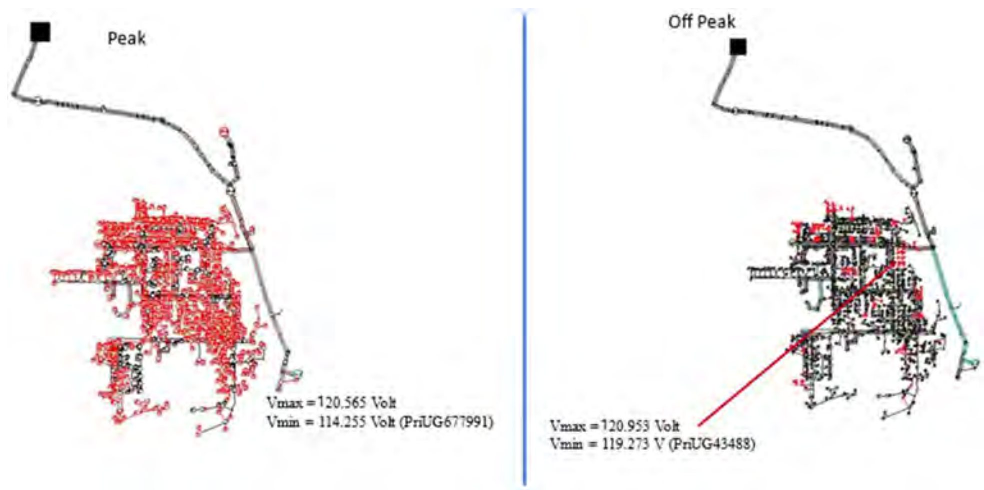

Figure 5-6: Load flow Analysis of feeder CBCLQ-410, existing condition

e. Feeder CBCLQ-412

The analysis found that there are no pre-existing undervoltage and thermal violations present in feeder CBCLQ-412. Figure 5-7 shows the simulation results of the voltage drop analysis.

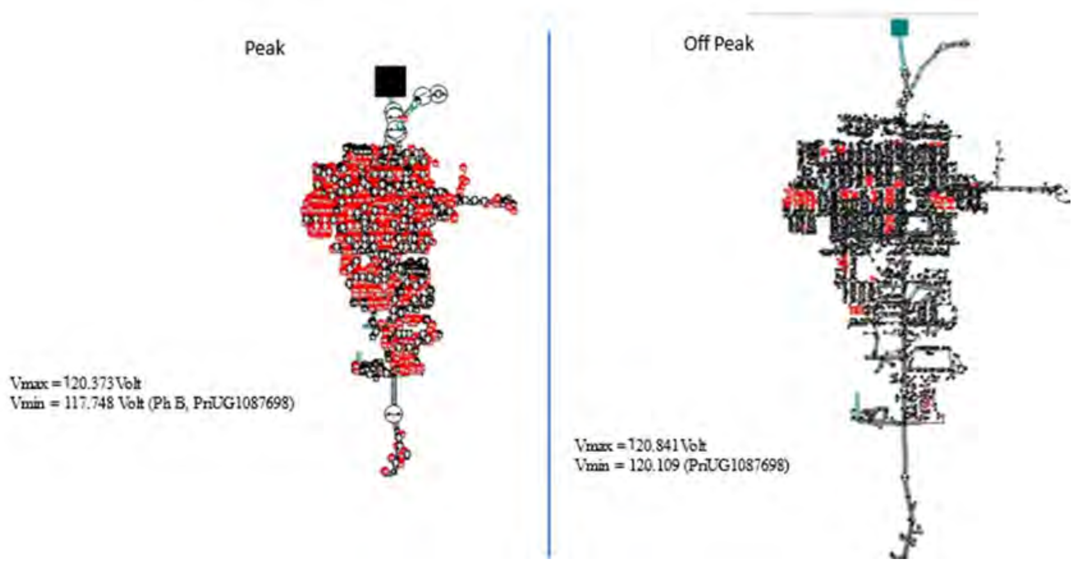

Figure 5-7: Load flow Analysis of feeder CBCLQ-412, existing condition

f. Feeder CBCNA-403

The analysis found that there are pre-existing undervoltage present in feeder CBCNA-403 (Vmin = 103.287 V at section PriOH354602). Figure 5-8 shows the simulation results of the voltage drop analysis.

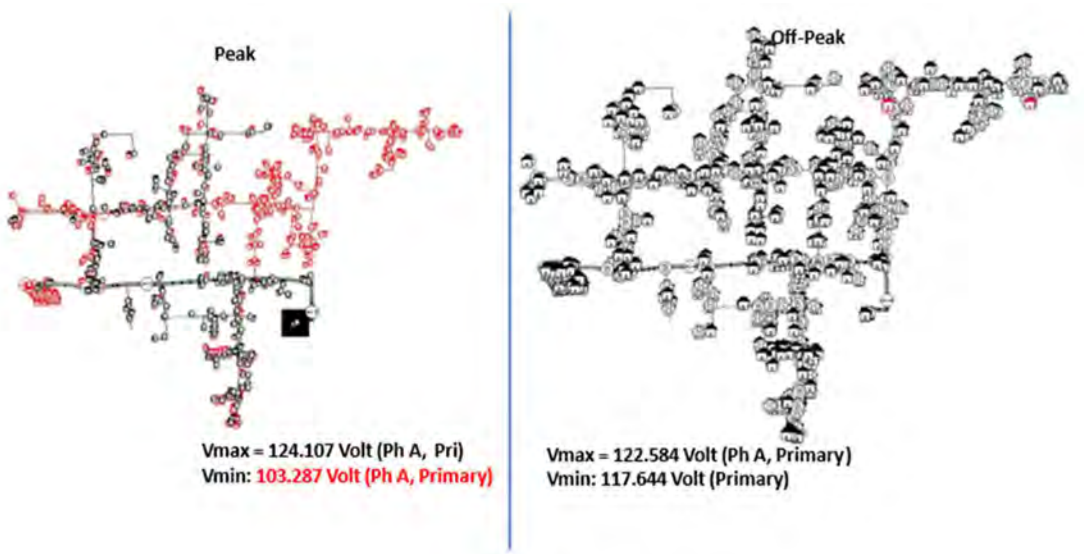

Figure 5-8: Load flow Analysis of feeder CBCNA-403, existing condition

Different mitigation methods were tried and the below-mentioned mitigation was found to be the most effective one.

- From PriOH416914 downstream to the end of the line, change phase BC to AC
- From PriOH416830 downstream to the end of the line, change all phase C to B
- From PriUG42555 downstream to the end of the line, change all phase C to B
- From PriOH386972 downstream to the end of the line, change all phase A to C
- From PriOH386967 downstream to the end of the line, change all phase A to C
- From PriUG43071 downstream to the end of the line, change all phase A to C
- From PriUG780208 downstream to the end of the line, change all phase A to B
- From PriOH416538 downstream to the end of the line, change phase A to B and keep phase C as it is.
- From PriOH386643 downstream to the end of the line, change phase A to B
- Add single phase regulator downstream of PriOH386601.

Figure 5-9 (below) shows results considering the above mitigation applied.

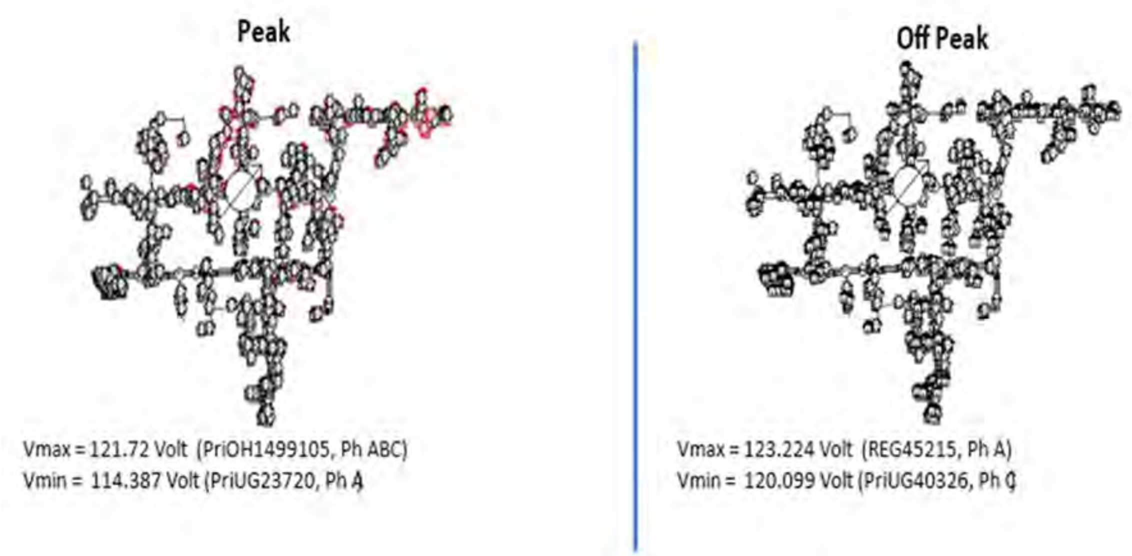

Figure 5-9: Load flow Analysis of feeder CBCNA-403, after mitigation

Figure 5-9 shows that the voltage values are within the limits.

g. Feeder CBCNA-405

The analysis found that there are no pre-existing undervoltage and thermal violations present in feeder CBCNA-405. Figure 5-10 shows the simulation results of the voltage drop analysis.

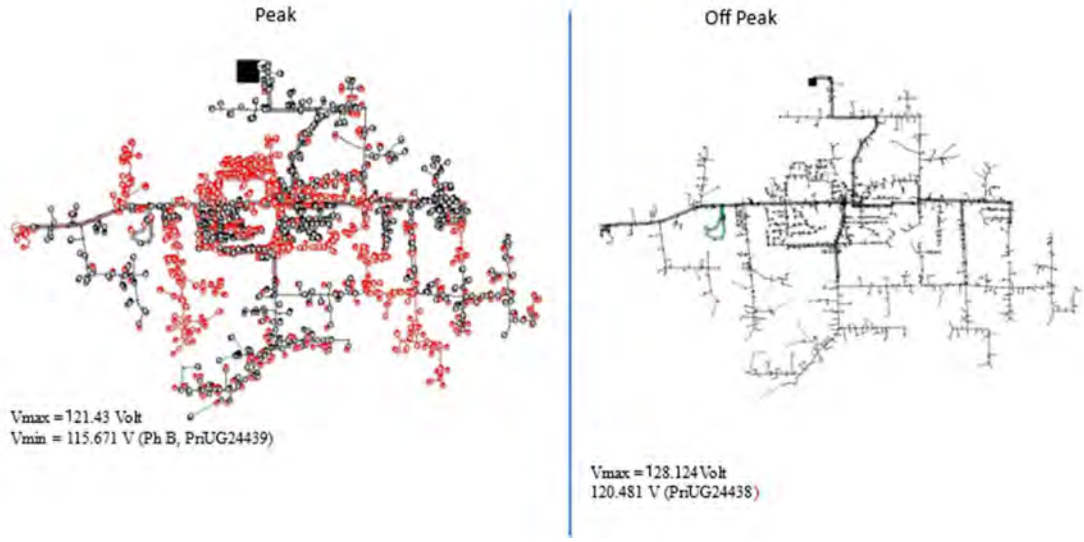

Figure 5-10: Load flow Analysis of feeder CBCNA-405, existing condition

h. Feeder CBMAT-420

The analysis found that there are pre-existing undervoltage present in feeder CBMAT-420 (Vmin = 107.764 V at section PriUG109627). Figure 5-11 shows the simulation results of the voltage drop analysis.

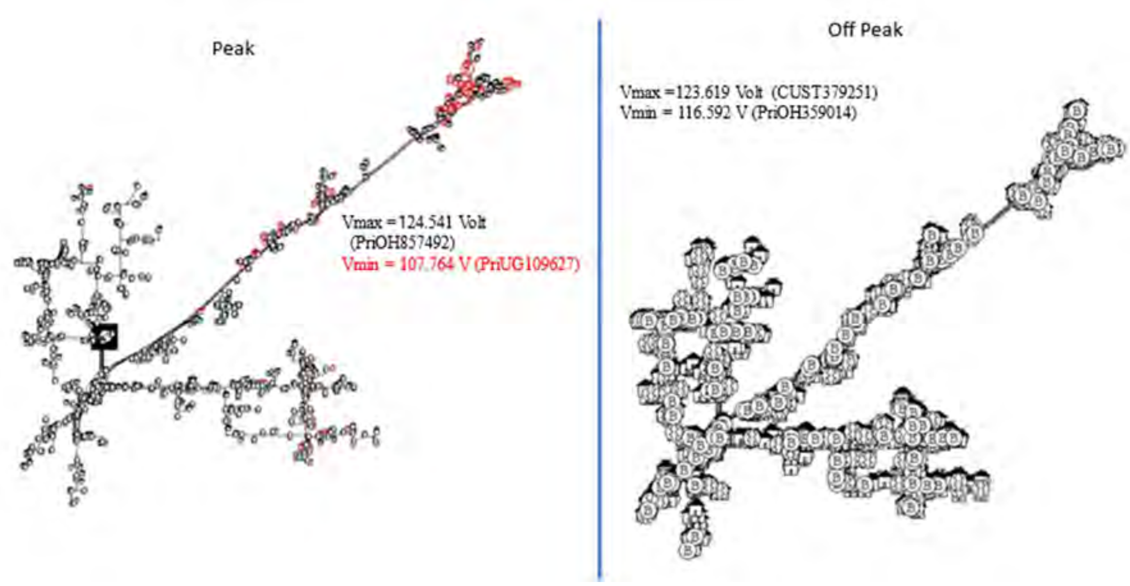

Figure 5-11: Load flow Analysis of feeder CBMAT-420, existing condition

Different mitigation methods were tried, and the below-mentioned mitigation was found to be the most effective one.

- Change CUST96494 to 3ph Load.

Figure 5-12 show results with the above mitigation applied.

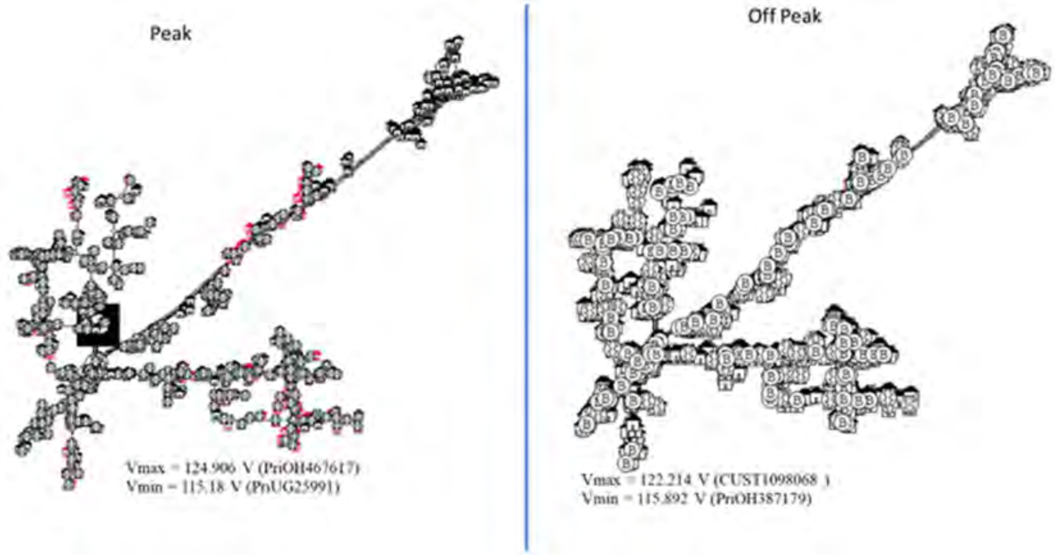

Figure 5-12: Load flow Analysis of feeder CBMAT-420, after mitigation

Figure 5-12 shows that the voltage values are within the limits.

i. Feeder CBTMS-412

The analysis found that there are no pre-existing undervoltage and thermal violations present in feeder CBTMS-412. Figure 5-13 shows the simulation results of the voltage drop analysis.

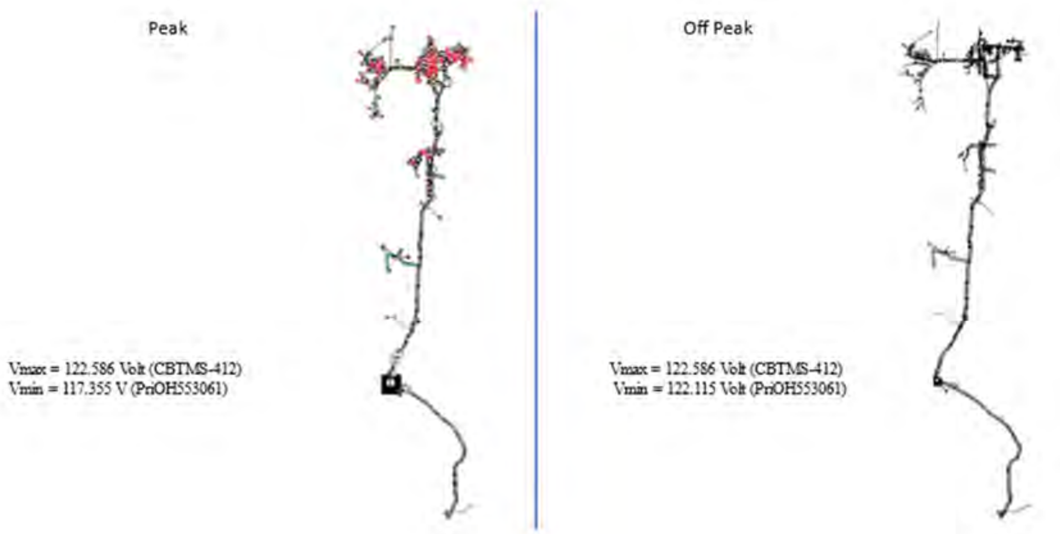

Figure 5-13: Load flow Analysis of feeder CBMAT-420, existing condition

j. Feeder CNA-421

The analysis found that there are pre-existing undervoltage present in feeder CNA-421 (Vmin = 113.996 V at section PriUG23720). Figure 5-14 shows the simulation results of the voltage drop analysis.

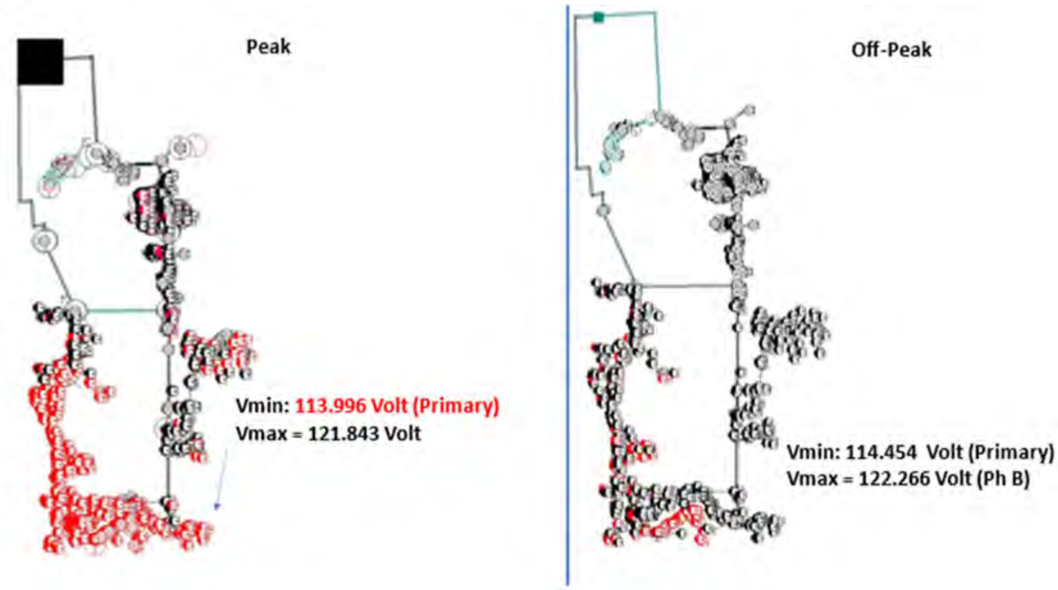

Figure 5-14: Load flow Analysis of feeder CBMAT-420, existing condition

Different mitigation methods were tried, and the below-mentioned mitigation was found to be the most effective one.

- Revise the setting of regulator (VR1921) downstream of PriOH508850 with the following settings:
  - Voltage Level = 124 Volts
  - First House High = 126 Volts
  - First House Low = 117 Volts
  - Bandwidth = 2 Volts

Figure 5-15 (below) shows results considering the above mitigation applied.

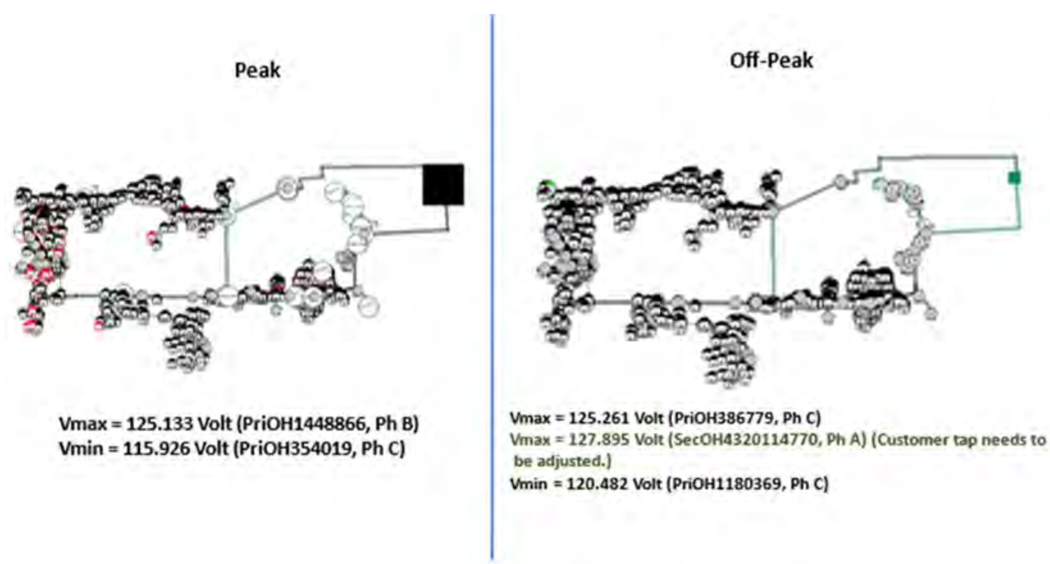

Figure 5-15: Load flow Analysis of feeder CNA-421, after mitigation

Figure 5-15 shows that the voltage values are within the limits.

6. Loss of Source/Transformer Analysis

Loss of source and transformer were simulated and analyzed for different scenarios. The analysis focused on the voltage and thermal violations. Mitigations are proposed to eliminate and reliably operate under contingency conditions. Violations and their respective mitigations are discussed in the sections below.

In this analysis, the following assumptions are made:

- All the line regulators (Existing + Newly proposed in this study) have bi-directional power flow handling capabilities. *Note: For any existing line regulators without this feature, it is assumed that Minnesota Power will identify and make necessary upgrades).*

- All the reclosers (Existing + Newly proposed in this study) have reverse power flow handling capabilities. *Note: For any existing reclosers without this feature, it is assumed that Minnesota Power will identify and make necessary upgrades).*

- If the circuits have elements with voltage level less than 114 Volts, the circuit is considered to have undervoltage condition and if the voltage level is greater than 126 Volts, the circuit is considered to have overvoltage condition. Undervoltage seen in the secondary side of circuits was neglected during the study per MNP suggestion.

a. Scenario 2: Loss of CLQ-404 Source; Served from CQN FDR

In this scenario, loss of CLQ-404 source is considered and CQN (CNA-421) feeder picks up the entire load of CLQ-404 customers. This is achieved by closing Tie-Switch SW45136-A and SW45141-A.

The mitigations proposed in the normal scenario (Section III) for CLQ 404, and CNA-421 feeders are considered in this analysis. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are no overloads noticed. However, undervoltage with Vmin = 113.90 V is noticed on the 12 kV side during peak load conditions.

The results are as shown below.

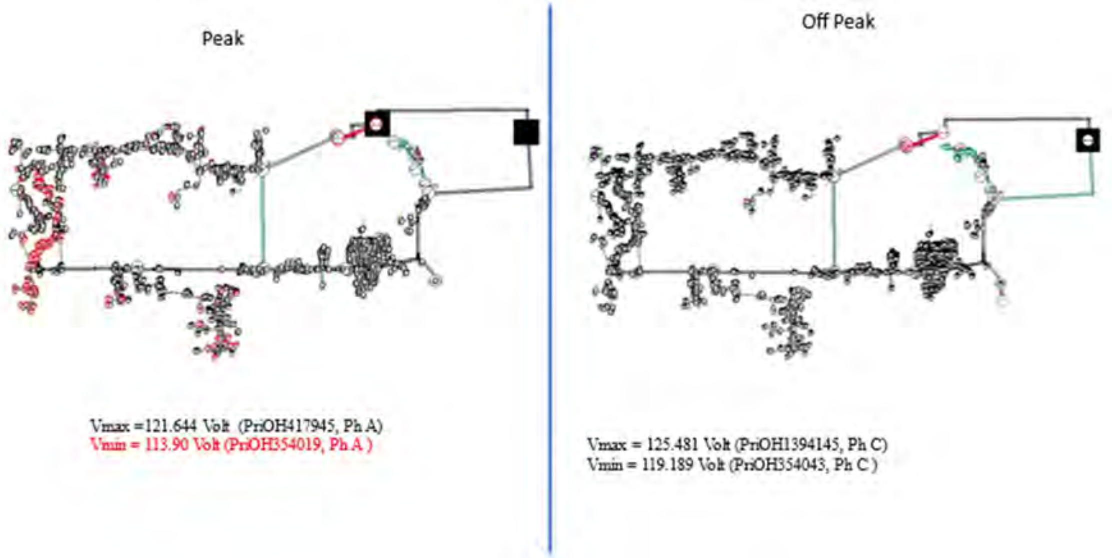

Figure 6-1: Voltage Results - Initial Condition (Scenario 2)

Several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Install a new 3Ph line regulator at downstream of PriOH413293 (Ph AC, CNA-421) with following settings:
  - Voltage Level: 120 V
  - First House High: 126 V
  - First Low High: 114 V
  - Bandwidth: 2 V
  - Bi-directional capabilities
- Add a 300 kVAR cap bank (117 V, 126 V) downstream of PriOH413450 (CNA-421).

Figure 6-2 (below) shows results with the above mitigation applied.

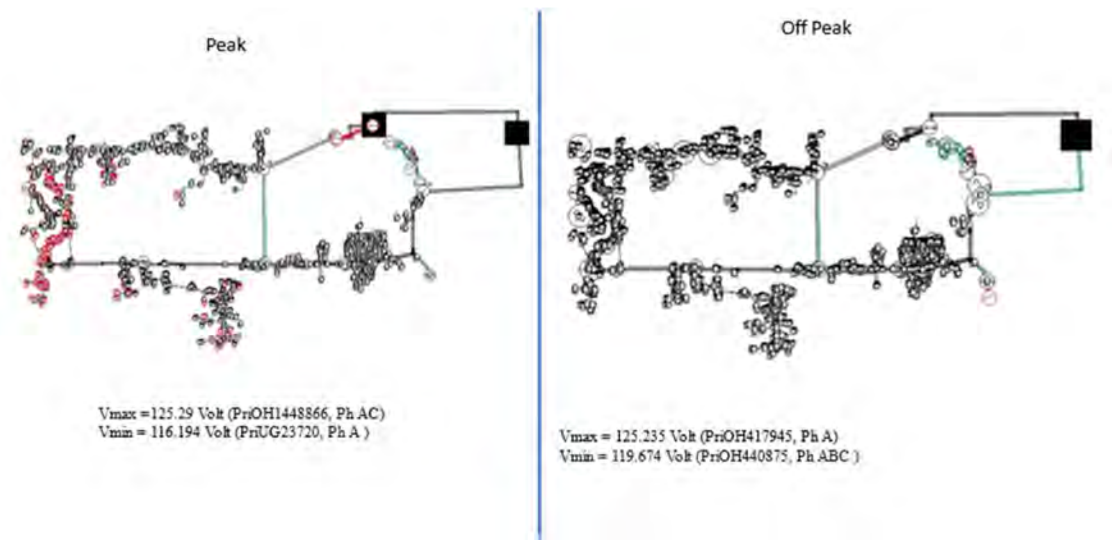

Figure 6-2: Voltage Results - After Mitigation (Scenario 2)

Figure 6-2 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 2 and Section III.

b. Scenario 3: Loss of CLQ-406 Source; Served from CQS-416 FDR

In this scenario, loss of CLQ-406 source is considered and CQS-416 (CNA-421) feeder picks up the entire load of CLQ-406 customers. This is achieved by closing 406-416 TIE Switch (Switch95057-B).

The mitigations proposed in the normal scenario (Section III) for CLQ-406 and CNA-421 feeders are considered in this analysis. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are both overload and undervoltage existed. The undervoltage with Vmin = 99.692 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

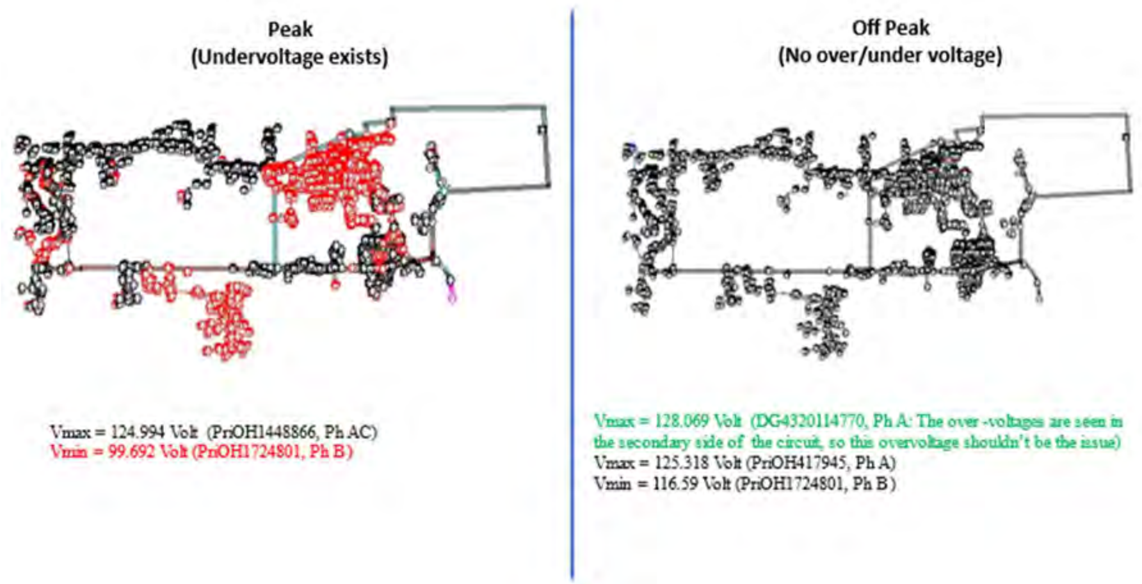

Figure 6-3: Voltage Results - Initial Condition (Scenario 3)

The sections where overloading is observed, and their suggested mitigations are listed in the table as

Table 6-1: Reconductoring Recommendation

Element Name	Thru Amps	Capacity Percentage	Existing Conductor type	Current Carrying Capacity	Suggested Conductor type	Current Carrying Capacity
PriUG765697	437.105	223.478	1/0 Al 15 kV 1/3 N	228	750 Al 15 kV 1/3 N	531
PriUG586475	437.105	223.478	1/0 Al 15 kV 1/3 N	228	750 Al 15 kV 1/3 N	531
PriOH458838	405.725	217.326	#1/0 ACSR 6/1	230	336 MCM ACSR 18/1	500
PriUG602785	359.415	189.522	1/0 Al 15 kV 1/3 N	228	500 Al 15 kV 1/3 N	467
PriUG711272	319.3	171.217	1/0 Al 15 kV 1/3 N	228	500 Al 15 kV 1/3 N	467
PriUG711273	319.3	171.217	1/0 Al 15 kV 1/3 N	228	500 Al 15 kV 1/3 N	467
PriUG45517	319.242	171.14	1/0 Al 15 kV 1/3 N	228	500 Al 15 kV 1/3 N	467
PriUG651120	308.911	166.447	1/0 Al 15 kV 1/3 N	228	500 Al 15 kV 1/3 N	467
PriUG710315	308.897	166.441	1/0 Al 15 kV 1/3 N	228	500 Al 15 kV 1/3 N	467
PriUG602480	359.415	132.549	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467
PriUG602473	359.409	132.547	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467
PriUG602471	359.409	132.547	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467
PriUG602477	354.189	131.39	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467
PriUG602478	354.188	131.39	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467
PriUG602479	354.157	131.38	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467
PriUG602476	355.276	131.376	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467
PriUG711274	312.881	117.717	4/0 Al 15 kV 1/3 N	326	500 Al 15 kV 1/3 N	467

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add new three-phase regulator downstream of PriOH441438 (CQS-416) and PriUG602785 (CLQ-406) with following settings:
  - Base Voltage = 120 V
  - Voltage Level = 124 V
  - First House High: 126 V
  - First House Low: 117 V
  - Bandwidth = 2 V
  - Bi-directional capabilities

Figure 6-4 (below) results show with the above mitigation applied.

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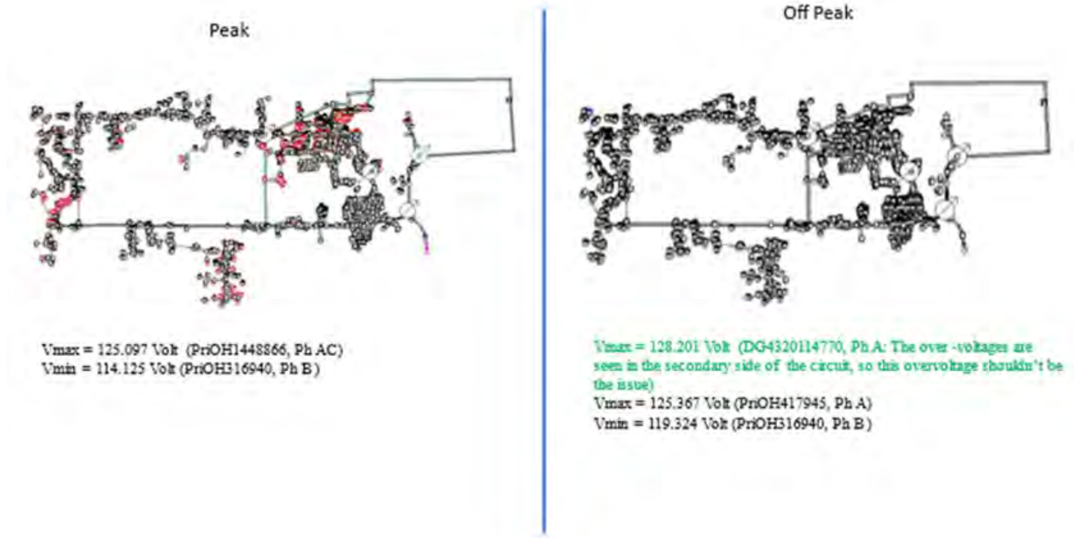

Figure 6-4: Voltage Results - After Mitigation (Scenario 3)

Figure 6-4 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 3 and Section III.

c. Scenario 4: Loss of CLQ-409 Source; Served from CNA-403 FDR

In this scenario, loss of CLQ-409 source is considered and CNA-403 feeder picks up the entire load of CLQ-409 customers. This is achieved by closing 403-409 TIE Switch (Switch682-B).

The mitigations proposed in the normal scenario (Section III) for CLQ-409 and CNA-403 feeders are considered in this analysis. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are both overload and undervoltage existed. The undervoltage with Vmin = 100.352 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

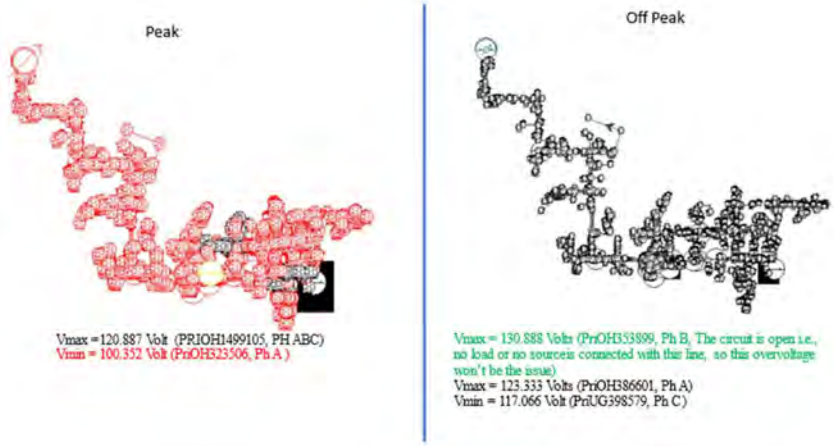

Figure 6-5: Voltage Results - Initial Condition (Scenario 4)

To mitigate the overloading condition, 3.054 miles of conductor (4/0 ACSR – 340 A, 1/0 ACSR 6/1 – 230 A) from PriOH437466 to PriOH446310 is overloaded (348.211 A) and needs to be upgraded to 336 MCM ACSR 18/1 (Rated 500 A).

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add new three-phase regulator downstream of PriOH437270 (CNA-403) and PriOH437068 (CLQ-409) with following settings:
  - Base Voltage = 120 V
  - Voltage Level = 124 V
  - First House High: 126 V
  - First House Low: 117 V
  - Bandwidth = 2 V
  - Bi-directional capabilities

Figure 6-6 results show with the above mitigation applied.

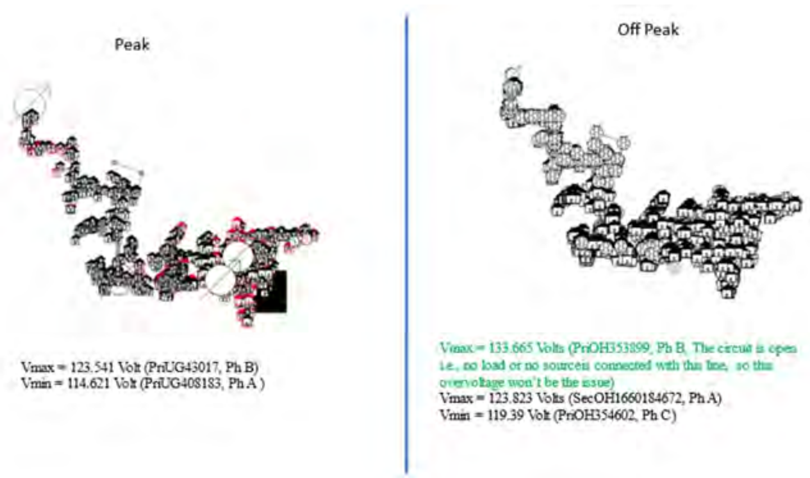

Figure 6-6: Voltage Results - After Mitigation (Scenario 4)

Figure 6-6 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 4 and Section III.

d. Scenario 5: Loss of CLQ-410 Source; Served from CNA-405 FDR

In this scenario, loss of CLQ-410 source is considered and CNA-405 feeder picks up the entire load of CLQ-410 customers. This is achieved by closing 405-410 TIE Switch (Switch1022-B).

The mitigations proposed in the normal scenario (Section III) for CLQ-410 and CNA-405 feeders are considered in this analysis. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

The pre-rephasing was done before the load flow analysis was done. The following rephasing activities were performed.

- Transfer PriOH383182 (CLQ-410) from phase B to phase A
- Transfer PriOH413771 (CLQ-410) from phase BC to AC (phase B -> phase A, phase C as it is)
- Transfer downstream of PriOH387015 (CNA-405) from phase B to phase A

In this scenario, there are no overloading condition existed. However, the undervoltage with Vmin = 104.098 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

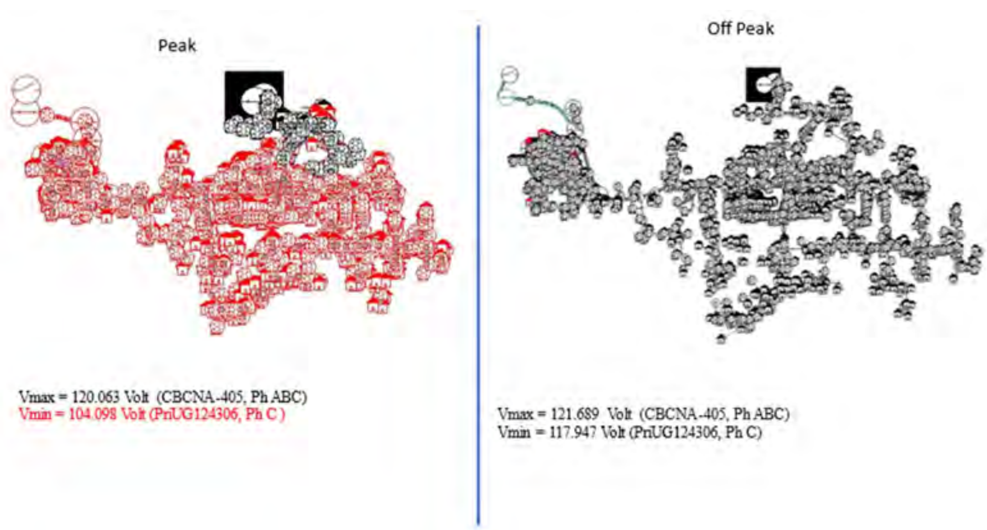

Figure 6-7: Voltage Results - Initial Condition (Scenario 5)

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add new three-phase regulator downstream of PriOH459411 (CNA-405) with following settings:
  - Base Voltage = 120 V
  - Voltage Level = 124 V
  - First House High: 126 V
  - First House Low: 117 V
  - Bandwidth = 2 V
  - Bi-directional capabilities
- Add new Cap bank 900 kVAR downstream of PriOH449960 (CLQ-410) with settings, (On Set: 117 V, Off Set: 126 V, Control phase: A)

Figure 6-8 results show with the above mitigation applied.

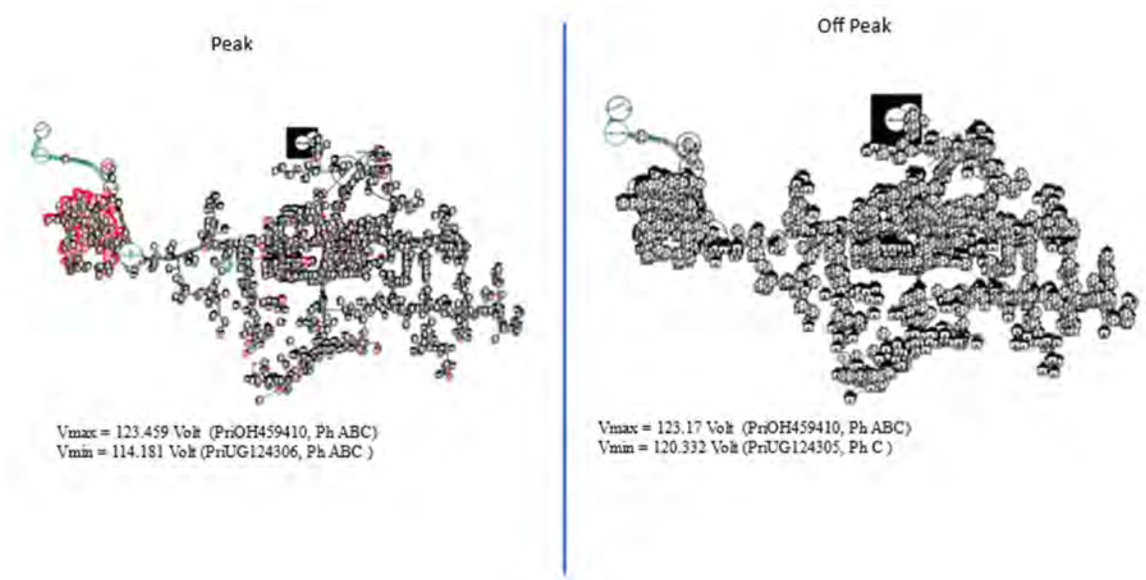

Figure 6-8: Voltage Results - After Mitigation (Scenario 5)

Figure 6-8 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 5 and Section III.

e. Scenario 6: Loss of CLQ-412 Source; Served from CQE-417 FDR

In this scenario, loss of CLQ-412 source is considered and CQE-417 (CNA-421) feeder picks up the entire load of CLQ-412 customers. This is achieved by closing 412-417 SCANLON TIE Switch (Switch1005-A).

The mitigations proposed in the normal scenario (Section III) for CLQ-412 and CNA-421 feeders are considered in this analysis. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are no overloading condition existed. However, the undervoltage with Vmin = 112.671 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

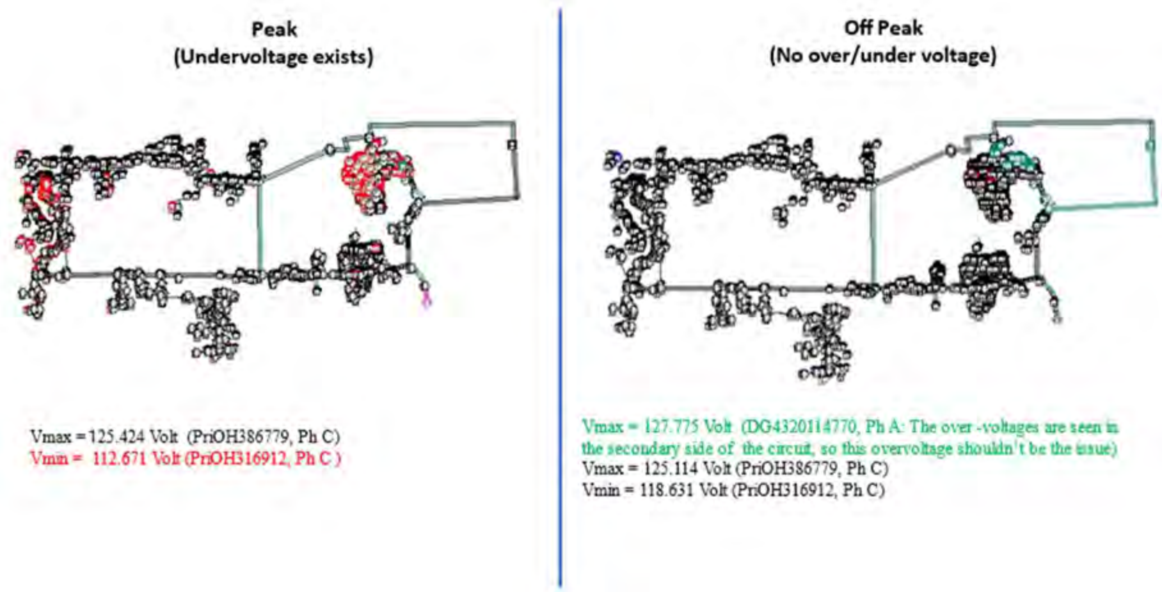

Figure 6-9: Voltage Results - Initial Condition (Scenario 6)

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add new three-phase regulator downstream of PriOH440200 (CLQ-412) with following settings:
  - Base Voltage = 120 V
  - Voltage Level = 124 V
  - First House High: 126 V
  - First House Low: 117 V
  - Bandwidth = 2 V
  - Bi-directional capabilities

Figure 6-10 shows with the above mitigation applied.

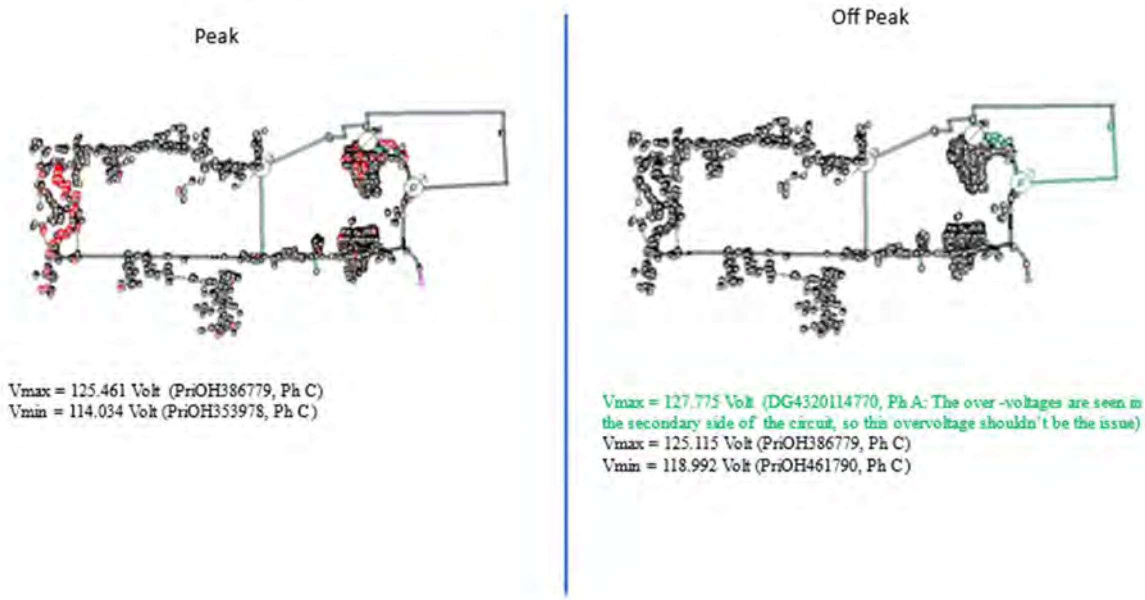

Figure 6-10: Voltage Results - After Mitigation (Scenario 6)

Figure 6-10 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 6 and Section III.

f. Scenario 7: Loss of CNA-403 FDR; Served from CLQ-409 FDR

In this scenario, loss CNA-403 source is considered, and CLQ-409 feeder picks up the entire load of CNA-403 customers. This is achieved by closing 403-409 TIE Switch (Switch682-B).

The mitigations proposed in the normal scenario (Section III) for CLQ-409 and CNA-403 feeders are considered in this analysis. The reconductoring and undervoltage mitigations proposed for Scenario 4 were also considered during the study. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there is no overload and undervoltage existed.

The voltage results are as shown below.

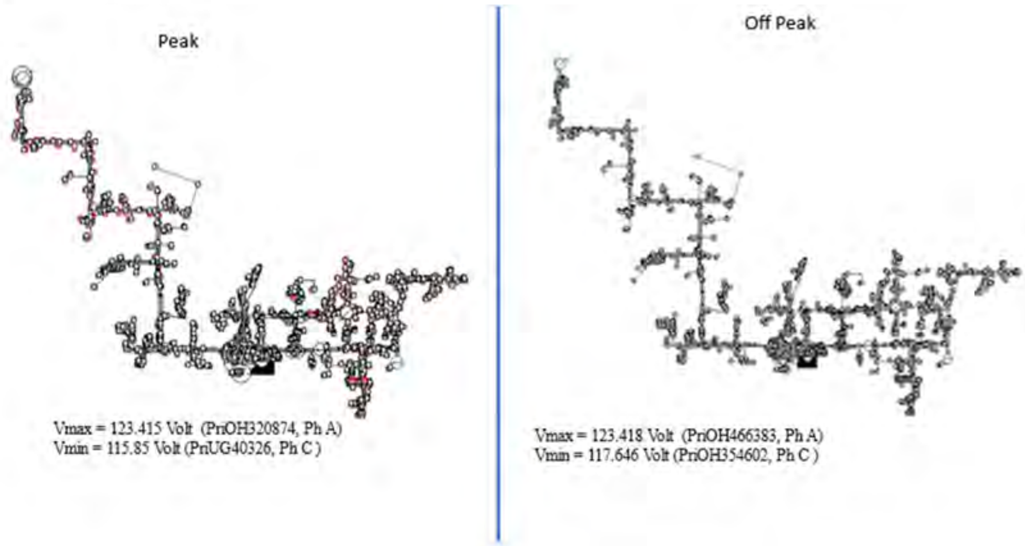

Figure 6-11: Voltage Result - Initial Condition (Scenario 7)

g. Scenario 8: Loss CNA-405 FDR; Served from CLQ-410 FDR

In this scenario, loss of CNA-405 source is considered and CLQ-410 feeder picks up the entire load of CNA-405 customers. This is achieved by closing 405-410 TIE Switch (Switch1022-B).

The mitigations proposed in the normal scenario (Section III) for CLQ-410 and CNA-405 feeders are considered in this analysis. The mitigations proposed for Scenario 5 were also considered in the study. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are no overloading condition existed. However, the undervoltage with Vmin = 108.676 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

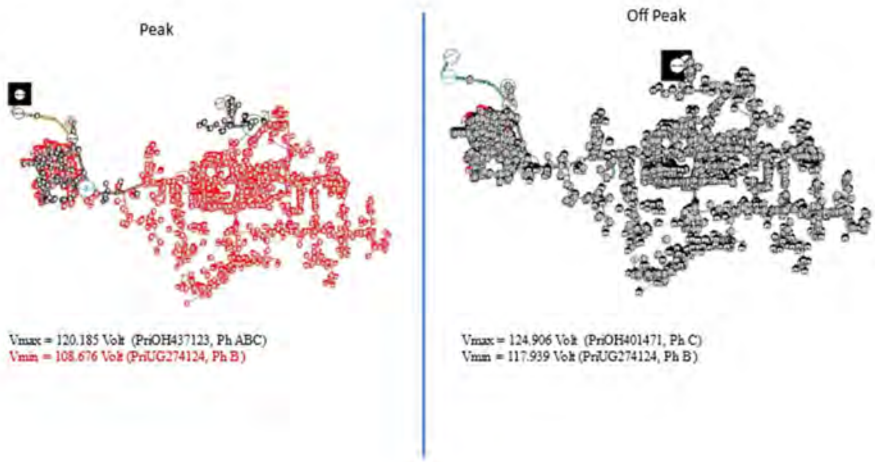

Figure 6-12: Voltage Results - Initial Condition (Scenario 8)

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add New regulator Downstream of PriOH440927 (from CBCLQ-410) with following settings:
  - Base Voltage = 120 V
  - Voltage Level = 124 V
  - First House High: 126 V
  - First House Low: 117 V
  - Bandwidth = 2 V
  - Bi-directional capabilities

Figure 6-13 (below) shows with the above mitigation applied.

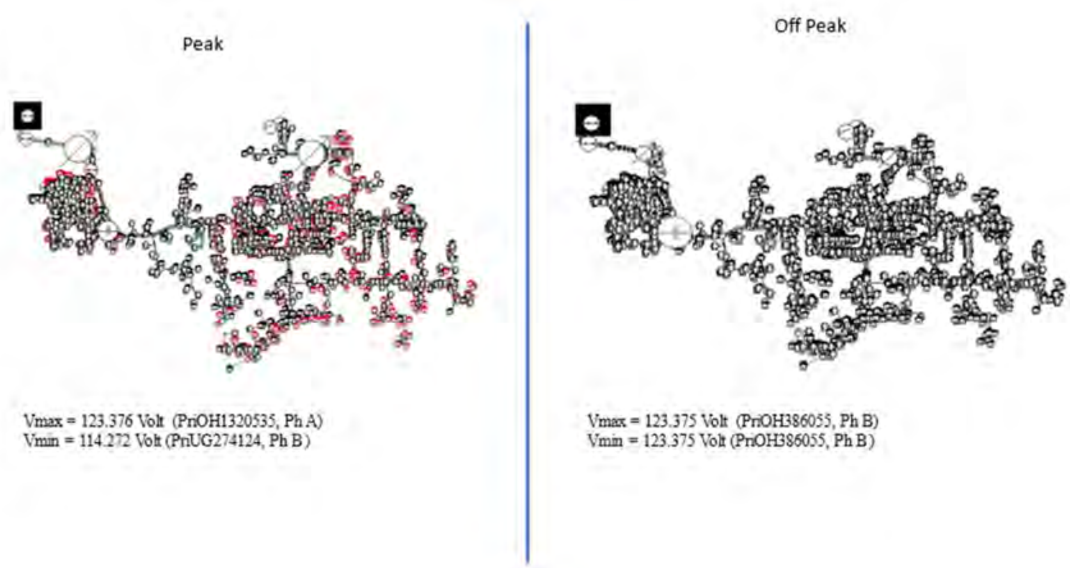

Figure 6-13: Voltage Results - After Mitigation (Scenario 8)

Figure 6-13 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 5 and Section III.

h. Scenario 9: Loss of TMS-412 Source; Served from CQE-417 FDR

In this scenario, loss of TMS-412 source is considered and CQE-417 (CNA-421) feeder picks up the entire load of TMS-412 customers. This is achieved by closing 412-417 CARLTON TIE Switch (Switch1123-B to SW41726-A: tie line length is 0.42763 miles).

The mitigations proposed in the normal scenario (Section III) for TMS-412 and CNA-421 feeders are considered in this analysis. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are no overloading condition existed. However, the undervoltage with Vmin = 113.597 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

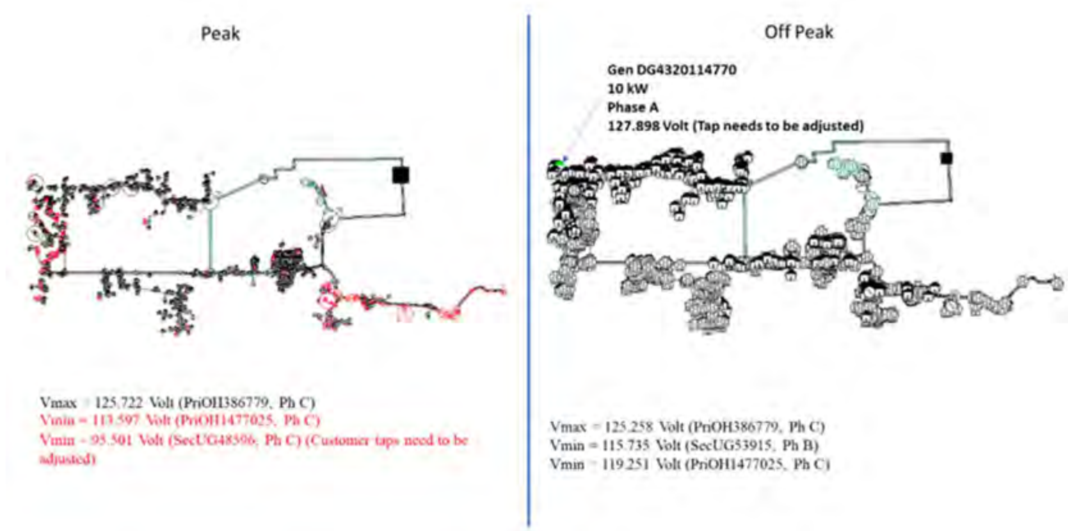

Figure 6-14: Voltage Results - Initial Condition (Scenario 9)

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add 600 kVAR Cap bank at section PriOH443102 (TMS-412) with settings (On Set: 117 V, Off Set: 126 V, Control phase: A).

Figure 6-15 (below) shows with the above mitigation applied.

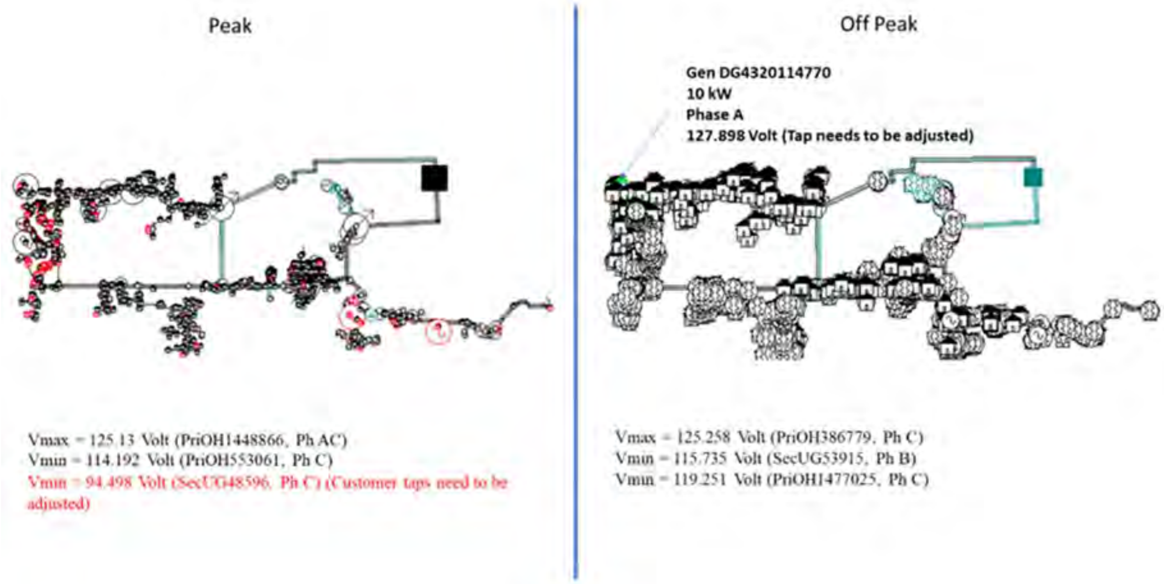

Figure 6-15: Voltage Results - After Mitigation (Scenario 9)

Figure 6-15 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 9 and Section III.

i. Scenario 10: Loss of Cloquet East 34.5/13.8 kV Stepdown; CQE-417 FDR Served from CLQ-412 FDR

In this scenario, loss of CQE-417 (CNA-421) source is considered and CLQ-412 feeder picks up the entire load of CQE-417 customers. This is achieved by closing 412-417 SCANLON TIE Switch (Switch1005-A).

The mitigations proposed in the normal scenario (Section III) for CLQ-412 and CNA-421 feeders are considered in this analysis. The mitigations proposed for Scenario 6 were also considered in the study. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are no overloading condition existed. However, the undervoltage with Vmin = 113.23 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

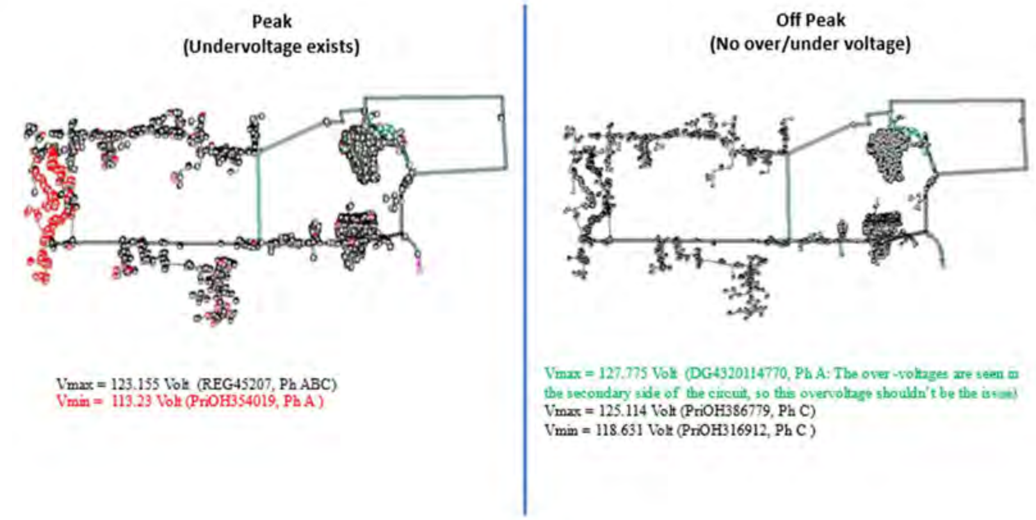

Figure 6-16: Voltage Results - Initial Condition (Scenario 10)

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Rephase downstream of PriUG42967 (CQE-417) from phase A to phase B
- Rephase downstream of PriOH353960 (CQE-417) from phase A to phase C

Figure 6-17 (below) shows with the above mitigation applied.

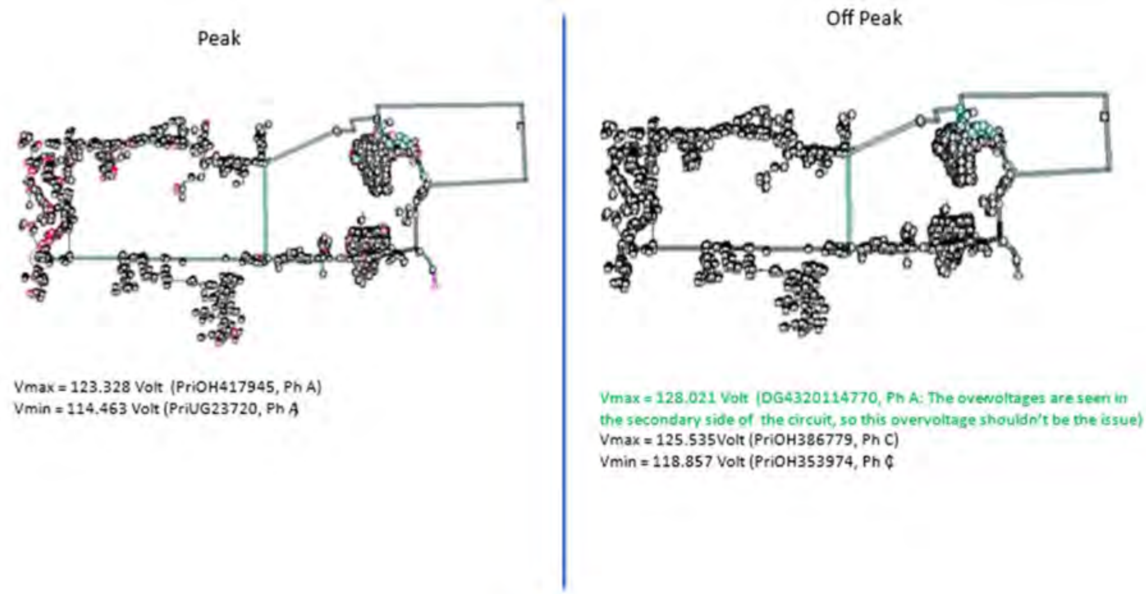

Figure 6-17: Voltage Results - After Mitigation (Scenario 10)

Figure 6-17 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 10 and Section III.

j. Scenario 11: Loss of Cloquet South 34.5/13.8 kV Stepdown; CQS-416 FDR served from CLQ-406 FDR

In this scenario, loss of CQS-416 (CNA-421) source is considered and CLQ-406 feeder picks up the entire load of CQS-416 customers. This is achieved by closing 406-416 TIE Switch (Switch95057-B).

The mitigations proposed in the normal scenario (Section III) for CLQ-406 and CNA-421 feeders are considered in this analysis. The reconductoring and undervoltage mitigations proposed for Scenario 6 were also considered in the study. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are both overload and undervoltage existed. The undervoltage with Vmin = 108.551 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

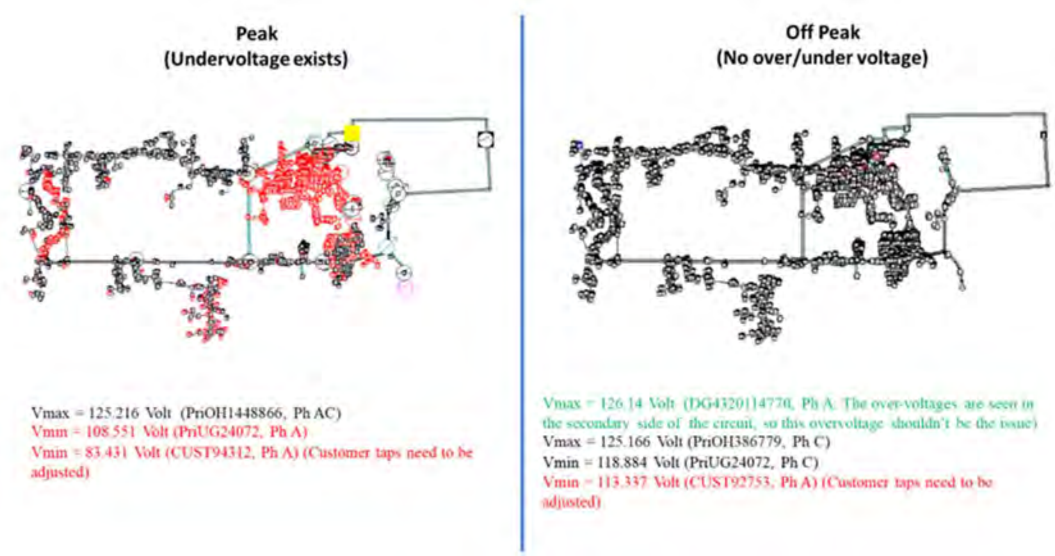

Figure 6-18: Voltage Results - Initial Condition (Scenario 11)

The sections where overloading is observed, and their suggested mitigations are listed in the table as

Table 6-2: Reconductoring Recommendation

Element Name	Thru Amps	Capacity Percentage	Conductor type	Current Carrying Capacity	Suggested Conductor type	Current Carrying Capacity
PriUG335227	452.158	102.333	500 Al 15 kV 1/3 N	467	750 Al 15 kV 1/3 N	531
PriUG493969	452.143	102.33	500 Al 15 kV 1/3 N	467	750 Al 15 kV 1/3 N	531
PriUG493680	452.142	102.33	500 Al 15 kV 1/3 N	467	750 Al 15 kV 1/3 N	531

For undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add new three-phase regulator downstream of PriOH440771 (CLQ-406) with following settings:
    - Base Voltage = 120 V
    - Voltage Level = 124 V
    - First House High: 126 V
    - First House Low: 117 V
    - Bandwidth = 2 V
    - Bi-directional capabilities

Figure 6-19 (below) shows with the above mitigation applied.

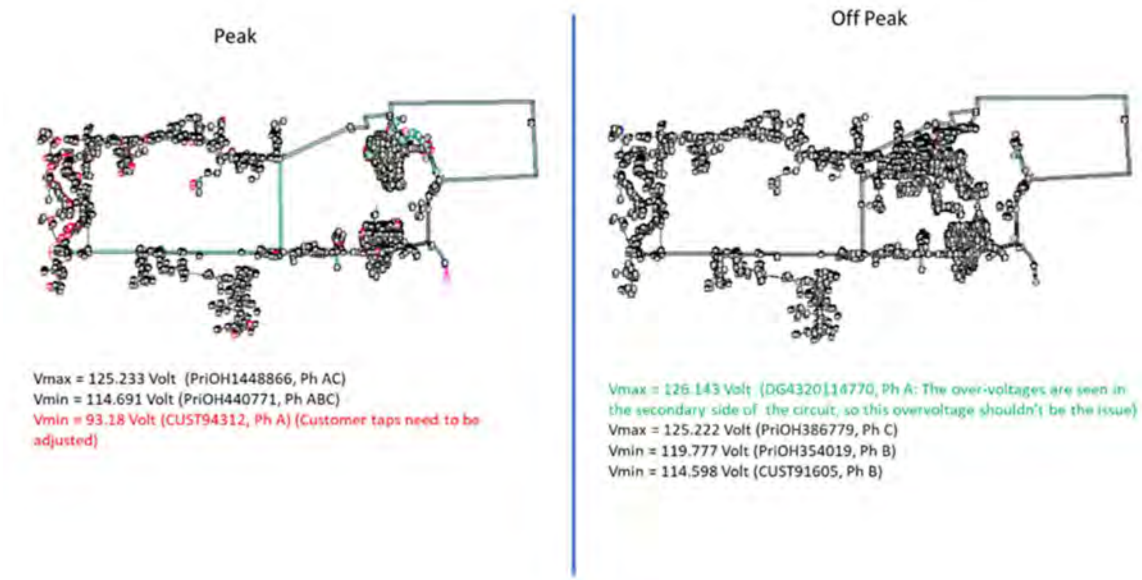

Figure 6-19: Voltage Results - After Mitigation (Scenario 11)

Figure 6-19 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 11 and Section III.

k. Scenario 12: Loss of CNA-421 Source; Served from MAT-420 FDR

In this scenario, loss of CNA-421 source is considered and MAT-420 feeder picks up the entire load of CNA-421 customers. This is achieved by closing SAWYER SUB 88 N.O. 14424 (Switch1027-A).

The mitigations proposed in the normal scenario (Section III) for MAT-420 and CNA-421 feeders are considered in this analysis. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, there are both overload and undervoltage condition existed. The undervoltage with Vmin = 97.412 V is noticed on the 12 kV side during peak load conditions.

The undervoltage results are as shown below.

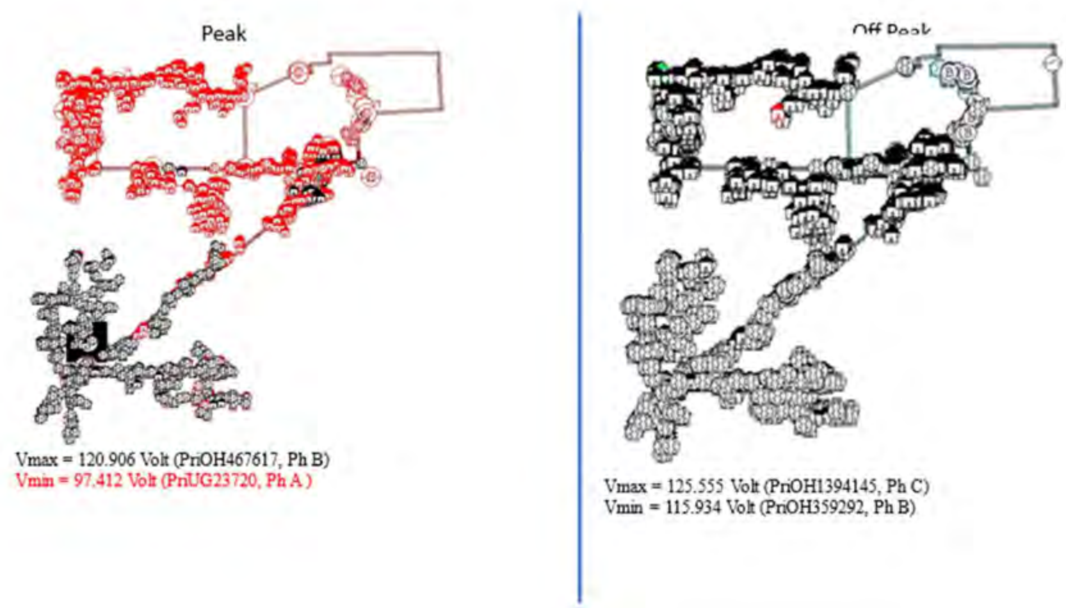

Figure 6-20: Voltage Results - Initial Condition (Scenario 12)

For overloading and undervoltage mitigation, several mitigation methods are tried and the below mentioned mitigation is found to be the effective mitigation.

- Add new three phase regulator downstream of PriOH443744 (CBMAT-420) with following settings:
  - Base Voltage = 120 V
  - Voltage Level = 124 V
  - First House High: 126 V
  - First House Low: 117 V

- Bandwidth = 2 V
- Bi-directional capabilities

- Add 900 kVAR Cap bank (On Set; 117 V, Off Set: 126 V, Control phase: A) at section OH45149 (CNA-421).
- Add 900 kVAR Cap bank (On Set; 117 V, Off Set: 126 V, Control phase: B) at section PriOH416425 (CNA-421).

Figure 6-21 (below) shows with the above mitigation applied.

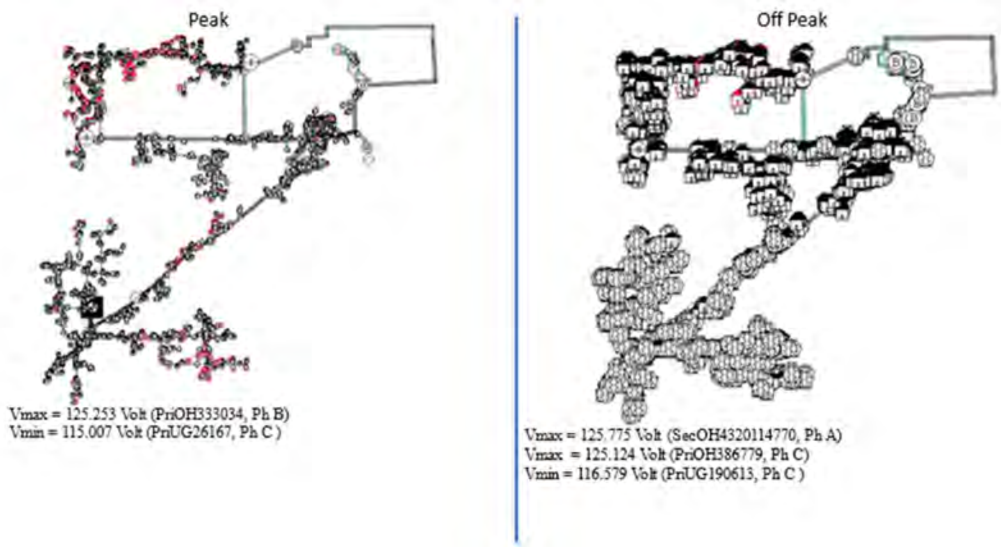

Figure 6-21: Voltage Results - After Mitigation (Scenario 12)

Figure 6-21 shows that, with the above mitigation applied, the voltage values are within the limits. Additionally, these new mitigation does not cause any adverse impacts when these circuits operate in Normal conditions with the mitigations proposed in Scenario 12 and Section III.

l. Scenario 13: Loss of MAT-420 Source; Served from CNA-421 FDR.

In this scenario, loss of MAT-420 source is considered and CNA-421 feeder picks up the entire load of MAT-420 customers. This is achieved by closing SAWYER SUB 88 N.O. 14424 (Switch1027-A).

The mitigations proposed in the normal scenario (Section III) for MAT-420 and CNA-421 feeders are considered in this analysis. The undervoltage mitigations proposed for Scenario 12 were also considered in the study. A load flow analysis is performed to evaluate the following conditions in both peak and minimum load cases.

- Thermal Overload
- Undervoltage violations
- Overvoltage violations

In this scenario, no overload and undervoltage conditions existed.

The voltage results are as shown below.

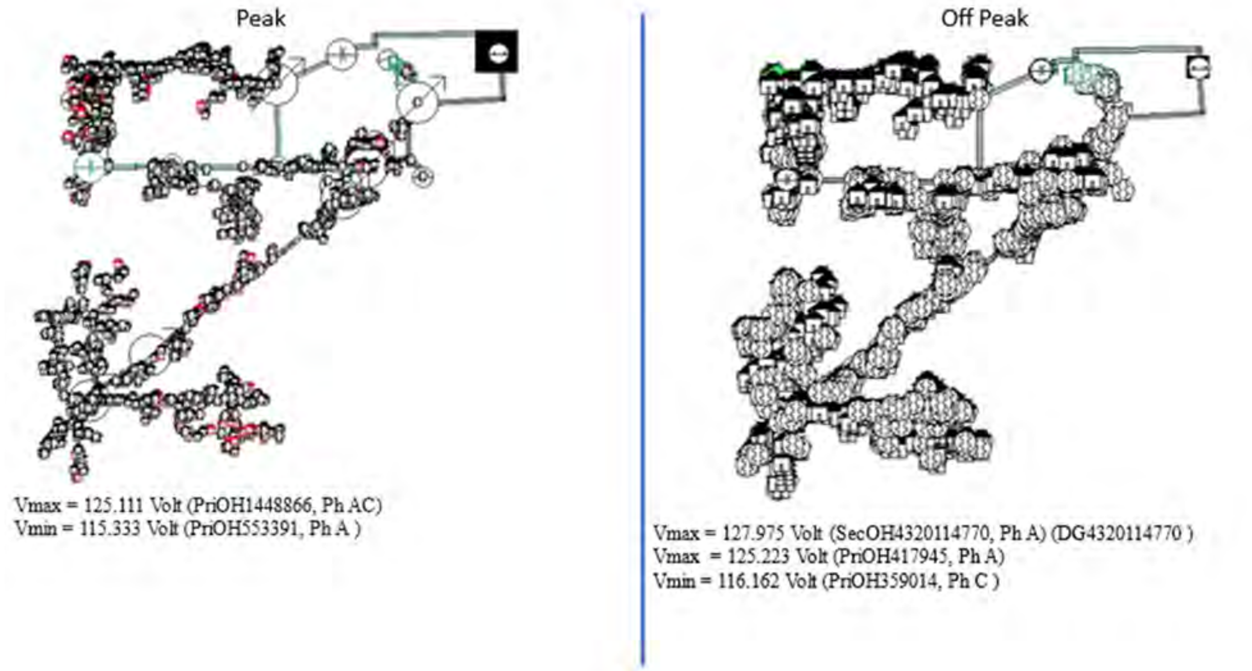

Figure 6-22: Voltage Results - Initial Condition (Scenario 13)

7. FLISR Analysis

FLISR is an effective solution designed to minimize the duration of customer outages that occur because of permanent faults. By constantly monitoring breakers, reclosers, and switches for any such faults and taking over once any involved protection is completed, FLISR ensures timely and efficient response. It achieves this by isolating the faulted area and utilizing alternative power sources from adjacent areas to restore electricity to the greatest number of affected customers.

In this study, we focused on the use of reclosers and sectionalizers as protective devices to prevent faults in a particular zone from affecting other zones with bulk consumers. We also considered the coordination of sectionalizers, which requires the presence of reclosers upstream of the sectionalizer locations. By installing Reclosers and Sectionalizers at strategic locations along the feeder, the FLISR system will be able to detect and isolate faults more quickly and efficiently. This will help to minimize the number of customers affected by a fault and reduce the duration of power outages, hence increasing the reliability. The FLISR study findings are summarized in Tables 7-1 and 7-2, and the equivalent one-line diagrams of feeders with the appropriate protective device locations are presented in the Appendix section.

Table 7-1: FLISR Summary - Normal Scenarios

Feeder	Proposed Reclosers Location	No. of consumers under protection zone	Proposed Sectionalizers Location	No. of consumers under protection zone
CBCLQ-404	None	None	None	None
CBCLQ-406	- CLQ-406 (Substation) - PriOH449891 - PriOH441113 - PriOH440925	- 52 - 134 - 258 - 128	- PriOH440941 - PriUG651120 - PriOH441086 - PriOH459041 - PriOH441167 - PriOH460445	- 193 - 171 - 123 - 159 - 194 - 99
CBCLQ-409	- CLQ-409 (Substation) - PriOH437072 - PriOH851031 - PriOH437073	- None - 223 - 386 - 434	- PriOH459442 - PriOH458994	- 50 - 80
CBCLQ-410	- CLQ-410 (Substation) - PriOH441320 - PriOH460641 (Relocated)	- 243 - 252 - 322	- PriOH441217 - PriOH1481825	- 47 - 76
CBCLQ-412	- CLQ-412 (Substation) - PriOH459040 - PriOH441016 - PriOH459043 (Replaced) - PriOH459039	- 76 - 139 - 435 - 254 - 228	- PriOH440846 - PriOH1339107 (Replaced) - PriOH441095 - PriOH387566 (Replaced) - PriOH441144 - PriOH460437 (Replaced) - PriOH460433 (Replaced)	- 23 - 241 - 74 - 129 - 191 - 166 - 121

			- PriOH460853 (Replaced)	- 78
CBCNA-403	- CNA-403 (Substation) - PriOH458996 (Replaced)	- 156 - 304	- PriOH437302	- 105
CBCNA-405	- CNA-405 (Substation) - PriOH437657 - PriOH1216850 - PriOH437660	- 186 - 224 - 307 - 480	- PriOH460184 (Replaced)	- 152
CBMAT-420	- MAT-420 (Substation) - PriOH450523 - PriOH463540	- None - 171 - 478	None	None
CBTMS-412	- TMS-412 (Substation) - PriOH460970 - PriOH460966	- 134 - 246 - 175	- PriOH443285 - PriOH1461670	- 5 - 133
CNA-421	- CNA-421 (Substation) - OH45143 - PriOH764578 (Rec169)	- None - 441 - 380	- PriOH441340 - PriOH1158612 - PriOH441579	- 33 - 304 - 255

Table 7-2: FLISR Summary - Contingency Scenarios

Scenarios	Proposed Reclosers Location	No. of consumers under protection zone	Proposed Sectionalizers Location	No. of consumers under protection zone
Loss of CLQ-404 Source; Served from CQN FDR	- OH45143 - PriOH764578 (Rec169)	- 443 - 380	- PriOH441340 - PriOH1158612 - PriOH441579	- 33 - 304 - 255
Loss of CLQ-406 Source; Served from CQS-416 FDR	- CLQ-406 (Substation) - OH45143 - PriOH764578 - PriOH449891 - PriOH441113 - PriOH440925	- - 441 - 380 - 134 - 258 - 52	- PriOH441340 - PriOH441579 - PriOH1158612 - PriOH440941 - PriUG651120 - PriOH441086 - PriOH459041 - PriOH441167 - PriOH460445	- 33 - 255 - 475 - 159 - 194 - 123 - 193 - 194 - 99
Loss of CQS-416 Source; Served from CLQ-406 FDR	- CLQ-406 (Substation) - OH45143 - PriOH764578 - PriOH449891 - PriOH441113 - PriOH440925	- - 441 - 380 - 134 - 258 - 128	- PriOH441340 - PriOH441579 - PriOH1158612 - PriOH440941 - PriUG651120 - PriOH441086 - PriOH459041 - PriOH441167 - PriOH460445	- 33 - 255 - None - 159 - 475 - 123 - 193 - 194 - 99
Loss of CLQ-406 Source; Served from CQS-416 FDR	- PriOH437072 - PriOH437073 - PriOH851031 - PriOH458996	- None - 434 - 386 - 304	- PriOH459442 - PriOH458994 - PriOH437302	- 50 - 80 - 328

Loss of CQS-416 Source; Served from CLQ-406 FDR	- PriOH437072 - PriOH437073 - PriOH851031 - PriOH458996	- 428 - 434 - 386 - 304	- PriOH459442 - PriOH458994 - PriOH437302	- 50 - 80 - 156
Loss of CLQ-410 Source; Served from CNA-405 FDR	- PriOH460641 (Relocate) - PriOH441320 - PriOH437657 - PriOH437660 - PriOH1216850 (Replaced) - PriOH441181	- 252 - 322 - 224 - 480 - 152 - 236	- PriOH1481825 - PriOH441217 - PriOH460184	- 76 - 47 - 152
Loss of CNA-405 Source; Served from CLQ-410 FDR	- PriOH460641 (Relocate) - PriOH441320 - PriOH437657 - PriOH437660 - PriOH1216850 (Replaced) - PriOH441181	- 252 - 322 - 224 - None - 152 - 236	- PriOH1481825 - PriOH441217 - PriOH460184 - PriOH441194	- 76 - 47 - 152 - 480
Loss of CLQ-412 Source; Served from CQE-417 FDR	- OH45143 - PriOH764578 - PriOH459039 - PriOH441016 - PriOH459040 - PriOH459043	- 441 - 380 - 228 - 435 - 139 - 254	- PriOH441340 - PriOH1158612 - PriOH764578 - PriOH441579 - PriOH440846 - PriOH1339107 - PriOH441095 - PriOH387566 - PriOH441144 - PriOH460437 - PriOH460433 - PriOH460853	- 33 - 304 - 380 - 255 - 23 - 241 - 75 - 218 - 191 - 166 - 121 - 78
Loss of CQE-417 Source; Served from CLQ-412 FDR	- OH45143 - PriOH764578 - PriOH459039 - PriOH441016 - PriOH459040 - PriOH459043	- 441 - 380 - 228 - 435 - 139 - 254	- PriOH441340 - PriOH1158612 - PriOH764578 - PriOH441579 - PriOH440846 - PriOH1339107 - PriOH441095 - PriOH387566 - PriOH441144 - PriOH460437 - PriOH460433 - PriOH460853	- None - 304 - 380 - 255 - 23 - 241 - 75 - 218 - 191 - 166 - 121 - 78
Loss of CBTMS-412 Source; Served from CQE-417 FDR	- PriOH460966 - PriOH460970 - OH45143 - PriOH764578	- 175 - 113 - 441 - 380	- PriOH443285 - PriOH1461670 - PriOH441340 - PriOH1158612 - PriOH441579 - PriOH443041	- 5 - 133 - 33 - 304 - 255 - 139
Loss of CNA-421 Source; Served from MAT-420 FDR	- PriOH463540 - PriOH450523 - PriOH463133 (Rec133) - PriOH949954 (Rec34243)	- 478 - 163 - 123 - 139	- PriOH441579 - PriOH1158612 - PriOH441340 - PriOH630825	- 255 - 304 - 33 - 449

	- OH45143 - PriOH764578 (Rec169) - PriOH331989 (Rec104)	- 441 - 114 - 266		
Loss of MAT-420 Source; Served from CNA-421 FDR	- PriOH463540 - PriOH450523 - PriOH463133 (Rec133) - PriOH949954 (Rec34243) - OH45143 - PriOH764578 (Rec169) - PriOH331989 (Rec104)	- 478 - None - 123 - 139 - 441 - 114 - 266	- PriOH441579 - PriOH1158612 - PriOH441340 - PriOH630825	- 255 - 304 - 33 - 24

8. Conclusion

Based on the simulation results, it was observed that most of the feeders in the primary circuits had undervoltage violations. However, this issue was addressed by implementing various methods such as the use of voltage regulators, capacitor banks, or rephasing techniques. Additionally, the problem of overloading in the primary circuits was resolved through the reconductoring method. It is noteworthy that there were no instances of overvoltage in the primary side of the feeders during the study.

To summarize the observed violations and the proposed solutions during the normal and contingency scenarios, please refer to Table 8-1 and Table 8-2.

Table 8-1: Feeders Performance Evaluation - Normal Scenarios

Feeder	Violations Observed	Mitigations we proposed
CBCLQ-404	No Violations	
CBCLQ-406	Undervoltage	o Change PriOH1458470 and downstream from phase B to phase C. o Add 900 kVAR 3 Ph Cap bank (On Set: 117 V, Off Set: 126 V, Control phase: A) downstream of PriOH332214.
CBCLQ-409	Undervoltage	o Rephase the existing 1Ph A overhead conductor from downstream of PriOH320872 to Ph B o Rephase the existing 1Ph C Underground conductor from downstream of PriUG40299 to Ph B
CBCLQ-410	No Violations	
CBCLQ-412	No Violations	
CBCNA-403	Undervoltage	o From PriOH416914 onwards, change phase BC to AC (B to C, C to A) o From PriOH416830 to downstream, change all phase C to B o From PriUG42555 to downstream, change all phase C to B o From PriOH386972 to downstream, change all phase A to C o From PriOH386967 to downstream, change all phase A to C o From PriUG43071 to downstream, change all phase A to C o From PriUG780208 to downstream, change all phase A to B o From PriOH416538 to downstream, change phase A to B and keep phase C as it is. o From PriOH386643 to downstream, change phase A to B o Add single phase regulator downstream of PriOH386601.
CBCNA-405	No Violations	
CBMAT-420	Undervoltage	o Change CUST96494 to 3ph Load.
CBTMS-412	No Violations	
CNA-421	Undervoltage	o Revise the setting of regulator (VR1921) downstream of PriOH508850 with the following settings: ▪ Voltage Level = 124 Volts ▪ First House High = 126 Volts ▪ First House Low = 117 Volts ▪ Bandwidth = 2 Volts

Table 8-2: Feeders Performance Evaluation - Contingency Scenarios

Scenarios	Violations Observed	Mitigations we proposed
Loss of CLQ-404 Source; Served from CQN FDR	Undervoltage	○ Install a new 3Ph line regulator at downstream of PriOH413293 (Ph AC, CNA-421) with following settings: ▪ Voltage Level: 120 V ▪ First House High: 126 V ▪ First Low High: 114 V ▪ Bandwidth: 2 V ▪ Bi-directional capabilities ○ Add a 300 kVAR cap bank (117 V, 126 V) downstream of PriOH413450 (CNA-421).
Loss of CLQ-406 Source; Served from CQS-416 FDR	Overloading and Undervoltage	○ Reconductoring three phase sections with overloading. (Section IV contains details). ○ Add new three-phase regulator downstream of PriOH441438 (CQS-416) and PriUG602785 (CLQ-406) with following settings: ▪ Base Voltage = 120 V ▪ Voltage Level = 124 V ▪ First House High: 126 V ▪ First House Low: 117 V ▪ Bandwidth = 2 V ▪ Bi-directional capabilities
Loss of CLQ-409 Source; Served from CNA-403 FDR	Overloading and Undervoltage	○ 3.054 miles of conductor (4/0 ACSR – 340 A, 1/0 ACSR 6/1 – 230 A) from PriOH437466 to PriOH446310 is upgraded to 336 MCM ACSR 18/1 (Rated 500 A). ○ Add new three-phase regulator downstream of PriOH437270 (CNA-403) and PriOH437068 (CLQ-409) with following settings: ▪ Base Voltage = 120 V ▪ Voltage Level = 124 V ▪ First House High: 126 V ▪ First House Low: 117 V ▪ Bandwidth = 2 V ▪ Bi-directional capabilities
Loss of CLQ-410 Source; Served from CNA-405 FDR	Undervoltage	○ Add new three-phase regulator downstream of PriOH459411 (CNA-405) with following settings: ▪ Base Voltage = 120 V ▪ Voltage Level = 124 V ▪ First House High: 126 V ▪ First House Low: 117 V ▪ Bandwidth = 2 V ▪ Bi-directional capabilities ○ Add new Cap bank 900 kVAR downstream of PriOH449960 (CLQ-410) with settings, (On Set: 117 V, Off Set: 126 V, Control phase: A)
Loss of CLQ-412 Source; Served from CQE-417 FDR	Undervoltage	○ Add new three-phase regulator downstream of PriOH440200 (CLQ-412) with following settings: ▪ Base Voltage = 120 V ▪ Voltage Level = 124 V ▪ First House High: 126 V ▪ First House Low: 117 V ▪ Bandwidth = 2 V ▪ Bi-directional capabilities

Loss of CNA-403 FDR; Served from CLQ-409 FDR	No Violations	
Loss of CNA-405 FDR; Served from CLQ-410 FDR	Undervoltage	○ Add New regulator Downstream of PriOH440927 (from CBCLQ-410) with following settings: ▪ Base Voltage = 120 V ▪ Voltage Level = 124 V ▪ First House High: 126 V ▪ First House Low: 117 V ▪ Bandwidth = 2 V ▪ Bi-directional capabilities
Loss of TMS-412 Source; Served from CQE-417 FDR	Undervoltage	○ Add 600 kVAR Cap bank at section PriOH443102 (CBTMS-412) with settings (On Set: 117 V, Off Set: 126 V, Control Phase: C).
Loss of Cloquet East 34.5/13.8 kV Stepdown; CQE-417 FDR Served from CLQ-412 FDR	Undervoltage	○ Rephase downstream of PriUG42967 (CQE-417) from phase A to phase B ○ Rephase downstream of PriOH353960 (CQE-417) from phase A to phase C
Loss of Cloquet South 34.5/13.8 kV Stepdown; CQS-416 FDR served from CLQ-406 FDR	Overloading and Undervoltage	○ Reconductoring three phase sections with overloading (Section IV contains details). ○ Add new three-phase regulator downstream of PriOH440771 (CLQ-406) with following settings: ▪ Base Voltage = 120 V ▪ Voltage Level = 124 V ▪ First House High: 126 V ▪ First House Low: 117 V ▪ Bandwidth = 2 V ▪ Bi-directional capabilities
Loss of CNA-421 Source; Served from MAT-420 FDR	Overloading and Undervoltage	○ Add new three phase regulator downstream of PriOH443744 (CBMAT-420) with following settings: ▪ Base Voltage = 120 V ▪ Voltage Level = 124 V ▪ First House High: 126 V ▪ First House Low: 117 V ▪ Bandwidth = 2 V ▪ Bi-directional capabilities ○ Add 900 kVAR Cap bank (On Set; 117 V, Off Set: 126 V, Control phase: A) at section OH45149 (CNA-421). ○ Add 900 kVAR Cap bank (On Set; 117 V, Off Set: 126 V, Control phase: B) at section PriOH416425 (CNA-421).
Loss of MAT-420 Source; Served from CNA-421 FDR	No Violation	

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9. Appendix

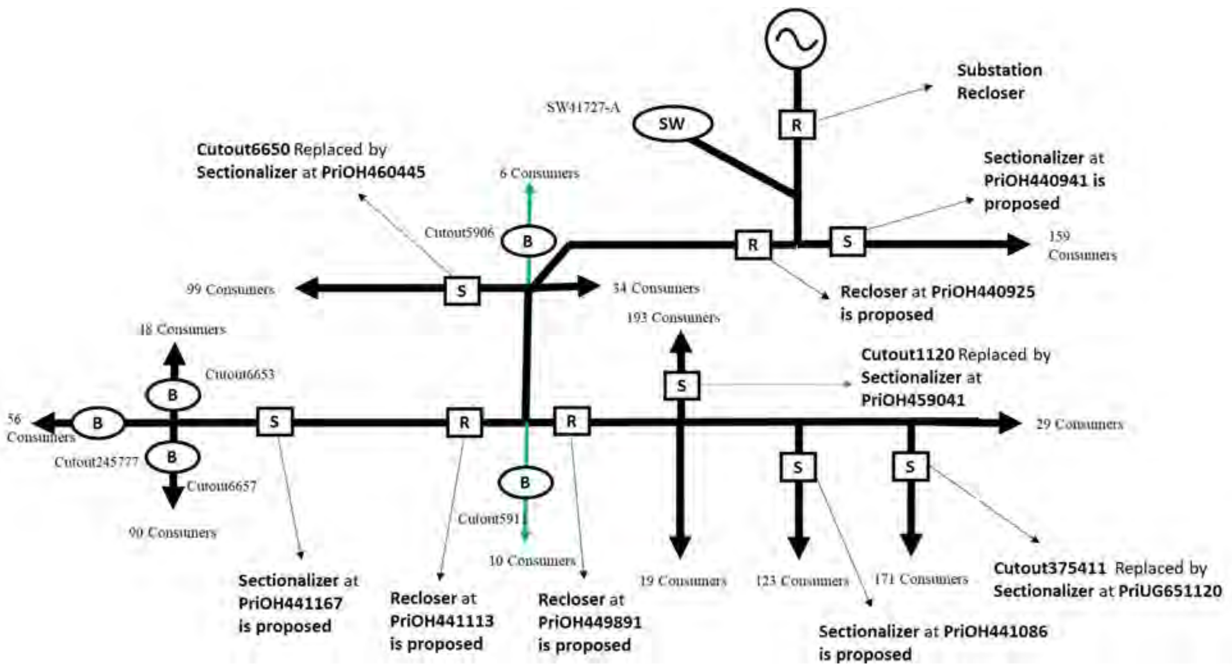

Figure 9-1: Equivalent One line diagram with proposed protective devices for feeder CBCLQ-406

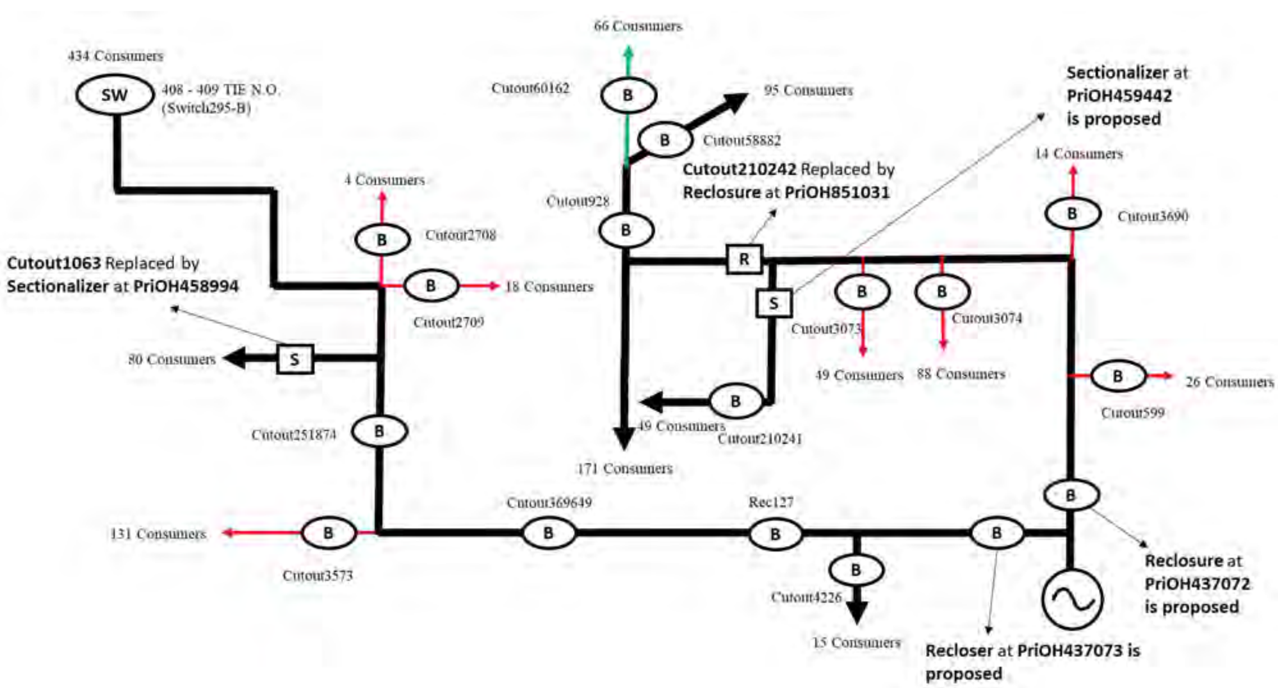

Figure 9-2: Equivalent One line diagram with proposed protective devices for feeder CBCLQ-409

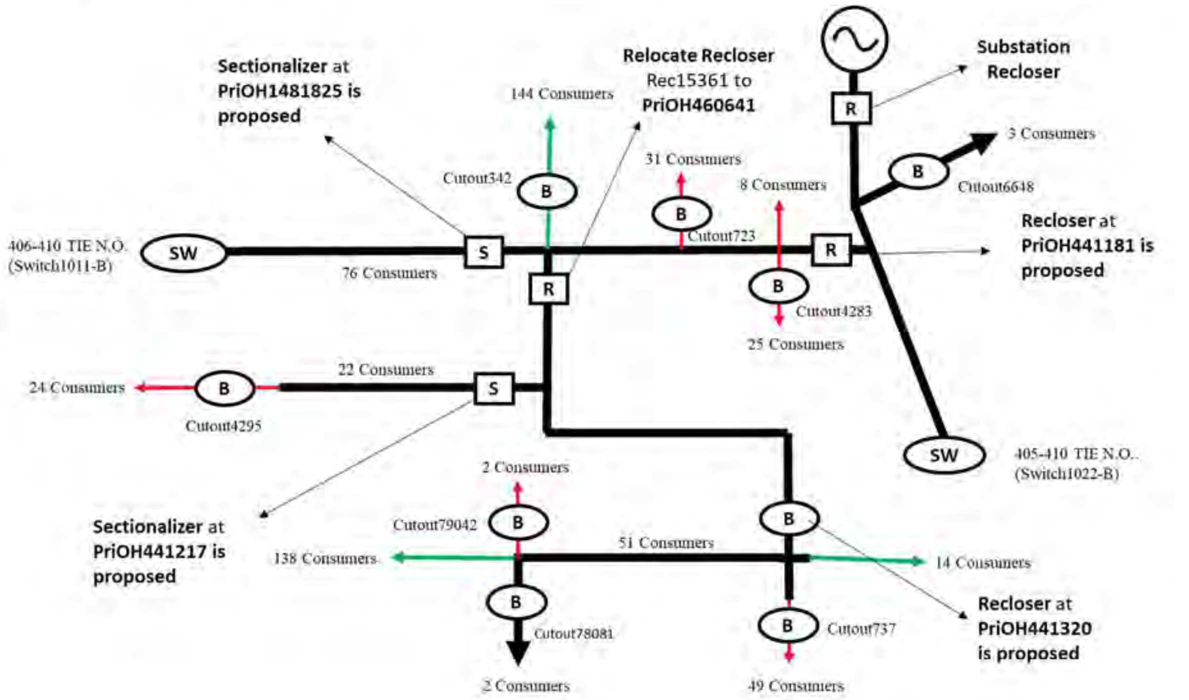

Figure 9-3: Equivalent One line diagram with proposed protective devices for feeder CBCLQ-410

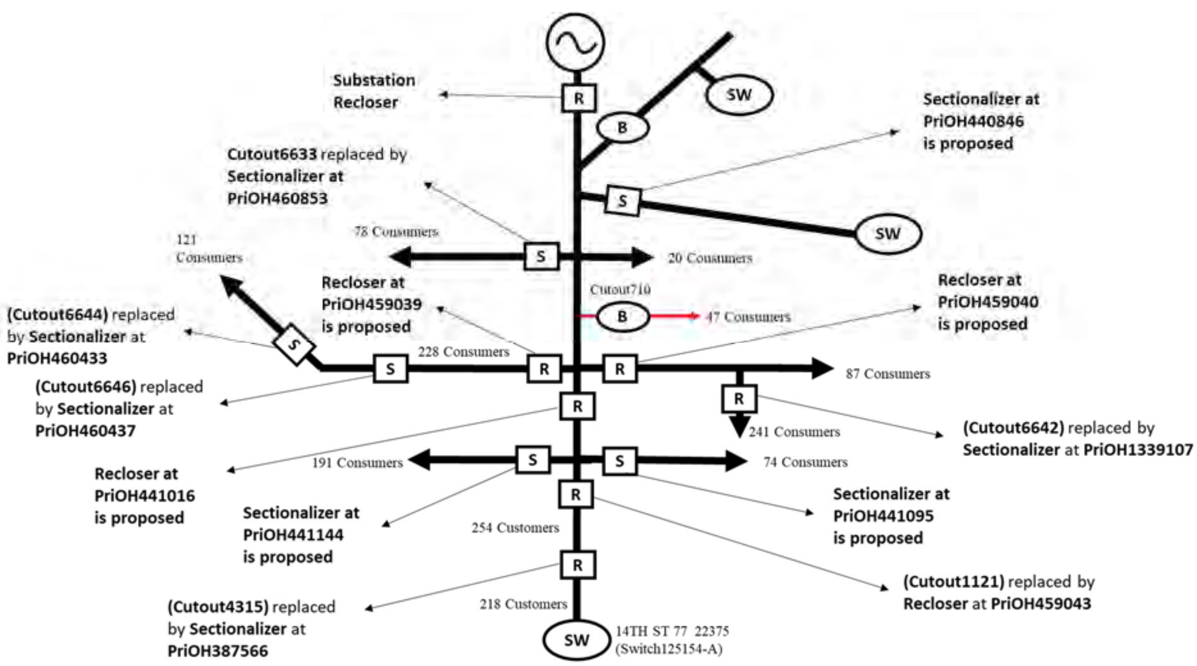

Figure 9-4: Equivalent One line diagram with proposed protective devices for feeder CBCLQ-412

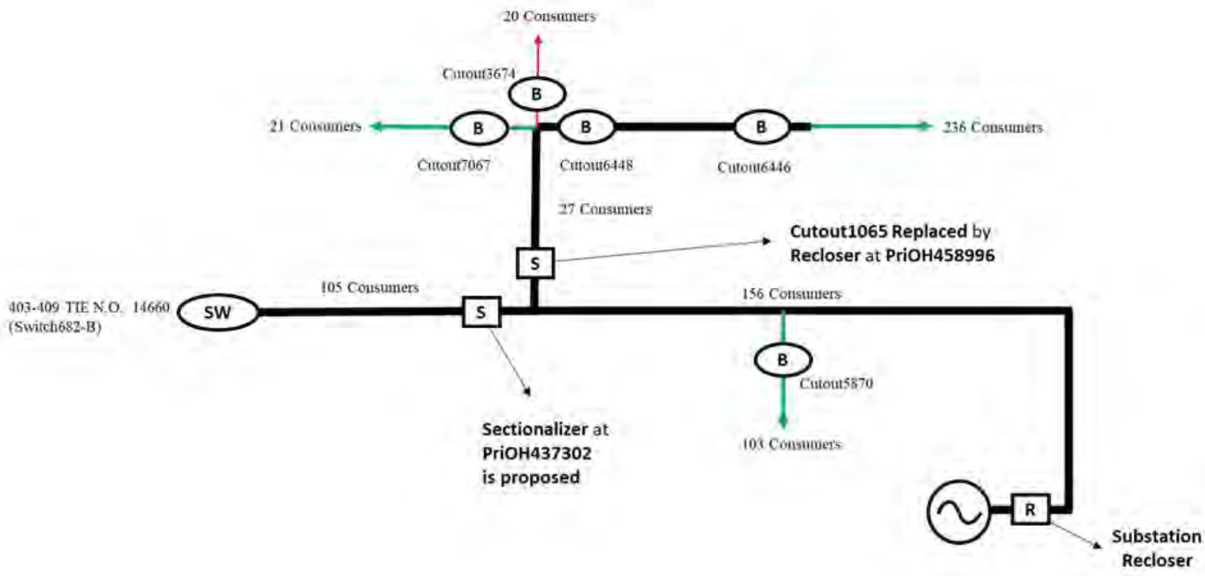

Figure 9-5: Equivalent One line diagram with proposed protective devices for feeder CBCNA-403

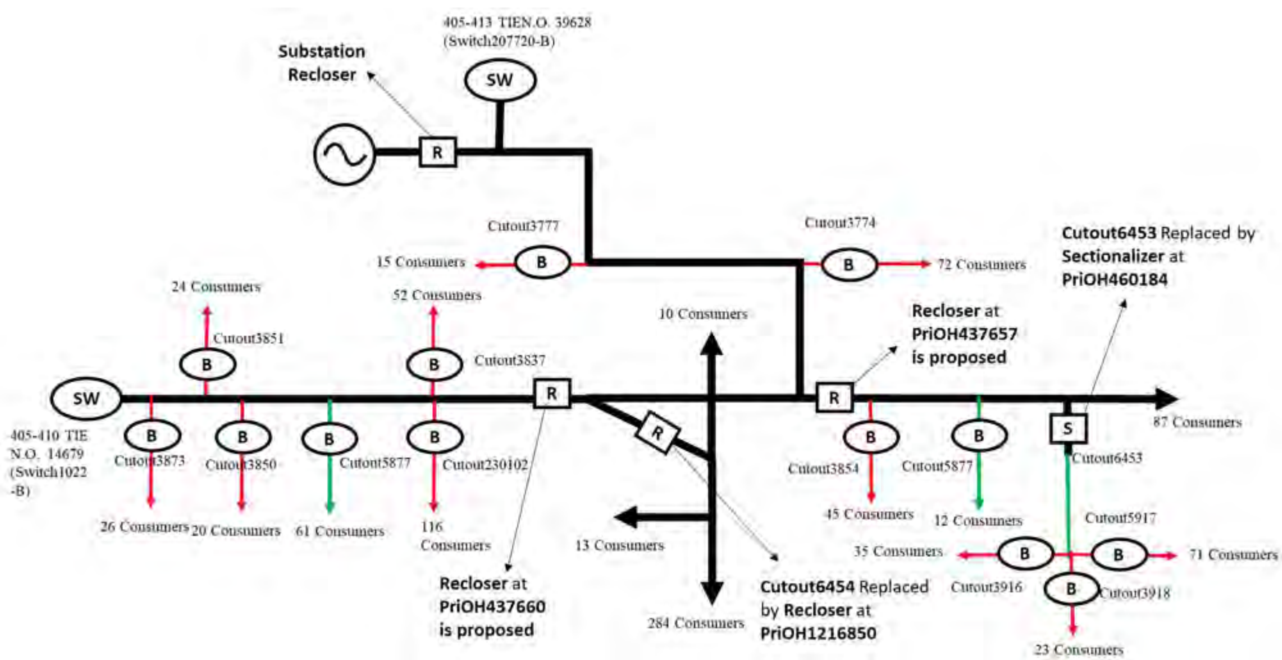

Figure 9-6: Equivalent One line diagram with proposed protective devices for feeder CBCNA-405

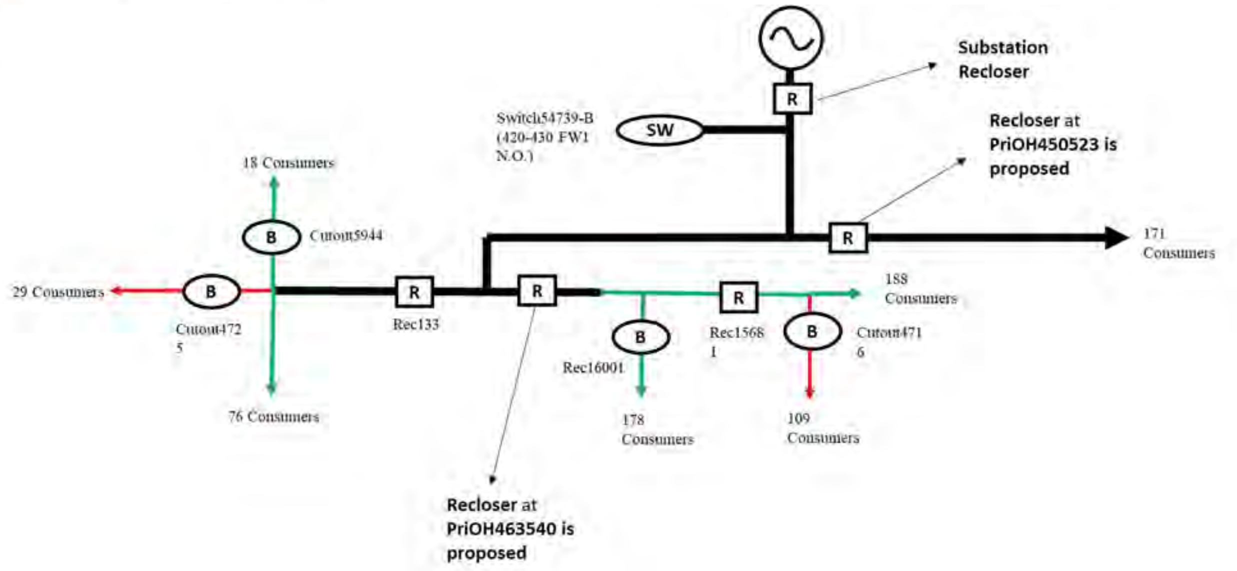

Figure 9-7: Equivalent One line diagram with proposed protective devices for feeder CBCMAT-420

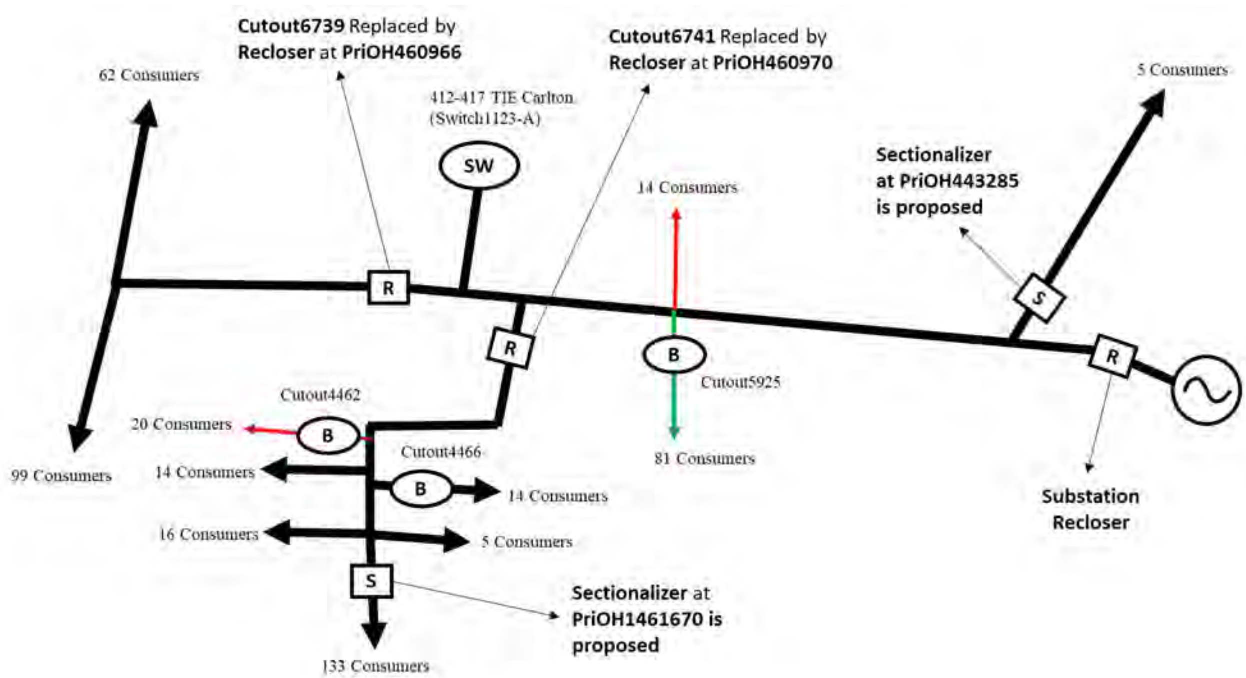

Figure 9-8: Equivalent One line diagram with proposed protective devices for feeder CBTMS-412

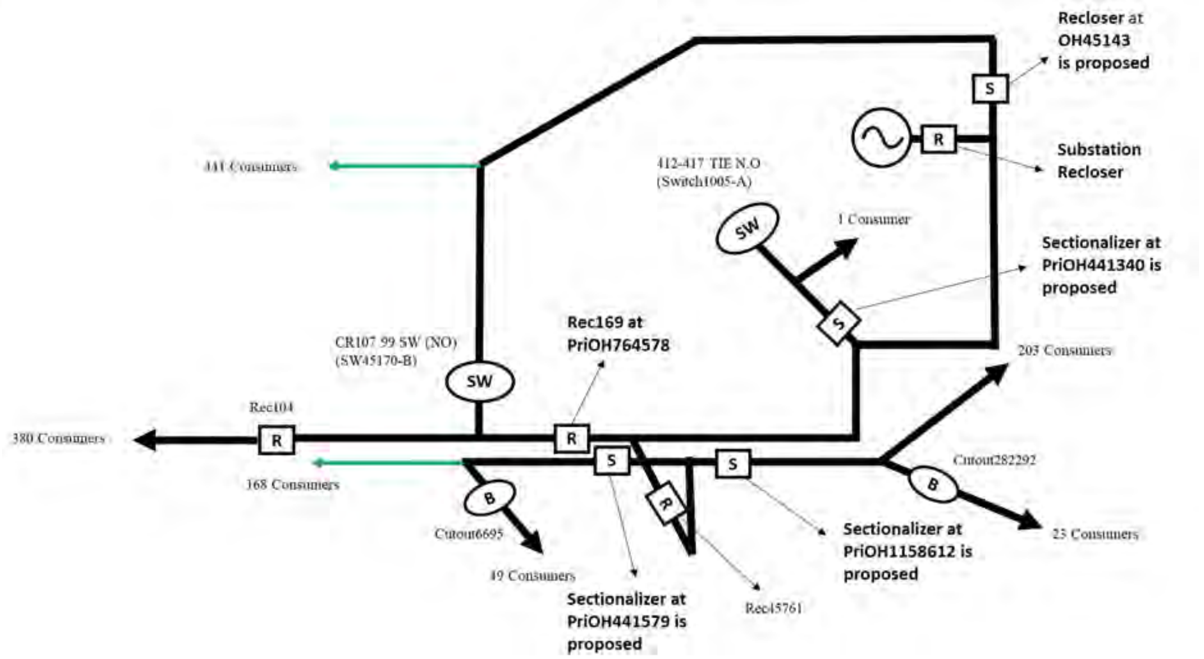

Figure 9-9: Equivalent One line diagram with proposed protective devices for feeder CNA-421

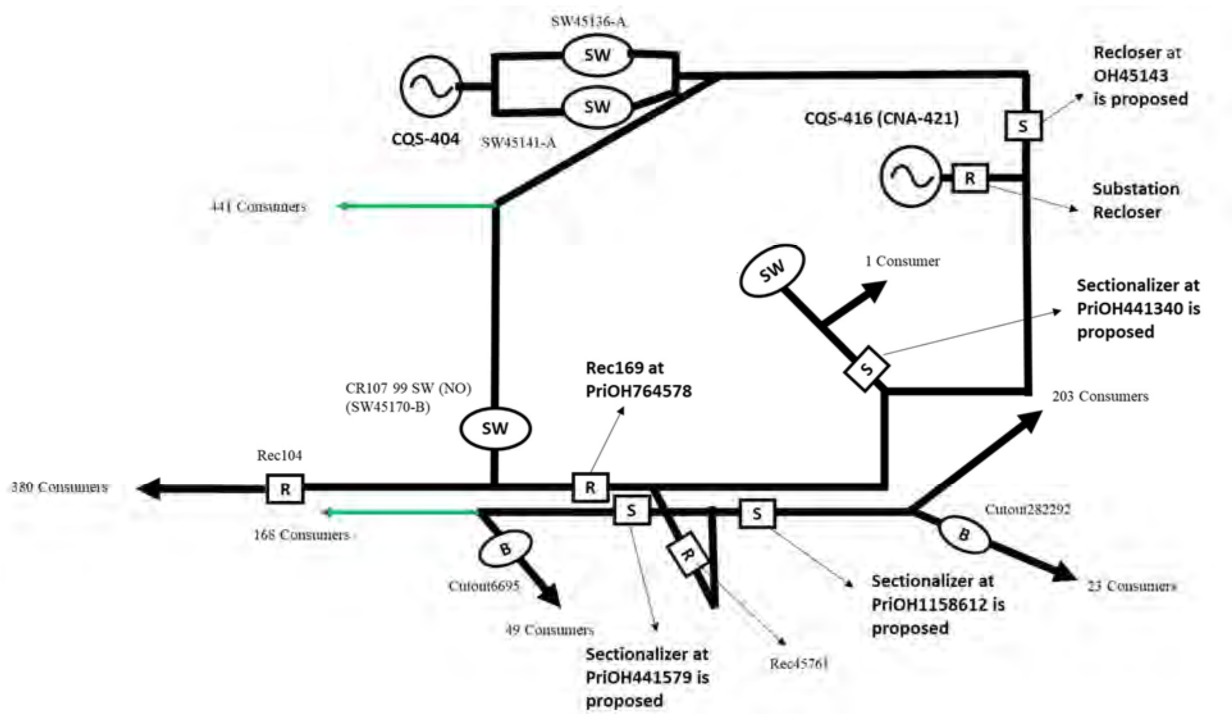

Figure 9-10: Equivalent One line diagram with proposed protective devices for Scenario 2

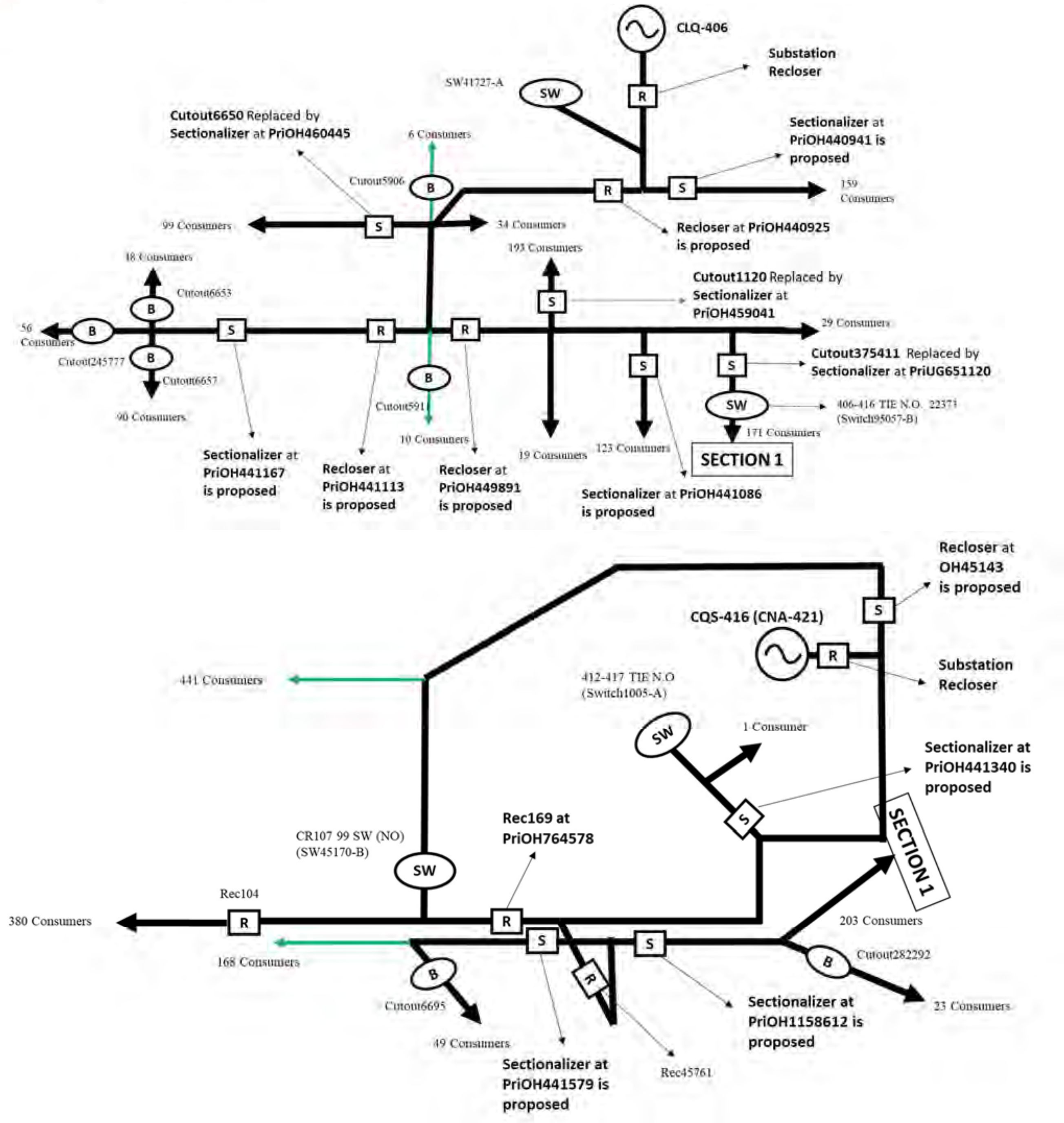

Figure 9-11: Equivalent One line diagram with proposed protective devices for Scenario 3 & 11

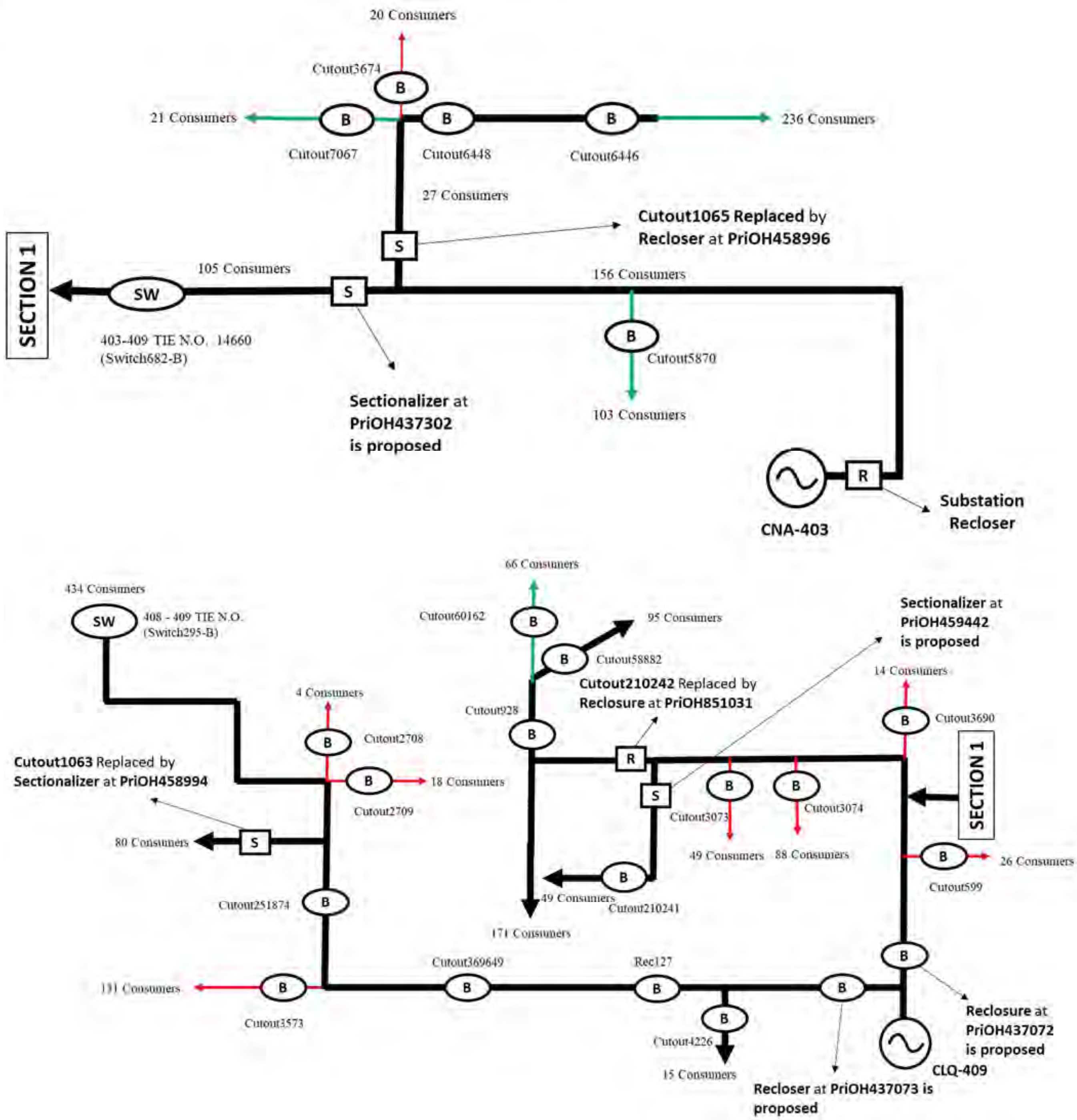

Figure 9-12: Equivalent One line diagram with proposed protective devices for Scenario 4 & 7

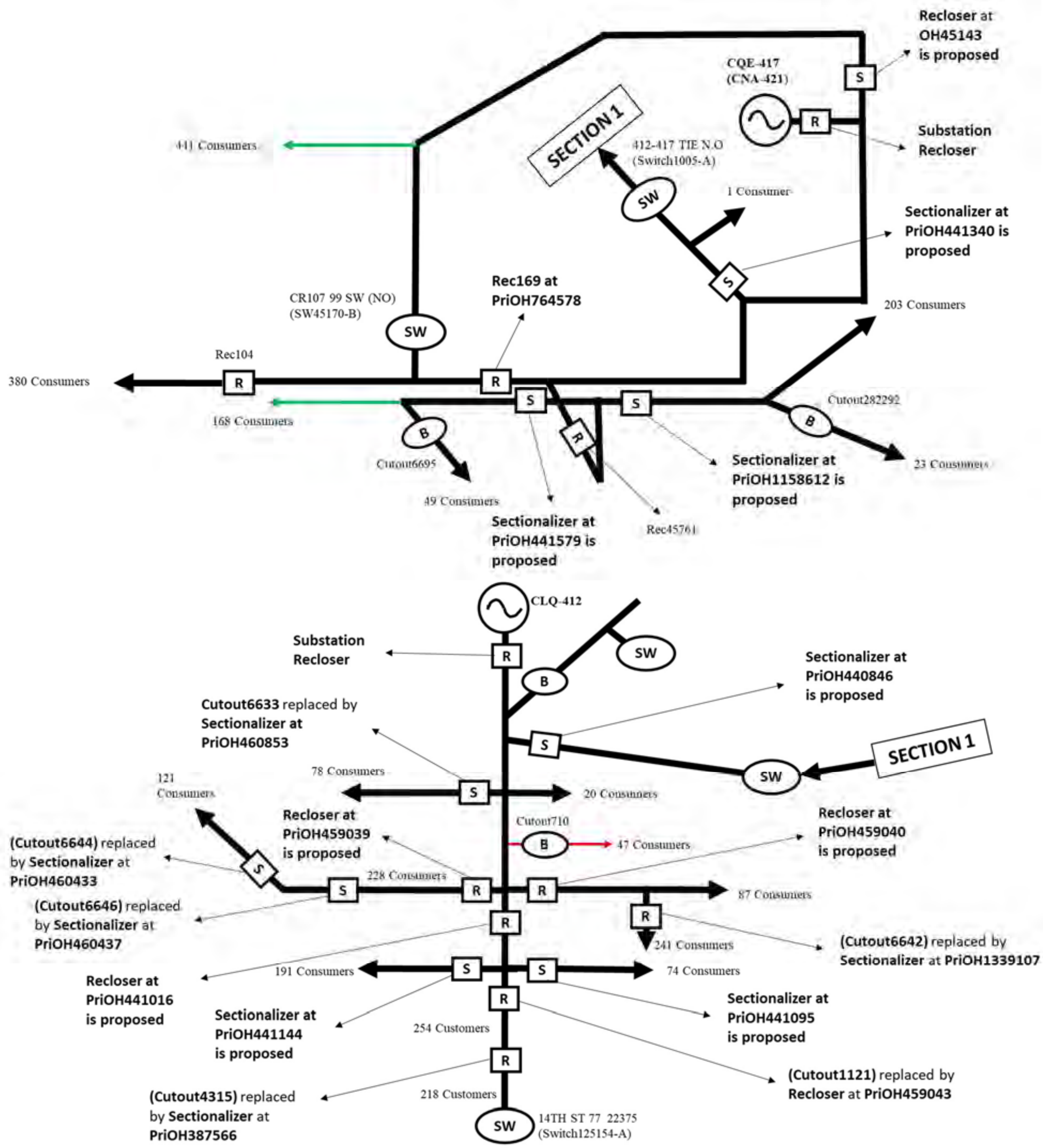

Figure 9-13: Equivalent One line diagram with proposed protective devices for Scenario 6 & 10

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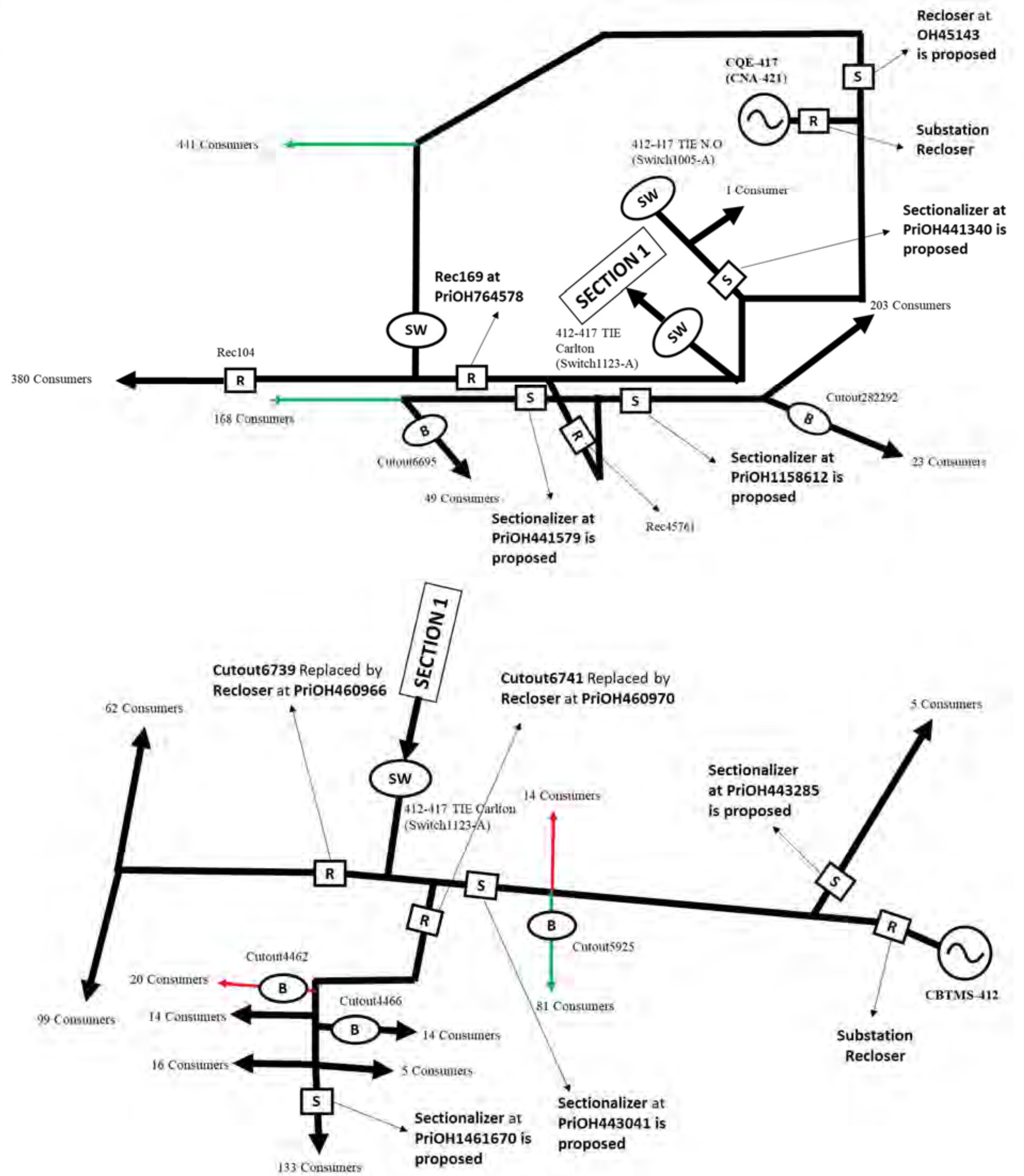

Figure 9-14: Equivalent One line diagram with proposed protective devices for Scenario 9

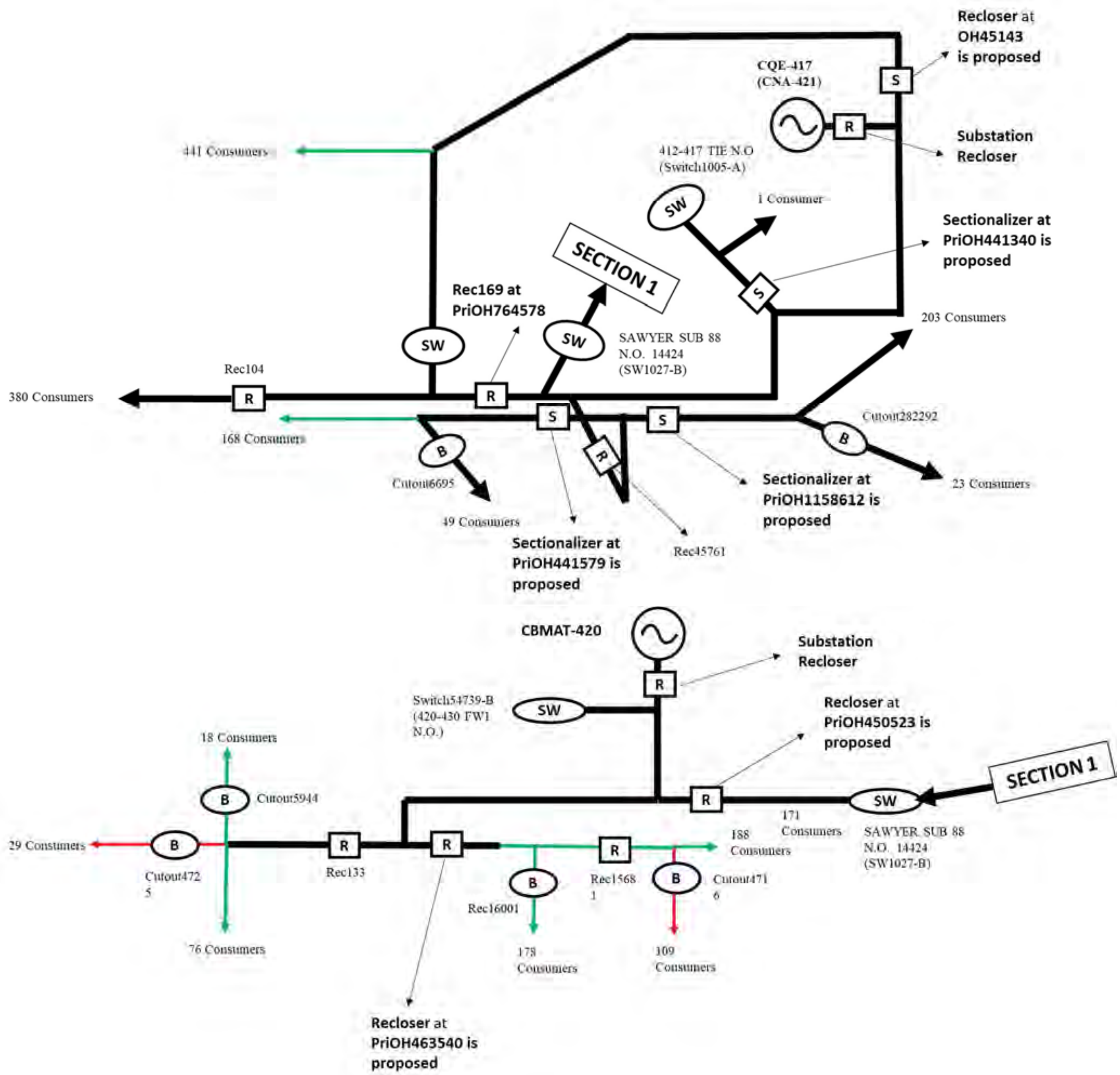

Figure 9-15: Equivalent One line diagram with proposed protective devices for Scenario 12 & 13

2022 Transmission-Distribution Substation Loading Summary[NOTE1,NOTE2]

Area	Substation	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	15th Ave West	115/14 kV	33.80	11.50	20.56	eDNA Historical Data
C	Bear Creek	69/46 kV	8.90	0.40	4.61	eDNA Historical Data Operated Networked
C	Big Rock	115/14 kV	5.20	2.40	3.26	eDNA Historical Data
C	Burnett	115/14 kV	1.96	0.39	0.96	Engineering Estimate
C	Canosia Road	115/14 kV	10.60	3.10	5.44	eDNA Historical Data
C	Cloquet	115/14 kV	29.91	10.55	19.66	eDNA Historical Data
C	Colbyville	115/14 kV	25.13	10.21	14.24	eDNA Historical Data
C	Four Corners	115/14 kV	13.63	4.82	7.61	eDNA Historical Data
C	French River	115/14 kV	5.20	0.70	2.37	eDNA Historical Data
C	Gary	115/14 kV	25.37	3.48	10.73	eDNA Historical Data
C	Haines Road	115/14 kV	24.22	8.94	13.92	eDNA Historical Data
C	Hibbard	115/14 kV	0.00	0.00	0.00	eDNA Historical Data
C	Hinckley East	69/46 kV	2.72	0.48	1.48	eDNA Historical Data (calc) Operated Networked
C	LSPI	115/14 kV	23.47	8.33	14.82	eDNA Historical Data
C	LSPI	115/34 kV	17.80	7.10	10.36	eDNA Historical Data
C	Mahtowa	115/23 kV	4.50	0.34	2.45	eDNA Historical Data
C	Mahtowa	115/46 kV	5.09	2.39	3.06	eDNA Historical Data
C	Meadowlands	115/14 kV	0.52	0.09	0.21	eDNA Historical Data
C	Ridgeview	115/14 kV	26.70	11.20	16.38	eDNA Historical Data
C	Floodwood/Savanna	115/14 kV	1.71	0.47	0.42	eDNA Historical Data
C	Silver Bay Hillside	115/14 kV	5.00	1.00	2.03	eDNA Historical Data
C	Swan Lake Road	115/34 kV	13.70	6.90	9.07	eDNA Historical Data
C	Swan Lake Road	115/14 kV	20.00	8.60	12.35	eDNA Historical Data
C	Taft	115/34 kV	6.18	1.98	3.05	eDNA Historical Data
C	Thomson	115/14 kV	5.06	1.78	2.38	eDNA Historical Data (calc)
C	Thomson	115/46 kV	1.59	0.16	0.76	eDNA Historical Data
C	Two Harbors	115/14 kV	8.20	-1.40	2.24	eDNA Historical Data
C	Wrenshall	115/14 kV	4.00	0.77	2.04	eDNA Historical Data
N	Babbitt	115/46 kV	5.10	1.60	2.65	eDNA Historical Data (calc) Operated Network
N	Big Fork Village	69/12 kV	1.80	0.60	0.91	eDNA Historical Data
N	Canisteo	115/14 kV	0.00	0.00	0.00	eDNA Historical Data
N	Diamond Lake	115/34 kV	0.00	0.00	0.00	eDNA Historical Data
N	Embarrass	115/23 kV	4.92	1.69	3.44	eDNA Historical Data
N	Hat Trick	115/23 kV	11.90	4.70	7.16	eDNA Historical Data
N	Hibbing	115/23 kV	39.60	7.54	19.43	eDNA Historical Data
N	International Falls	115/14 kV	13.78	5.79	6.75	eDNA Historical Data
N	Laskin	115/23 kV	2.21	0.94	0.38	eDNA Historical Data
N	Laskin	115/46 kV	2.47	0.25	0.77	eDNA Historical Data (calc)
N	Lind-Greenway	115/23 kV	5.02	0.27	2.31	eDNA Historical Data (calc)
N	Maturi	115/34 kV	0.00	0.00	0.00	eDNA Historical Data
N	Maturi	115/23 kV	1.90	0.40	0.91	eDNA Historical Data
N	Nashwauk	115/23 kV	5.97	1.78	3.50	eDNA Historical Data
N	Tower	115/46 kV	11.20	3.30	9.25	eDNA Historical Data (calc) Operated Network
N	Virginia	115/23 kV	23.98	9.59	14.76	eDNA Historical Data
N	Virginia	115/46 kV	6.53	1.85	3.67	eDNA Historical Data (calc) Operated Network
N	Zemple	115/23 kV	2.70	0.90	1.38	eDNA Historical Data
W	Akeley	115/34 kV	17.90	5.50	8.31	eDNA Historical Data
W	Baxter	115/34 kV	13.57	2.36	5.48	eDNA Historical Data
W	Blanchard	115/34 kV	18.85	-4.90	9.32	eDNA Historical Data
W	Dog Lake	115/34 kV	11.10	2.60	6.51	eDNA Historical Data
W	Eagle Valley	115/34 kV	14.60	3.90	7.47	eDNA Historical Data
W	Little Falls	115/34 kV	40.18	14.41	22.81	eDNA Historical Data
W	Long Prairie	115/34 kV	25.81	10.27	16.78	eDNA Historical Data
W	Pepin Lake	115/34 kV	13.10	4.50	7.39	eDNA Historical Data
W	Pequot Lakes	115/34 kV	14.00	4.10	7.37	eDNA Historical Data
W	Pine River	115/34 kV	5.70	2.70	0.87	eDNA Historical Data

2022 Transmission-Distribution Substation Loading Summary[NOTE1,NOTE2]

Area	Substation	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Platte River	115/34 kV	5.40	0.30	3.27	eDNA Historical Data
W	Riverton	115/34 kV	18.22	6.25	8.77	eDNA Historical Data
W	Straight River	115/34 kV	1.80	0.50	1.16	eDNA Historical Data
W	Verndale	115/34 kV	32.49	12.64	18.62	eDNA Historical Data

NOTES

1. Values in table are non-coincident and shouldn't be added together

2. Values represent real power loading (MW) only; apparent power loading (MVA) will generally be slightly higher

3. Daytime Minimum corresponds to minimum hourly load between 0800-1800 where available or 20% of peak load where direct data is not available

4. Except as noted, values are based on hourly load data from the MP eDNA Data Historian at the distribution bus

5. Where possible, the effective load reduction from large-scale distribution-connected generation has been excluded

2022 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	Bear Creek - Hinckley	BCR-198	46 kV	6.60	0.90	3.26	eDNA Historical Data Operated Network
C	Bear Creek	BCR-23	46 kV	2.00	0.50	1.06	eDNA Historical Data
C	Bear Creek	MAT-59	46 kV	0.80	0.30	0.30	eDNA Historical Data
C	Big Rock	BGR-272	14 kV	5.20	2.40	3.26	eDNA Historical Data
C	Big Rock	BGR-274	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	Burnett	BUR-407	14 kV	0.27	0.05	0.00	Engineering Estimate
C	Burnett	BUR-408	14 kV	1.69	0.22	0.83	Aclara
C	Cloquet	CLQ-404	14 kV	9.68	1.67	5.99	eDNA Historical Data
C	Cloquet	CLQ-406	14 kV	10.70	4.80	6.26	eDNA Historical Data
C	Cloquet	CLQ-409	14 kV	7.62	3.08	4.14	eDNA Historical Data
C	Cloquet	CLQ-410	14 kV	3.96	1.35	2.57	eDNA Historical Data
C	Cloquet	CLQ-412	14 kV	0.41	-0.10	0.70	eDNA Historical Data
C	Canosia Road	CNA-403	14 kV	1.70	0.40	0.80	eDNA Historical Data
C	Canosia Road	CNA-405	14 kV	5.00	1.50	2.68	eDNA Historical Data
C	Canosia Road	CNA-413	14 kV	4.10	1.10	1.97	eDNA Historical Data
C	Colbyville	COL-240	14 kV	7.77	2.23	4.07	eDNA Historical Data
C	Colbyville	COL-241	14 kV	4.19	1.41	2.17	eDNA Historical Data
C	Colbyville	COL-242	14 kV	7.01	2.96	4.14	eDNA Historical Data
C	Colbyville	COL-244	14 kV	5.66	1.94	2.79	eDNA Historical Data
C	Colbyville	COL-245	14 kV	1.76	0.24	1.07	eDNA Historical Data
C	Four Corners	FCS-214	14 kV	7.80	3.05	4.56	eDNA Historical Data
C	Four Corners	FCS-215	14 kV	6.02	1.43	3.05	eDNA Historical Data
C	15th Ave West	FIF-219	14 kV	6.80	0.10	3.40	eDNA Historical Data
C	15th Ave West	FIF-220	14 kV	2.00	0.80	1.24	eDNA Historical Data
C	15th Ave West	FIF-221	14 kV	2.90	0.10	0.60	eDNA Historical Data
C	15th Ave West	FIF-222	14 kV	0.40	0.00	0.11	eDNA Historical Data
C	15th Ave West	FIF-226	14 kV	3.40	1.00	1.71	eDNA Historical Data
C	15th Ave West	FIF-228	14 kV	3.10	1.10	1.92	eDNA Historical Data
C	15th Ave West	FIF-230	14 kV	5.90	2.80	4.02	eDNA Historical Data
C	15th Ave West	FIF-231	14 kV	2.10	0.20	0.87	eDNA Historical Data

2022 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	15th Ave West	FIF-232	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	15th Ave West	FIF-233	14 kV	2.90	0.90	1.57	eDNA Historical Data
C	15th Ave West	FIF-234	14 kV	0.50	0.10	0.24	eDNA Historical Data
C	15th Ave West	FIF-260	14 kV	5.50	2.30	1.23	eDNA Historical Data
C	15th Ave West	FIF-261	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	15th Ave West	FIF-264	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	15th Ave West	FIF-265	14 kV	2.20	0.90	1.47	eDNA Historical Data
C	15th Ave West	FIF-266	14 kV	3.50	1.40	2.16	eDNA Historical Data
C	Floodwood/Savanna	FLF-402	14 kV	1.71	0.39	0.42	eDNA Historical Data
C	French River	FRR-275	14 kV	3.30	0.70	1.48	eDNA Historical Data
C	French River	FRR-276	14 kV	2.10	0.40	0.89	eDNA Historical Data
C	Gary	GRY-200	14 kV	3.49	1.20	1.77	eDNA Historical Data
C	Gary	GRY-201	14 kV	4.92	1.35	2.39	eDNA Historical Data
C	Gary	GRY-210	14 kV	4.72	0.51	3.48	eDNA Historical Data
C	Haines Road	HNS-229	14 kV	7.95	3.74	4.86	eDNA Historical Data
C	Haines Road	HNS-235	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	Haines Road	HNS-236	14 kV	8.66	2.39	3.69	eDNA Historical Data
C	Haines Road	HNS-237	14 kV	3.62	1.39	2.00	eDNA Historical Data
C	Haines Road	HNS-238	14 kV	2.56	0.69	1.25	eDNA Historical Data
C	Haines Road	HNS-239	14 kV	1.33	0.28	0.68	eDNA Historical Data
C	Haines Road	HNS-247	14 kV	2.56	1.10	1.44	eDNA Historical Data
C	Hinckley East	HKZ-463	14 kV	2.72	0.48	1.48	eDNA Historical Data (calc) Operated Networked
C	LSPI	LSP-208	34 kV	8.80	3.70	5.40	eDNA Historical Data
C	LSPI	LSP-223	14 kV	8.31	3.40	4.91	eDNA Historical Data
C	LSPI	LSP-224	14 kV	3.86	0.22	0.90	eDNA Historical Data
C	LSPI	LSP-225	14 kV	5.99	2.07	3.43	eDNA Historical Data
C	LSPI	LSP-280	14 kV	5.20	1.41	3.15	eDNA Historical Data
C	LSPI	LSP-281	14 kV	3.37	1.30	1.87	eDNA Historical Data
C	LSPI	LSP-282	14 kV	0.75	0.25	0.41	eDNA Historical Data
C	Mahtowa	MAT-420	23 kV	4.50	0.34	2.45	eDNA Historical Data

2022 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	Meadowlands	MDL-401	14 kV	0.52	0.09	0.21	eDNA Historical Data
C	Hibbard	MLH-267	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	Hibbard	MLH-268	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	Hibbard	MLH-279	14 kV	0.00	0.00	0.00	eDNA Historical Data
C	Ridgeview	RGV-251	14 kV	2.30	0.70	1.23	eDNA Historical Data
C	Ridgeview	RGV-252	14 kV	7.30	3.00	4.34	eDNA Historical Data
C	Ridgeview	RGV-253	14 kV	4.70	1.40	2.61	eDNA Historical Data
C	Ridgeview	RGV-254	14 kV	4.90	2.10	3.01	eDNA Historical Data
C	Ridgeview	RGV-255	14 kV	7.00	3.20	4.31	eDNA Historical Data
C	Ridgeview	RGV-256	14 kV	1.60	0.60	0.88	eDNA Historical Data
C	Silver Bay Hillside	SBH-271	14 kV	5.00	1.00	2.03	eDNA Historical Data (calc)
C	Swan Lake	SLA-203	34 kV	13.70	6.90	9.07	eDNA Historical Data
C	Swan Lake	SLA-250	14 kV	8.50	3.50	5.25	eDNA Historical Data
C	Swan Lake	SLA-257	14 kV	5.80	2.50	3.45	eDNA Historical Data
C	Swan Lake	SLA-258	14 kV	6.30	2.20	3.64	eDNA Historical Data
C	Taft	TFT-202	34 kV	6.18	1.98	3.05	eDNA Historical Data
C	Thomson	TMS-412	14 kV	5.06	1.78	2.38	eDNA Historical Data (calc)
C	Thomson	TMS-23	46 kV	1.59	0.16	0.76	eDNA Historical Data
C	Two Harbors	TWH-273	14 kV	8.20	-1.40	2.24	eDNA Historical Data (calc)
C	Wrenshall	WRN-411	14 kV	4.00	0.77	2.04	eDNA Historical Data
N	Laskin	AUR-313	23 kV	2.21	0.94	0.38	eDNA Historical Data
N	Laskin	30 LINE	46 kV	1.52	0.61	0.56	eDNA Historical Data
N	Babbitt-Winton	31 LINE	46 kV	5.10	1.60	2.65	eDNA Historical Data (calc)
N	Big Fork	BFV-1	12 kV	1.80	0.60	0.91	eDNA Historical Data
N	Canisteo	CNS-382	14 kV	0.00	0.00	0.00	eDNA Historical Data
N	Diamond Lake	DML-380	34 kV	0.00	0.00	0.00	eDNA Historical Data
N	Embarrass	EMB-317	23 kV	4.92	1.69	3.44	eDNA Historical Data
N	Grand Rapids	GRR-325	23 kV	0.30	0.10	1.52	eDNA Historical Data
N	Hat Trick	HAT-321	23 kV	7.10	2.10	4.08	eDNA Historical Data
N	Hat Trick	HAT-332	23 kV	4.50	1.80	3.08	eDNA Historical Data
N	Hibbing	HIB-307	23 kV	15.47	4.13	5.17	eDNA Historical Data

2022 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
N	Hibbing	HIB-308	23 kV	4.88	1.45	3.54	eDNA Historical Data
N	Hibbing	HIB-310	23 kV	7.41	2.59	4.09	eDNA Historical Data
N	Hibbing	HIB-312	23 kV	7.31	0.28	2.72	eDNA Historical Data
N	Hibbing	HIB-315	23 kV	1.25	0.31	0.75	eDNA Historical Data
N	International Falls	INF-1	12 kV	2.25	0.84	1.31	eDNA Historical Data
N	International Falls	INF-2	12 kV	4.45	1.65	2.32	eDNA Historical Data
N	International Falls	INF-3	12 kV	4.10	1.81	1.78	eDNA Historical Data
N	International Falls	INF-4	12 kV	3.38	1.20	1.34	eDNA Historical Data
N	International Falls	INF-5	12 kV	0.00	0.00	0.00	eDNA Historical Data
N	Lind-Greenway	LGW-334	23 kV	2.08	0.24	1.04	eDNA Historical Data (calc)
N	Lind-Greenway	LGW-335	23 kV	3.12	0.36	1.57	eDNA Historical Data (calc)
N	Maturi	MTU-330	23 kV	1.90	0.40	0.91	eDNA Historical Data
N	Maturi	MTU-381	34 kV	0.00	0.00	0.00	eDNA Historical Data
N	Nashwauk	NAS-314	23 kV	2.88	1.08	1.63	eDNA Historical Data
N	Nashwauk	NAS-318	23 kV	0.09	0.02	0.96	eDNA Historical Data
N	Nashwauk	NAS-319	23 kV	3.31	0.98	0.92	eDNA Historical Data
N	Tower-Winton	TOW-32	46 kV	8.70	3.00	7.36	eDNA Historical Data (calc)
N	Virginia	VRG-301	23 kV	2.78	0.81	1.46	eDNA Historical Data
N	Virginia	VRG-302	23 kV	6.72	2.35	3.49	eDNA Historical Data
N	Virginia	VRG-303	23 kV	1.81	0.94	1.11	eDNA Historical Data
N	Virginia	VRG-304	23 kV	0.80	0.16	0.45	eDNA Historical Data
N	Virginia	VRG-305	23 kV	0.41	0.03	0.38	eDNA Historical Data
N	Virginia	VRG-306	23 kV	13.00	3.66	6.51	eDNA Historical Data
N	Virginia	VRG-311	23 kV	2.56	0.53	1.37	eDNA Historical Data
N	Virginia	30 LINE	46 kV	3.69	0.47	1.78	eDNA Historical Data
N	Virginia-Tower	199 LINE	46 kV	3.40	0.80	1.89	eDNA Historical Data (calc)
N	Winton	33 LINE	46 kV	12.60	3.10	2.76	eDNA Historical Data
N	Zemple	ZMP-335	23 kV	0.00	0.00	0.00	eDNA Historical Data
N	Zemple	ZMP-337	23 kV	2.70	0.90	1.38	eDNA Historical Data
W	Akeley	AKY-543	34 kV	9.80	3.40	4.82	eDNA Historical Data
W	Akeley	AKY-544	34 kV	9.80	1.80	3.48	eDNA Historical Data

2022 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Baxter	BAX-531	34 kV	5.74	1.15	2.59	eDNA Historical Data
W	Baxter	BAX-534	34 kV	6.22	2.07	2.88	eDNA Historical Data
W	Blanchard	BLD-508	34 kV	4.77	-7.80	1.49	eDNA Historical Data
W	Blanchard	BLD-511	34 kV	6.73	2.01	2.93	eDNA Historical Data
W	Blanchard	BLD-521	34 kV	2.30	0.60	1.16	eDNA Historical Data
W	Blanchard	BLD-524	34 kV	4.07	1.58	3.74	eDNA Historical Data
W	Birch Lake	BLS-509	34 kV	8.50	2.10	4.47	eDNA Historical Data
W	Birch Lake	BLS-516	34 kV	5.20	0.60	2.15	eDNA Historical Data
W	Blueberry	BLU-552	34 kV	8.00	2.40	5.02	eDNA Historical Data
W	Dog Lake	DOG-503	34 kV	11.10	2.60	6.51	eDNA Historical Data
W	Eagle Valley	EGV-513	34 kV	5.30	1.20	2.57	eDNA Historical Data
W	Eagle Valley	EGV-517	34 kV	10.40	2.90	4.90	eDNA Historical Data
W	Little Falls	LFL-525	34 kV	13.65	5.49	9.04	eDNA Historical Data
W	Little Falls	LFL-526	34 kV	9.99	3.33	5.35	eDNA Historical Data
W	Little Falls	LFL-529	34 kV	13.69	2.84	6.08	eDNA Historical Data
W	Little Falls	LFL-536	34 kV	5.20	1.27	2.34	eDNA Historical Data
W	Long Lake	LNG-540	34 kV	0.20	0.00	0.03	eDNA Historical Data
W	Long Lake	LNG-541	34 kV	10.40	3.20	5.00	eDNA Historical Data
W	Long Lake	LNG-542	34 kV	7.40	1.80	4.36	eDNA Historical Data
W	Long Lake	LNG-545	34 kV	3.20	0.40	1.47	eDNA Historical Data
W	Long Prairie	LPR-501	34 kV	7.64	0.85	4.30	eDNA Historical Data
W	Long Prairie	LPR-527	34 kV	6.66	2.23	4.03	eDNA Historical Data
W	Long Prairie	LPR-535	34 kV	13.99	4.74	8.44	eDNA Historical Data
W	Platte River	PLA-546	34 kV	2.40	-0.60	1.65	eDNA Historical Data
W	Platte River	PLA-547	34 kV	4.00	0.70	1.62	eDNA Historical Data
W	Pine River	PNV-549	34 kV	4.00	2.30	0.59	eDNA Historical Data
W	Pine River	PNV-550	34 kV	1.90	0.30	0.29	eDNA Historical Data
W	Pepin Lake	PPL-514	34 kV	9.40	3.30	5.26	eDNA Historical Data
W	Pepin Lake	PPL-539	34 kV	3.90	1.00	2.14	eDNA Historical Data
W	Pequot Lakes	PQT-507	34 kV	6.40	2.50	3.48	eDNA Historical Data
W	Pequot Lakes	PQT-531	34 kV	8.00	2.30	3.89	eDNA Historical Data

2022 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Riverton	RVT-505	34 kV	5.13	1.70	2.82	eDNA Historical Data
W	Riverton	RVT-506	34 kV	7.07	2.92	1.67	eDNA Historical Data
W	Riverton	RVT-530	34 kV	2.39	0.59	1.35	eDNA Historical Data
W	Riverton	RVT-532	34 kV	9.42	0.14	2.93	eDNA Historical Data
W	Straight River	STG-551	34 kV	1.80	0.50	1.16	eDNA Historical Data
W	Sylvan	SYL-502	34 kV	0.40	0.10	0.21	eDNA Historical Data
W	Verndale	VRD-503	34 kV	8.72	3.42	5.06	eDNA Historical Data
W	Verndale	VRD-510	34 kV	4.78	1.17	1.89	eDNA Historical Data
W	Verndale	VRD-519	34 kV	3.89	0.23	1.87	eDNA Historical Data
W	Verndale	VRD-533	34 kV	16.50	5.96	9.80	eDNA Historical Data

NOTES

1. Values in table are non-coincident and shouldn't be added together

2. Values represent real power loading (MW) only; apparent power loading (MVA) will generally be slightly higher

3. Daytime Minimum corresponds to minimum hourly load between 0800-1800 where available or 20% of peak load where direct data is not available

4. Except as noted, values are based on hourly load data from the MP eDNA Data Historian

5. Where possible, the effective load reduction from large-scale distribution-connected generation has been excluded

2022 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area		Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	Bear Creek	BCR 23 LINE	Askov	ASK-6521	12 kV	1.53	0.31	N/A	Aclara
C	Bear Creek	BCR 23 LINE	Kerrick	KER-6501	12 kV	0.72	0.14	N/A	Aclara
C	Bear Creek	59 LINE	Anderson Corner	FIN-6511	12 kV	2.27	0.45	N/A	Aclara
C	Bear Creek - Hinckley	198 LINE	Sandstone	SNT-452	12 kV	1.38	0.28	N/A	Engineering Estimate
C	Bear Creek - Hinckley	198 LINE	Hinckley West	HKZ-461	14 kV	1.13	0.23	N/A	Engineering Estimate
C	Bear Creek - Hinckley	198 LINE	Hinckley West	HKZ-462	14 kV	4.09	0.82	N/A	Engineering Estimate
C	Cloquet	CLQ-409	Big Lake	CQB-6301	12 kV	1.25	0.25	N/A	Engineering Estimate
C	Taft	TFT-202	Fredenburg	FBG-269	14 kV	3.32	0.66	N/A	Aclara
C	Taft	TFT-202	Pioneer Rd	PIO-270	14 kV	3.88	0.78	N/A	Aclara
C	Mahtowa	59 LINE	Barnum	BAR-6421	12 kV	2.23	0.45	N/A	Aclara
C	Mahtowa	59 LINE	Denham	DEN-6431	12 kV	6.18	1.24	N/A	Aclara
C	Mahtowa	MAT-420	Mahtowa	MAH-6411	12 kV	1.55	0.31	N/A	Aclara
C	Mahtowa	MAT-420	Olsonville East	OLE-4471	4 kV	0.36	0.07	N/A	Engineering Estimate
C	Mahtowa	MAT-420	Olsonville West	OLW-4471	4 kV	0.36	0.07	N/A	Engineering Estimate
C	Scanlon	SCH-420	Sawyer	SAW-6311	12 kV	1.04	0.21	N/A	Aclara
C	Scanlon	SCH-420	Moorhead Rd	MHR-451	14 kV	1.34	0.27	N/A	Aclara
C	Silver Bay Hillside	SBH-271	Silver Bay Townsite	SBT-4301	4 kV	1.14	0.23	N/A	Aclara
C	Silver Bay Hillside	SBH-271	Silver Bay Townsite	SBT-4302	4 kV	0.24	0.05	N/A	Engineering Estimate
C	Thomson	TMS-412	Scanlon	SCH-420	23 kV	2.20	0.44	N/A	eDNA Historical Data
C	Thomson	TMS 23 LINE	Military Rd	MLT-414	14 kV	1.58	0.16	0.76	eDNA Historical Data
C	Wrenshall	WRN-411	Wrenshall Riverside	WRR-6321	12 kV	4.17	0.83	N/A	Aclara
C	LSPI	LSP-208	25th Ave West	TFW-243	14 kV	3.30	0.66	N/A	eDNA Historical Data
C	Swan Lake	SLA-203	2nd Ave East	SND-217	14 kV	4.10	0.82	N/A	eDNA Historical Data
C	Swan Lake	SLA-203	2nd Ave East	SND-218	14 kV	2.90	0.58	N/A	eDNA Historical Data
C	LSPI	LSP-208	4th Ave West	FOR-262	14 kV	2.00	0.40	N/A	eDNA Historical Data
C	LSPI	LSP-208	4th Ave West	FOR-263	14 kV	3.00	0.60	N/A	eDNA Historical Data
C	Swan Lake	SLA-203	9th Ave East	NIN-246	14 kV	2.50	0.50	N/A	eDNA Historical Data
C	Swan Lake	SLA-203	9th Ave East	NIN-248	14 kV	3.20	0.64	N/A	eDNA Historical Data
C	Four Corners	FCS-214	Caribou Lake	CBL-214	12 kV	1.26	0.25	N/A	Aclara
C	Four Corners	FCS-214	Pike Lake	PLR-214	12 kV	0.50	0.10	N/A	Aclara
C	Four Corners	FCS-215	Seville Rd	SVR-215	12 kV	2.25	0.45	N/A	Engineering Estimate
N	Embarrass	EMB-317	Aurora	AUN-1	4 kV	1.68	0.34	N/A	Aclara
N	Embarrass	EMB-317	Aurora	AUN-2	4 kV	3.69	0.74	N/A	Aclara
N	Babbitt	31 LINE	Babbitt Townsite	BAB-1	4 kV	3.28	0.66	N/A	Aclara
N	Babbitt	31 LINE	Babbitt Townsite	BAB-2	4 kV	0.40	0.08	N/A	Aclara
N	Hibbing	HIB-310	Balkan	BAL-1	12 kV	1.09	0.22	N/A	Aclara
N	Hibbing	HIB-310	Balkan	BAL-2	12 kV	0.33	0.07	N/A	Aclara
N	Embarrass	EMB-317	Biwabik	BIW-1	12 kV	1.72	0.34	N/A	Aclara
N	Embarrass	EMB-317	Biwabik	BIW-2	12 kV	1.46	0.29	N/A	Engineering Estimate
N	Hibbing	HIB-310	Chisholm	CHL-1	4 kV	2.28	0.46	N/A	Aclara
N	Hibbing	HIB-310	Chisholm	CHL-2	4 kV	1.17	0.23	N/A	Aclara
N	Hibbing	HIB-310	Chisholm	CHL-3	4 kV	2.05	0.41	N/A	Aclara
N	Lind-Greenway	LGW-335	Cohasset	COA-1	4 kV	0.15	0.03	N/A	Engineering Estimate
N	Lind-Greenway	LGW-334	Coleraine COE	COE-1	4 kV	0.08	0.02	N/A	Engineering Estimate
N	Lind-Greenway	LGW-334	Coleraine COF	COF-1	4 kV	0.16	0.03	N/A	Engineering Estimate
N	Zemple	ZMP-337	Deer River DRR	DRR-2	4 kV	1.49	0.30	N/A	Aclara
N	Zemple	ZMP-337	Deer River DRV	DRV-1	4 kV	0.03	0.01	N/A	Engineering Estimate

2022 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area		Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
N	Zemple	ZMP-337	Deer River DRW	DRW-1	4 kV	0.03	0.01	N/A	Engineering Estimate
N	Babbitt	31 LINE	Dunka River	DUN-1	4 kV	0.51	0.10	N/A	Aclara
N	Hat Trick	HAT-321	Ely Lake Olaughlin EOQ	EOQ-1	4 kV	0.05	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Ely Lake Olaughlin EOS	EOS-1	4 kV	0.03	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Ely Lake Shady Lane	ESL-1	4 kV	0.03	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Eveleth	ESS-1	4 kV	2.53	0.51	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Eveleth	ESS-2	4 kV	0.79	0.16	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Ely Lake Woodlawn Pt	EWP-1	4 kV	0.02	0.00	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Half Moon Lake	HML-1	4 kV	0.14	0.03	N/A	Engineering Estimate
N	Laskin	AUR-313	Hoyt Lakes	HYN-1	4 kV	0.60	0.12	N/A	Aclara
N	Laskin	AUR-313	Hoyt Lakes	HYN-2	4 kV	2.03	0.41	N/A	Aclara
N	Virginia	VRG-311	Iron Bowl North	IBN-1	4 kV	0.08	0.02	N/A	Engineering Estimate
N	Virginia	VRG-311	Iron Bowl South	IBS-1	4 kV	0.08	0.02	N/A	Engineering Estimate
N	Virginia	VRG-311	Iron	INJ-1	12 kV	1.11	0.22	N/A	Aclara
N	Hibbing	HIB-315	Kelly Lake	KLY-1	4 kV	0.60	0.12	N/A	Aclara
N	Laskin	AUR-313	Laskin Energy Park	LEP-1	4 kV	0.61	0.12	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Marble	MAR-1	4 kV	0.69	0.14	N/A	Aclara
N	Hat Trick	HAT-332	Eveleth OHV	OHV-1	4 kV	0.02	0.00	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Pengilly North	PNN-1	4 kV	0.16	0.03	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Pengilly South	PNS-1	4 kV	0.16	0.03	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Rural Camp Warren	RCW-1	4 kV	0.05	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Rural Long Lake Rd	RLL-1	4 kV	0.01	0.00	N/A	Engineering Estimate
N	Winton	33 LINE	St. Croix	STC-1	12 kV	0.37	0.07	N/A	Aclara
N	Winton	33 LINE	St. Croix	STC-2	12 kV	1.56	0.31	N/A	Aclara
N	Maturi	MTU-330	Stuntz	STZ-1	4 kV	0.39	0.08	N/A	Engineering Estimate
N	Maturi	MTU-330	Stuntz	STZ-2	4 kV	0.74	0.15	N/A	Aclara
N	Maturi	MTU-330	Spudville East	SVE-1	4 kV	0.18	0.04	N/A	Aclara
N	Maturi	MTU-330	Spudville West	SVW-1	4 kV	0.28	0.06	N/A	Aclara
N	Hibbing	HIB-308	Stuntz Wilpen Bridge	SWB-1	4 kV	0.20	0.04	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Taconite Village	TAC-1	4 kV	0.30	0.06	N/A	Engineering Estimate
N	Tower	32 LINE	Tower Soudan	TWN-1	12 kV	1.67	0.33	N/A	Aclara
N	Tower	32 LINE	Tower Soudan	TWN-2	12 kV	1.74	0.35	N/A	Aclara
N	Virginia	VRG-311	West Eveleth Hwy 101	WEH-1	4 kV	0.01	0.00	N/A	Engineering Estimate
W	Akeley	AKY-543	Akeley Dist	AKE-1	4 kV	1.13	0.23	N/A	Aclara
W	Verndale	VRD-503	Aldrich	ALD-1	4 kV	0.67	0.13	N/A	Aclara
W	Birch Lake	BLS-516	Backus	BAC-1	12 kV	2.21	0.44	N/A	Aclara
W	Long Prairie	LPR-535	Big Bear	BBR-1	12 kV	1.20	0.24	N/A	Engineering Estimate
W	Eagle Valley	EGV-513	Bertha	BER-1	12 kV	0.88	0.18	N/A	Aclara
W	Verndale	VRD-510	Blue Grass	BLG-1	4 kV	0.08	0.02	N/A	Engineering Estimate
W	Eagle Valley	EGV-517	Browerville	BRW-1	12 kV	1.21	0.24	N/A	Aclara
W	Eagle Valley	EGV-517	Browerville	BRW-2	12 kV	1.03	0.21	N/A	Aclara
W	Blanchard	BLD-524	Bowlus	BSD-1	12 kV	0.28	0.06	N/A	Engineering Estimate
W	Blanchard	BLD-524	Bowlus	BSD-2	12 kV	1.25	0.25	N/A	Aclara
W	Eagle Valley	EGV-517	Clarissa	CLR-1	12 kV	1.40	0.28	N/A	Aclara
W	Eagle Valley	EGV-517	Clarissa	CLR-2	12 kV	0.28	0.06	N/A	Aclara
W	Blanchard	BLD-508	Camp Ripley Rural	CRS-1	12 kV	0.74	0.15	N/A	Aclara
W	Riverton	RVT-506	Cotton Tail Drive	CTD-1	12 kV	0.15	0.03	N/A	Engineering Estimate

2022 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area		Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Riverton	RVT-505	Crosby	CSB-1	4 kV	3.20	0.64	N/A	Engineering Estimate
W	Riverton	RVT-505	Crosby	CSB-2	4 kV	2.40	0.48	N/A	Engineering Estimate
W	Riverton	RVT-506	Cuyuna	CUY-1	4 kV	0.23	0.05	N/A	Aclara
W	Riverton	RVT-506	Deerwood	DER-1	12 kV	1.60	0.32	N/A	Aclara
W	Riverton	RVT-506	Deerwood	DER-2	12 kV	2.35	0.47	N/A	Aclara
W	Riverton	RVT-506	Deerwood Highway	DHY-1	12 kV	0.23	0.05	N/A	Aclara
W	Long Lake	LNG-540	Dorset	DOR-1	4 kV	0.32	0.06	N/A	Engineering Estimate
W	Long Lake	LNG-541	Explorer Circle	ECS-1	4 kV	0.15	0.03	N/A	Engineering Estimate
W	Eagle Valley	EGV-513	Eagle Bend	EGB-1	12 kV	1.36	0.27	N/A	Aclara
W	Pepin Lake	PPL-514	Flensburg	FLN-1	12 kV	0.19	0.04	N/A	Aclara
W	Pepin Lake	PPL-514	Flensburg	FLN-2	12 kV	0.77	0.15	N/A	Aclara
W	Sylvan	SYL-502	Fort Ripley	FTR-1	4 kV	0.25	0.05	N/A	Engineering Estimate
W	Pepin Lake	PPL-539	Grey Eagle	GES-1	12 kV	1.54	0.31	N/A	Aclara
W	Long Prairie	LPR-527	Gutches Grove	GGR-1	12 kV	2.09	0.42	N/A	Aclara
W	Blanchard	BLD-508	Ginger Rd	GIN-1	12 kV	1.36	0.27	N/A	Aclara
W	Baxter	BAX-531	Gull Lake	GLL-1	12 kV	3.73	0.75	N/A	Engineering Estimate
W	Baxter	BAX-531	Gull Lake	GLL-2	12 kV	1.57	0.31	N/A	Aclara
W	Birch Lake	BLS-509	Hackensack	HCS-1	12 kV	1.94	0.39	N/A	Aclara
W	Verndale	VRD-519	Hewitt	HEW-1	12 kV	0.29	0.06	N/A	Aclara
W	Baxter	BAX-531	Hole in the Day	HID-1	12 kV	1.59	0.32	N/A	Aclara
W	Long Prairie	LPR-535	Harts Press	HPS-1	12 kV	0.51	0.10	N/A	Engineering Estimate
W	Hubbard	HBB-523	Hubbard Dist	HUB-1	12 kV	0.33	0.07	N/A	Engineering Estimate
W	Riverton	RVT-505	Ironton	IRN-1	4 kV	0.98	0.20	N/A	Aclara
W	Pine River	PNV-549	Jenkins	JKS-1	12 kV	1.59	0.32	N/A	Aclara
W	Long Prairie	LPR-535	Lake Charlotte	LCH-1	12 kV	0.65	0.13	N/A	Engineering Estimate
W	Little Falls	LFL-529	Little Falls East Side	LFE-1	12 kV	1.85	0.37	N/A	Aclara
W	Little Falls	LFL-529	Little Falls Hospital	LFG-1	12 kV	1.57	0.31	N/A	Engineering Estimate
W	Little Falls	LFL-529	Little Falls South Side	LFS-1	12 kV	2.79	0.56	N/A	Aclara
W	Little Falls	LFL-525	Little Falls West Side	LFW-1	12 kV	1.63	0.33	N/A	Aclara
W	Little Falls	LFL-525	Little Falls West Side	LFW-2	12 kV	2.11	0.42	N/A	Aclara
W	Little Falls	LFL-525	Little Falls North Side	NTH-1	12 kV	0.85	0.17	N/A	Engineering Estimate
W	Little Falls	LFL-525	Little Falls North Side	NTH-2	12 kV	0.15	0.03	N/A	Engineering Estimate
W	Long Lake	LNG-541	Long Lake Park Rapids	LGL-1	4 kV	0.75	0.15	N/A	Engineering Estimate
W	Pepin Lake	PPL-514	Long Lake Stepdown	LLK-1	12 kV	0.72	0.14	N/A	Engineering Estimate
W	Long Prairie	LPR-527	Long Prairie Dist	LPD-1	4 kV	1.49	0.30	N/A	Aclara
W	Long Prairie	LPR-527	Long Prairie Dist	LPD-2	4 kV	2.54	0.51	N/A	Aclara
W	Long Prairie	LPR-535	Long Prairie North	LPN-1	12 kV	0.05	0.01	N/A	Engineering Estimate
W	Hubbard	HBB-523	Menahga	MEN-1	12 kV	0.65	0.13	N/A	Aclara
W	Dog Lake	DOG-503	Motley	MOT-1	12 kV	1.44	0.29	N/A	Aclara
W	Dog Lake	DOG-503	Motley	MOT-2	12 kV	0.92	0.18	N/A	Aclara
W	Long Prairie	LPR-501	Long Prairie Rural	LGP-1	12 kV	0.81	0.16	N/A	Engineering Estimate
W	Akeley	AKY-544	Nevis	NEV-1	4 kV	1.45	0.29	N/A	Aclara
W	Pequot Lakes	PQT-531	Nisswa Pumping Station	NPS-1	12 kV	1.40	0.28	N/A	Aclara
W	Pequot Lakes	PQT-531	Nisswa	NSW-1	12 kV	1.84	0.37	N/A	Aclara
W	Pequot Lakes	PQT-531	Nisswa	NSW-2	12 kV	2.40	0.48	N/A	Aclara
W	Baxter	BAX-534	Lynch Lake	LNL-1	12 kV	0.20	0.04	N/A	Engineering Estimate
W	Long Lake	LNG-541	Mud Lake Stepdown	MSD-1	4 kV	0.07	0.01	N/A	Engineering Estimate

2022 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area		Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Pequot Lakes	PQT-531	Northwest Gull Lake	NWG-1	12 kV	0.64	0.13	N/A	Aclara
W	Pequot Lakes	PQT-531	Northwest Gull Lake	NWG-2	12 kV	1.06	0.21	N/A	Aclara
W	Baxter	BAX-534	Pillager Dist	PIL-1	12 kV	1.68	0.34	N/A	Aclara
W	Long Lake	LNG-542	Park Rapids Dist #2	PKD-1	4 kV	2.39	0.48	N/A	Aclara
W	Long Lake	LNG-542	Park Rapids Dist #1	PKR-1	4 kV	1.38	0.28	N/A	Aclara
W	Baxter	BAX-534	Pine Beach	PNB-1	12 kV	1.24	0.25	N/A	Aclara
W	Baxter	BAX-534	Pine Beach	PNB-2	12 kV	1.92	0.38	N/A	Aclara
W	Pine River	PNV-550	Pine River Dist	PNR-1	12 kV	1.11	0.22	N/A	Aclara
W	Pine River	PNV-550	Pine River Dist	PNR-2	12 kV	0.88	0.18	N/A	Aclara
W	Pequot Lakes	PQT-507	Pequot Lakes Dist	PQL-1	12 kV	3.40	0.68	N/A	Engineering Estimate
W	Pequot Lakes	PQT-507	Pequot Lakes Dist	PQL-2	12 kV	3.38	0.68	N/A	Aclara
W	Long Lake	LNG-541	Park Rapids Hospital	PRH-1	4 kV	0.49	0.10	N/A	Aclara
W	Little Falls	LFL-526	Pierz-Genola	PZG-1	12 kV	2.83	0.57	N/A	Engineering Estimate
W	Little Falls	LFL-526	Pierz-Genola	PZG-2	12 kV	1.72	0.34	N/A	Aclara
W	Riverton	RVT-532	Riverton Dist	RVD-1	12 kV	0.47	0.09	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Round Lake	RDL-2	12 kV	1.33	0.27	N/A	Aclara
W	Platte River	PLA-547	Rice	RIC-1	12 kV	2.75	0.55	N/A	Aclara
W	Blanchard	BLD-511	Royalton	ROY-1	12 kV	2.01	0.40	N/A	Aclara
W	Pequot Lakes	PQT-531	Round Lake	RDL-1	12 kV	0.80	0.16	N/A	Engineering Estimate
W	Little Falls	LFL-526	Rich Prairie	RPR-1	12 kV	1.23	0.25	N/A	Aclara
W	Blanchard	BLD-511	Royalton	ROY-2	12 kV	2.02	0.40	N/A	Engineering Estimate
W	Blueberry	BLU-552	Sebeka Nimrod	SEB-1	12 kV	1.61	0.32	N/A	Aclara
W	Blueberry	BLU-552	Spirit Lake	SLS-1	12 kV	2.00	0.40	N/A	Aclara
W	Pine River	PNV-549	South Pine River	SPR-1	12 kV	2.59	0.52	N/A	Aclara
W	Dog Lake	DOG-503	Staples Rural	STR-1	12 kV	0.28	0.06	N/A	Engineering Estimate
W	Pepin Lake	PPL-514	Swanville	SWN-1	12 kV	1.83	0.37	N/A	Aclara
W	Riverton	RVT-530	Sylvan Dist	SYN-1	12 kV	1.20	0.24	N/A	Aclara
W	Birch Lake	BLS-509	Tenmile Lake	TML-1	12 kV	0.54	0.11	N/A	Aclara
W	Riverton	RVT-506	Trommald	TRM-1	4 kV	0.14	0.03	N/A	Engineering Estimate
W	Blanchard	BLD-524	Upsala	UPS-1	12 kV	2.34	0.47	N/A	Aclara
W	Blanchard	BLD-524	Upsala	UPS-2	12 kV	1.14	0.23	N/A	Aclara
W	Verndale	VRD-510	Verndale Dist	VND-1	4 kV	1.35	0.27	N/A	Aclara
W	Akeley	AKY-543	Walker #1	WAK-1	12 kV	3.11	0.62	N/A	Aclara
W	Akeley	AKY-543	Walker #2	WBK-1	12 kV	3.03	0.61	N/A	Aclara
W	Akeley	AKY-543	Walker Wye	WYE-1	12 kV	0.69	0.14	N/A	Aclara

NOTES

1. Values in table are non-coincident and shouldn't be added together

2. Values represent real power loading (MW) only; apparent power loading (MVA) will generally be slightly higher

3. Daytime Minimum corresponds to minimum hourly load between 0800-1800 where available or 20% of peak load where direct data is not available

4. Except as noted, values are based on hourly load data from the MP eDNA Data Historian

2021 Transmission-Distribution Substation Loading Summary[NOTE1,NOTE2]

Area	Substation	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	15th Ave West	115/14 kV	40.30	11.50	22.38	eDNA Data Historian
C	Bear Creek	69/46 kV	9.40	2.50	4.88	eDNA Data Historian Operated Networked
C	Big Rock	115/14 kV	7.40	2.40	3.69	eDNA Data Historian
C	Burnett	115/14 kV	1.81	0.36	N/A	Engineering Estimate
C	Canosia Road	115/14 kV	9.90	2.60	4.96	eDNA Data Historian
C	Cloquet	115/14 kV	30.43	11.00	19.60	eDNA Data Historian
C	Colbyville	115/14 kV	24.98	7.65	14.15	eDNA Data Historian
C	Floodwood	115/14 kV	1.50	0.08	0.79	Line Sensor
C	Four Corners	115/14 kV	12.93	5.20	7.54	eDNA Data Historian
C	French River	115/14 kV	5.30	1.30	2.25	eDNA Data Historian
C	Gary	115/14 kV	24.25	4.06	9.91	eDNA Data Historian
C	Haines Road	115/14 kV	23.75	7.88	13.81	eDNA Data Historian
C	Hibbard	115/14 kV	6.39	0.65	1.13	eDNA Data Historian
C	Hinckley East	69/46 kV	2.55	0.81	1.38	eDNA Data Historian Operated Networked
C	LSPI	115/14 kV	26.22	9.26	15.45	eDNA Data Historian
C	LSPI	115/34 kV	7.50	3.90	3.58	eDNA Data Historian
C	Mahtowa	115/23 kV	4.21	0.56	2.49	eDNA Data Historian
C	Mahtowa	115/46 kV	7.81	-2.32	2.12	eDNA Data Historian Operated Networked
C	Meadowlands	115/14 kV	1.10	0.22	N/A	Engineering Estimate
C	Ridgeview	115/14 kV	28.20	12.50	16.75	eDNA Data Historian
C	Silver Bay Hillside	115/14 kV	5.20	0.90	2.92	eDNA Data Historian (Calc)
C	Swan Lake Road	115/34 kV	15.80	5.50	8.98	eDNA Data Historian
C	Swan Lake Road	115/14 kV	19.80	8.80	11.84	eDNA Data Historian
C	Taft	115/34 kV	6.56	2.06	2.95	eDNA Data Historian
C	Thomson	115/14 kV	5.51	1.65	2.82	eDNA Data Historian
C	Thomson	115/46 kV	1.50	0.13	0.60	eDNA Data Historian
C	Two Harbors	115/14 kV	4.53	1.26	2.29	eDNA Data Historian (Calc)
C	Wrenshall	115/14 kV	4.07	0.90	2.01	eDNA Data Historian
N	Babbitt	115/46 kV	5.10	1.00	2.53	eDNA Data Historian Operated Networked
N	Big Fork Village	69/12 kV	0.60	0.20	0.92	eDNA Data Historian
N	Canisteo	115/14 kV	0.00	0.00	0.00	eDNA Data Historian
N	Diamond Lake	115/34 kV	0.00	0.00	0.00	eDNA Data Historian
N	Embarrass	115/23 kV	6.45	2.01	3.30	eDNA Data Historian
N	Hat Trick	115/23 kV	11.90	2.50	6.96	eDNA Data Historian
N	Hibbing	115/23 kV	41.21	16.57	23.49	eDNA Data Historian
N	International Falls	115/14 kV	13.94	6.22	7.06	eDNA Data Historian
N	Laskin	115/23 kV	3.25	0.20	1.48	eDNA Data Historian (Calc)
N	Laskin	115/46 kV	2.45	0.14	0.65	eDNA Data Historian (Calc)
N	Lind-Greenway	115/23 kV	5.40	1.20	2.89	eDNA Data Historian (Calc)
N	Maturi	115/34 kV	0.00	0.00	0.00	eDNA Data Historian
N	Maturi	115/23 kV	1.80	0.40	0.95	eDNA Data Historian
N	Nashwauk	115/23 kV	5.79	2.45	3.47	eDNA Data Historian
N	Tower	115/46 kV	11.80	2.60	6.45	eDNA Data Historian Operated Networked
N	Virginia	115/23 kV	28.03	12.38	16.82	eDNA Data Historian
N	Virginia	115/46 kV	3.09	0.41	1.57	eDNA Data Historian Operated Networked
N	Zemple	115/23 kV	2.60	0.90	1.37	eDNA Data Historian
W	Akeley	115/34 kV	18.30	5.60	8.53	eDNA Data Historian
W	Baxter	115/34 kV	11.73	3.59	5.46	eDNA Data Historian
W	Blanchard	115/34 kV	19.98	7.93	11.41	eDNA Data Historian
W	Dog Lake	115/34 kV	10.90	3.10	6.34	eDNA Data Historian
W	Eagle Valley	115/34 kV	12.40	4.00	7.07	eDNA Data Historian
W	Little Falls	115/34 kV	33.52	12.65	17.79	eDNA Data Historian
W	Long Prairie	115/34 kV	26.75	10.22	16.96	eDNA Data Historian

2021 Transmission-Distribution Substation Loading Summary[NOTE1,NOTE2]

Area	Substation	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Pepin Lake	115/34 kV	12.60	4.70	7.12	eDNA Data Historian
W	Pequot Lakes	115/34 kV	13.10	4.20	6.05	eDNA Data Historian
W	Pine River	115/34 kV	5.60	1.70	3.24	eDNA Data Historian
W	Platte River	115/34 kV	5.90	0.10	2.91	eDNA Data Historian
W	Riverton	115/34 kV	15.35	5.93	8.16	eDNA Data Historian
W	Straight River	115/34 kV	2.10	0.50	1.19	eDNA Data Historian
W	Verndale	115/34 kV	32.00	13.42	18.66	eDNA Data Historian

NOTES

1. Values in table are non-coincident and shouldn't be added together

2. Values represent real power loading (MW) only; apparent power loading (MVA) will generally be slightly higher

3. Daytime Minimum corresponds to minimum hourly load between 0800-1800 where available or 20% of peak load where direct data is not available

4. Except as noted, values are based on hourly load data from the MP eDNA Data Historian at the distribution bus

5. Where possible, the effective load reduction from large-scale distribution-connected generation has been excluded

2021 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	15th Ave West	FIF-219	14 kV	7.10	0.10	3.52	eDNA Data Historian
C	15th Ave West	FIF-220	14 kV	2.30	0.90	1.54	eDNA Data Historian
C	15th Ave West	FIF-221	14 kV	3.20	0.00	0.70	eDNA Data Historian
C	15th Ave West	FIF-222	14 kV	0.30	0.00	0.10	eDNA Data Historian
C	15th Ave West	FIF-226	14 kV	3.50	1.00	1.68	eDNA Data Historian
C	15th Ave West	FIF-228	14 kV	3.10	1.10	1.86	eDNA Data Historian
C	15th Ave West	FIF-230	14 kV	5.70	2.90	3.58	eDNA Data Historian
C	15th Ave West	FIF-231	14 kV	2.20	0.20	0.80	eDNA Data Historian
C	15th Ave West	FIF-232	14 kV	0.00	0.00	0.00	eDNA Data Historian
C	15th Ave West	FIF-233	14 kV	3.00	1.00	1.97	eDNA Data Historian
C	15th Ave West	FIF-234	14 kV	0.40	0.10	0.56	eDNA Data Historian
C	15th Ave West	FIF-260	14 kV	6.50	2.10	3.42	eDNA Data Historian
C	15th Ave West	FIF-261	14 kV	0.00	0.00	0.00	eDNA Data Historian
C	15th Ave West	FIF-264	14 kV	0.00	0.00	0.00	eDNA Data Historian
C	15th Ave West	FIF-265	14 kV	2.10	1.00	0.62	eDNA Data Historian
C	15th Ave West	FIF-266	14 kV	3.50	1.30	1.47	eDNA Data Historian
C	Bear Creek	23 LINE	46 kV	1.80	0.60	1.00	eDNA Data Historian
C	Bear Creek	59 LINE	46 kV	4.10	0.20	1.17	eDNA Data Historian (calc)
C	Bear Creek - Hinckley	198 LINE	46 kV	6.50	0.70	2.71	eDNA Data Historian (calc) Operated Networked
C	Big Rock	BGR-272	14 kV	5.50	2.40	3.14	eDNA Data Historian
C	Big Rock	BGR-274	14 kV	3.20	0.30	0.55	eDNA Data Historian
C	Burnett	BUR-407	14 kV	0.25	0.05	N/A	Engineering Estimate
C	Burnett	BUR-408	14 kV	1.56	0.31	N/A	Engineering Estimate
C	Canosia Road	CNA-403	14 kV	1.80	0.40	0.77	eDNA Data Historian
C	Canosia Road	CNA-405	14 kV	4.80	1.60	2.48	eDNA Data Historian
C	Canosia Road	CNA-413	14 kV	3.60	0.90	1.72	eDNA Data Historian
C	Cloquet	CLQ-404	14 kV	9.53	1.62	5.84	eDNA Data Historian
C	Cloquet	CLQ-406	14 kV	10.67	5.10	6.20	eDNA Data Historian
C	Cloquet	CLQ-409	14 kV	7.65	3.41	4.42	eDNA Data Historian
C	Cloquet	CLQ-410	14 kV	4.25	1.47	2.56	eDNA Data Historian

2021 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	Cloquet	CLQ-412	14 kV	0.33	0.06	0.58	eDNA Data Historian
C	Colbyville	COL-240	14 kV	7.92	2.79	4.14	eDNA Data Historian
C	Colbyville	COL-241	14 kV	4.37	1.50	2.05	eDNA Data Historian
C	Colbyville	COL-242	14 kV	7.01	2.70	4.02	eDNA Data Historian
C	Colbyville	COL-244	14 kV	5.01	1.96	2.89	eDNA Data Historian
C	Colbyville	COL-245	14 kV	1.76	1.00	1.04	eDNA Data Historian
C	Floodwood	FLF-402	14 kV	1.90	0.38	N/A	Engineering Estimate
C	Four Corners	FCS-214	14 kV	7.25	3.25	4.43	eDNA Data Historian
C	Four Corners	FCS-215	14 kV	6.04	1.55	3.11	eDNA Data Historian
C	French River	FRR-275	14 kV	3.10	0.80	1.40	eDNA Data Historian
C	French River	FRR-276	14 kV	2.30	0.50	0.85	eDNA Data Historian
C	Gary	GRY-200	14 kV	4.28	1.20	1.78	eDNA Data Historian
C	Gary	GRY-201	14 kV	4.63	1.50	2.30	eDNA Data Historian
C	Gary	GRY-210	14 kV	4.75	0.44	3.18	eDNA Data Historian
C	Haines Road	HNS-229	14 kV	7.76	3.66	4.72	eDNA Data Historian
C	Haines Road	HNS-235	14 kV	0.00	0.00	0.00	eDNA Data Historian
C	Haines Road	HNS-236	14 kV	6.77	1.63	3.67	eDNA Data Historian
C	Haines Road	HNS-237	14 kV	4.73	1.39	1.98	eDNA Data Historian
C	Haines Road	HNS-238	14 kV	2.80	0.63	1.34	eDNA Data Historian
C	Haines Road	HNS-239	14 kV	1.54	0.34	0.62	eDNA Data Historian
C	Haines Road	HNS-247	14 kV	2.55	0.95	1.47	eDNA Data Historian
C	Hibbard	MLH-267	14 kV	0.00	0.00	0.02	eDNA Data Historian
C	Hibbard	MLH-268	14 kV	6.39	0.65	1.11	eDNA Data Historian
C	Hibbard	MLH-279	14 kV	0.00	0.00	0.00	eDNA Data Historian
C	Hinckley East	HKE-463	14 kV	2.55	0.81	1.38	eDNA Data Historian (Calc)
C	LSPI	LSP-208	34 kV	7.50	3.90	3.58	eDNA Data Historian
C	LSPI	LSP-223	14 kV	10.19	3.65	4.98	eDNA Data Historian
C	LSPI	LSP-224	14 kV	5.31	0.34	0.63	eDNA Data Historian
C	LSPI	LSP-225	14 kV	8.53	1.89	4.05	eDNA Data Historian
C	LSPI	LSP-280	14 kV	5.69	1.69	3.38	eDNA Data Historian
C	LSPI	LSP-281	14 kV	3.47	1.45	1.89	eDNA Data Historian

2021 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	LSPI	LSP-282	14 kV	0.72	0.26	0.40	eDNA Data Historian
C	Mahtowa	MAT-420	23 kV	4.21	0.56	2.49	eDNA Data Historian
C	Meadowlands	MDL-401	14 kV	1.10	0.22	N/A	Engineering Estimate
C	Ridgeview	RGV-251	14 kV	2.40	0.80	1.77	eDNA Data Historian
C	Ridgeview	RGV-252	14 kV	7.40	3.50	4.42	eDNA Data Historian
C	Ridgeview	RGV-253	14 kV	4.70	1.60	2.36	eDNA Data Historian
C	Ridgeview	RGV-254	14 kV	5.10	2.20	3.01	eDNA Data Historian
C	Ridgeview	RGV-255	14 kV	6.70	3.10	4.32	eDNA Data Historian
C	Ridgeview	RGV-256	14 kV	1.60	0.50	0.87	eDNA Data Historian
C	Silver Bay Hillside	SBH-271	14 kV	5.20	0.90	2.92	eDNA Data Historian (Calc)
C	Swan Lake	SLA-203	34 kV	15.80	5.50	8.98	eDNA Data Historian
C	Swan Lake	SLA-250	14 kV	8.50	4.00	5.29	eDNA Data Historian
C	Swan Lake	SLA-257	14 kV	5.20	2.40	3.08	eDNA Data Historian
C	Swan Lake	SLA-258	14 kV	6.50	2.00	3.48	eDNA Data Historian
C	Taft	TFT-202	34 kV	6.52	1.72	2.95	eDNA Data Historian
C	Thomson	TMS-412	14 kV	5.51	1.65	2.82	eDNA Data Historian
C	Thomson	23 LINE	46 kV	1.50	0.13	0.60	eDNA Data Historian
C	Two Harbors	TWH-273	14 kV	4.53	1.26	2.29	eDNA Data Historian (Calc)
C	Wrenshall	WRN-411	14 kV	4.06	0.90	2.01	eDNA Data Historian
N	Babbitt-Winton	31 LINE	46 kV	5.10	1.00	2.53	eDNA Data Historian
N	Big Fork	BFV-1	12 kV	2.00	0.60	0.92	eDNA Data Historian
N	Canisteo	CNS-382	14 kV	0.00	0.00	0.00	eDNA Data Historian
N	Diamond Lake	DML-380	34 kV	0.00	0.00	0.00	eDNA Data Historian
N	Embarrass	EMB-317	23 kV	6.45	2.01	3.30	eDNA Data Historian
N	Grand Rapids	GRR-325	23 kV	0.30	0.14	0.10	eDNA Data Historian
N	Hat Trick	HAT-321	23 kV	7.10	2.40	3.85	eDNA Data Historian
N	Hat Trick	HAT-332	23 kV	4.90	1.60	3.12	eDNA Data Historian
N	Hibbing	HIB-307	23 kV	15.05	4.74	7.59	eDNA Data Historian
N	Hibbing	HIB-308	23 kV	4.50	1.92	3.10	eDNA Data Historian
N	Hibbing	HIB-310	23 kV	7.09	2.84	4.00	eDNA Data Historian
N	Hibbing	HIB-312	23 kV	7.41	0.31	2.80	eDNA Data Historian

2021 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
N	Hibbing	HIB-315	23 kV	1.16	0.31	0.67	eDNA Data Historian
N	International Falls	INF-1	12 kV	2.37	0.87	1.16	eDNA Data Historian
N	International Falls	INF-2	12 kV	4.27	1.88	2.13	eDNA Data Historian
N	International Falls	INF-3	12 kV	4.66	2.02	2.23	eDNA Data Historian
N	International Falls	INF-4	12 kV	2.98	1.04	1.47	eDNA Data Historian
N	International Falls	INF-5	12 kV	0.15	0.05	0.07	eDNA Data Historian
N	Laskin	AUR-313	23 kV	3.25	0.20	1.15	eDNA Data Historian (Calc)
N	Laskin	30 LINE	46 kV	1.45	0.63	0.56	eDNA Data Historian
N	Lind-Greenway	LGW-334	23 kV	3.94	0.88	2.11	eDNA Data Historian (Calc)
N	Lind-Greenway	LGW-335	23 kV	1.46	0.32	0.78	eDNA Data Historian (Calc)
N	Maturi	MTU-330	23 kV	1.80	0.40	0.95	eDNA Data Historian
N	Maturi	MTU-381	34 kV	0.00	0.00	0.00	eDNA Data Historian
N	Nashwauk	NAS-314	23 kV	2.95	0.97	1.59	eDNA Data Historian
N	Nashwauk	NAS-318	23 kV	0.11	0.02	0.03	eDNA Data Historian
N	Nashwauk	NAS-319	23 kV	3.34	1.30	1.85	eDNA Data Historian
N	Tower-Winton	32 LINE	46 kV	9.40	2.80	4.80	eDNA Data Historian
N	Virginia	VRG-301	23 kV	7.60	1.10	3.65	eDNA Data Historian
N	Virginia	VRG-302	23 kV	2.34	0.97	0.91	eDNA Data Historian
N	Virginia	VRG-303	23 kV	5.04	1.92	2.83	eDNA Data Historian
N	Virginia	VRG-304	23 kV	1.81	0.94	1.25	eDNA Data Historian
N	Virginia	VRG-305	23 kV	0.82	0.21	0.42	eDNA Data Historian
N	Virginia	VRG-306	23 kV	0.00	0.00	0.00	eDNA Data Historian
N	Virginia	VRG-311	23 kV	12.52	4.68	7.34	eDNA Data Historian
N	Virginia	30 LINE	46 kV	3.09	0.41	1.57	eDNA Data Historian
N	Virginia-Tower	199 LINE	46 kV	2.70	1.00	1.65	eDNA Data Historian
N	Winton	33 LINE	46 kV	13.40	2.90	4.78	eDNA Data Historian
N	Zemple	ZMP-335	23 kV	0.00	0.00	0.00	eDNA Data Historian
N	Zemple	ZMP-337	23 kV	2.60	0.90	1.37	eDNA Data Historian
W	Akeley	AKY-543	34 kV	10.00	3.70	5.20	eDNA Data Historian
W	Akeley	AKY-544	34 kV	9.70	1.60	3.33	eDNA Data Historian
W	Baxter	BAX-531	34 kV	5.74	1.71	2.57	eDNA Data Historian

2021 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Baxter	BAX-534	34 kV	6.27	1.81	2.90	eDNA Data Historian
W	Birch Lake	BLS-509	34 kV	9.00	2.30	4.02	eDNA Data Historian
W	Birch Lake	BLS-516	34 kV	2.20	0.30	1.05	eDNA Data Historian
W	Blanchard	BLD-508	34 kV	5.89	1.48	3.04	eDNA Data Historian
W	Blanchard	BLD-511	34 kV	7.38	2.15	3.34	eDNA Data Historian
W	Blanchard	BLD-521	34 kV	1.90	0.50	1.16	eDNA Data Historian
W	Blanchard	BLD-524	34 kV	6.89	1.72	3.87	eDNA Data Historian
W	Blueberry	BLU-552	34 kV	8.00	3.00	4.46	eDNA Data Historian
W	Dog Lake	DOG-503	34 kV	10.90	3.10	6.34	eDNA Data Historian
W	Eagle Valley	EGV-513	34 kV	4.30	1.50	2.51	eDNA Data Historian
W	Eagle Valley	EGV-517	34 kV	8.20	2.50	4.56	eDNA Data Historian
W	Hubbard	HBB-523	34 kV	2.60	0.70	0.47	eDNA Data Historian
W	Little Falls	LFL-525	34 kV	6.31	1.45	2.50	eDNA Data Historian
W	Little Falls	LFL-526	34 kV	10.22	3.38	5.33	eDNA Data Historian
W	Little Falls	LFL-529	34 kV	13.46	4.08	6.54	eDNA Data Historian
W	Little Falls	LFL-536	34 kV	7.74	2.91	3.42	eDNA Data Historian
W	Long Lake	LNG-540	34 kV	0.20	0.00	0.01	eDNA Data Historian
W	Long Lake	LNG-541	34 kV	9.20	3.80	5.02	eDNA Data Historian
W	Long Lake	LNG-542	34 kV	7.80	1.80	4.60	eDNA Data Historian
W	Long Lake	LNG-545	34 kV	17.60	2.40	4.98	eDNA Data Historian
W	Long Prairie	LPR-501	34 kV	7.17	1.08	4.57	eDNA Data Historian
W	Long Prairie	LPR-527	34 kV	7.13	2.77	4.28	eDNA Data Historian
W	Long Prairie	LPR-535	34 kV	15.70	5.25	8.12	eDNA Data Historian
W	Pepin Lake	PPL-514	34 kV	8.90	3.30	5.23	eDNA Data Historian
W	Pepin Lake	PPL-539	34 kV	3.90	0.80	1.89	eDNA Data Historian
W	Pequot Lakes	PQT-507	34 kV	4.20	1.20	2.09	eDNA Data Historian
W	Pequot Lakes	PQT-531	34 kV	9.30	2.60	3.96	eDNA Data Historian
W	Pine River	PNV-549	34 kV	4.00	1.20	2.36	eDNA Data Historian
W	Pine River	PNV-550	34 kV	2.10	0.10	0.88	eDNA Data Historian
W	Platte River	PLA-546	34 kV	2.60	0.10	1.29	eDNA Data Historian
W	Platte River	PLA-547	34 kV	3.90	0.60	1.62	eDNA Data Historian

2021 Parent Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Riverton	RVT-505	34 kV	5.70	2.15	2.67	eDNA Data Historian
W	Riverton	RVT-506	34 kV	7.49	2.53	2.87	eDNA Data Historian
W	Riverton	RVT-530	34 kV	1.89	0.10	0.97	eDNA Data Historian
W	Riverton	RVT-532	34 kV	1.76	0.18	1.66	eDNA Data Historian
W	Straight River	STG-551	34 kV	2.10	0.50	1.19	eDNA Data Historian
W	Sylvan	SYL-502	34 kV	0.40	0.10	0.18	eDNA Data Historian
W	Verndale	VRD-503	34 kV	8.58	3.71	5.10	eDNA Data Historian
W	Verndale	VRD-510	34 kV	4.50	1.45	2.25	eDNA Data Historian
W	Verndale	VRD-519	34 kV	3.80	0.88	1.89	eDNA Data Historian
W	Verndale	VRD-533	34 kV	16.41	6.14	9.42	eDNA Data Historian

NOTES

1. Values in table are non-coincident and shouldn't be added together

2. Values represent real power loading (MW) only; apparent power loading (MVA) will generally be slightly higher

3. Daytime Minimum corresponds to minimum hourly load between 0800-1800 where available or 20% of peak load where direct data is not available

4. Except as noted, values are based on hourly load data from the MP eDNA Data Historian

5. Where possible, the effective load reduction from large-scale distribution-connected generation has been excluded

6. Customer Count includes customers connected to stepdown feeders (see "Stepdown Feeder" tab)

2021 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
C	Bear Creek	59 LINE	Anderson Corner	FIN-6511	12 kV	0.80	0.16	N/A	Engineering Estimate
C	Bear Creek	BCR 23 LINE	Askov	ASK-6521	12 kV	1.10	0.22	N/A	Engineering Estimate
C	Bear Creek	BCR 23 LINE	Kerrick	KER-6501	12 kV	0.81	0.20	N/A	Engineering Estimate
C	Bear Creek - Hinckley	198 LINE	Sandstone	SNT-452	12 kV	1.51	0.45	N/A	Engineering Estimate
C	Bear Creek - Hinckley	198 LINE	Hinckley West	HKZ-461	14 kV	1.24	0.45	N/A	Engineering Estimate
C	Bear Creek - Hinckley	198 LINE	Hinckley West	HKZ-462	14 kV	4.60	1.94	N/A	Engineering Estimate
C	Cloquet	CLQ-409	Big Lake	CQB-6301	12 kV	1.20	0.24	N/A	Engineering Estimate
C	Four Corners	FCS-214	Caribou Lake	CBL-214	12 kV	0.96	0.19	N/A	Engineering Estimate
C	Four Corners	FCS-214	Pike Lake	PLR-214	12 kV	0.52	0.10	N/A	Engineering Estimate
C	Four Corners	FCS-215	Seville Rd	SVR-215	12 kV	2.43	0.49	N/A	Engineering Estimate
C	LSPI	LSP-208	25th Ave West	TFW-243	14 kV	3.40	1.10	1.51	eDNA Historian
C	LSPI	LSP-208	4th Ave West	FOR-262	14 kV	2.00	0.80	0.87	eDNA Historian
C	LSPI	LSP-208	4th Ave West	FOR-263	14 kV	2.90	1.30	1.29	eDNA Historian
C	Mahtowa	59 LINE	Barnum	BAR-6421	12 kV	2.04	0.41	N/A	Engineering Estimate
C	Mahtowa	59 LINE	Denham	DEN-6431	12 kV	1.90	0.38	N/A	Engineering Estimate
C	Mahtowa	MAT-420	Mahtowa	MAH-6411	12 kV	1.43	0.29	N/A	Engineering Estimate
C	Mahtowa	MAT-420	Olsonville East	OLE-4471	4 kV	0.30	0.06	N/A	Engineering Estimate
C	Mahtowa	MAT-420	Olsonville West	OLW-4471	4 kV	0.30	0.06	N/A	Engineering Estimate
C	Scanlon	SCH-420	Sawyer	SAW-6311	12 kV	1.30	0.26	N/A	Engineering Estimate
C	Scanlon	SCH-420	Moorhead Rd	MHR-451	14 kV	0.82	0.16	N/A	Engineering Estimate
C	Silver Bay Hillside	SBH-271	Silver Bay Townsite	SBT-4301	4 kV	1.13	0.23	N/A	Engineering Estimate
C	Silver Bay Hillside	SBH-271	Silver Bay Townsite	SBT-4302	4 kV	0.22	0.04	N/A	Engineering Estimate
C	Swan Lake	SLA-203	2nd Ave East	SND-217	14 kV	3.90	1.80	2.26	eDNA Historian
C	Swan Lake	SLA-203	2nd Ave East	SND-218	14 kV	3.00	0.70	1.30	eDNA Historian
C	Swan Lake	SLA-203	9th Ave East	NIN-246	14 kV	2.50	1.10	1.71	eDNA Historian
C	Swan Lake	SLA-203	9th Ave East	NIN-248	14 kV	3.10	1.50	1.49	eDNA Historian
C	Taft	TFT-202	Fredenburg	FBG-269	14 kV	2.22	0.44	N/A	Engineering Estimate
C	Taft	TFT-202	Pioneer Rd	PIO-270	14 kV	3.61	0.72	N/A	Engineering Estimate
C	Thomson	TMS 23 LINE	Military Rd	MLT-414	14 kV	2.81	0.13	0.65	eDNA Historian
C	Thomson	TMS-412	Scanlon	SCH-420	23 kV	2.10	0.70	1.14	eDNA Historian
C	Wrenshall	WRN-411	Wrenshall Riverside	WRR-6321	12 kV	0.68	0.13	N/A	Engineering Estimate
N	Babbitt	31 LINE	Babbitt Townsite	BAB-1	4 kV	1.64	0.33	N/A	Engineering Estimate
N	Babbitt	31 LINE	Babbitt Townsite	BAB-2	4 kV	0.40	0.08	N/A	Engineering Estimate
N	Babbitt	31 LINE	Dunka River	DUN-1	4 kV	0.46	0.09	N/A	Engineering Estimate
N	Embarrass	EMB-317	Aurora	AUN-1	4 kV	1.56	0.31	N/A	Engineering Estimate
N	Embarrass	EMB-317	Aurora	AUN-2	4 kV	2.12	0.42	N/A	Engineering Estimate
N	Embarrass	EMB-317	Biwabik	BIW-1	12 kV	1.66	0.33	N/A	Engineering Estimate
N	Embarrass	EMB-317	Biwabik	BIW-2	12 kV	1.94	0.39	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Ely Lake Olaughlin EOQ	EOQ-1	4 kV	0.05	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Ely Lake Olaughlin EOS	EOS-1	4 kV	0.03	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Ely Lake Shady Lane	ESL-1	4 kV	0.03	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Eveleth	ESS-1	4 kV	2.35	0.47	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Eveleth	ESS-2	4 kV	0.73	0.15	N/A	Engineering Estimate

2021 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
N	Hat Trick	HAT-321	Ely Lake Woodlawn Pt	EWP-1	4 kV	0.02	0.00	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Half Moon Lake	HML-1	4 kV	0.13	0.03	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Rural Camp Warren	RCW-1	4 kV	0.05	0.01	N/A	Engineering Estimate
N	Hat Trick	HAT-321	Rural Long Lake Rd	RLL-1	4 kV	0.01	0.00	N/A	Engineering Estimate
N	Hat Trick	HAT-332	Eveleth OHV	OHV-1	4 kV	0.02	0.00	N/A	Engineering Estimate
N	Hibbing	HIB-308	Stuntz Wilpen Bridge	SWB-1	4 kV	0.20	0.04	N/A	Engineering Estimate
N	Hibbing	HIB-310	Balkan	BAL-1	12 kV	1.11	0.22	N/A	Engineering Estimate
N	Hibbing	HIB-310	Balkan	BAL-2	12 kV	0.30	0.06	N/A	Engineering Estimate
N	Hibbing	HIB-310	Chisholm	CHL-1	4 kV	2.30	0.46	N/A	Engineering Estimate
N	Hibbing	HIB-310	Chisholm	CHL-2	4 kV	1.15	0.23	N/A	Engineering Estimate
N	Hibbing	HIB-310	Chisholm	CHL-3	4 kV	1.87	0.37	N/A	Engineering Estimate
N	Hibbing	HIB-315	Kelly Lake	KLY-1	4 kV	0.56	0.11	N/A	Engineering Estimate
N	Laskin	AUR-313	Hoyt Lakes	HYN-1	4 kV	0.56	0.11	N/A	Engineering Estimate
N	Laskin	AUR-313	Hoyt Lakes	HYN-2	4 kV	1.89	0.38	N/A	Engineering Estimate
N	Laskin	AUR-313	Laskin Energy Park	LEP-1	4 kV	0.57	0.11	N/A	Engineering Estimate
N	Lind-Greenway	LGW-334	Coleraine COE	COE-1	4 kV	0.15	0.03	N/A	Engineering Estimate
N	Lind-Greenway	LGW-334	Coleraine COF	COF-1	4 kV	0.30	0.06	N/A	Engineering Estimate
N	Lind-Greenway	LGW-335	Cohasset	COA-1	4 kV	0.15	0.03	N/A	Engineering Estimate
N	Maturi	MTU-330	Stuntz	STZ-1	4 kV	0.39	0.08	N/A	Engineering Estimate
N	Maturi	MTU-330	Stuntz	STZ-2	4 kV	0.70	0.14	N/A	Engineering Estimate
N	Maturi	MTU-330	Spudville East	SVE-1	4 kV	0.09	0.02	N/A	Engineering Estimate
N	Maturi	MTU-330	Spudville West	SVW-1	4 kV	0.26	0.05	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Marble	MAR-1	4 kV	0.64	0.13	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Pengilly North	PNN-1	4 kV	0.15	0.03	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Pengilly South	PNS-1	4 kV	0.15	0.03	N/A	Engineering Estimate
N	Nashwauk	NAS-319	Taconite Village	TAC-1	4 kV	0.30	0.06	N/A	Engineering Estimate
N	Tower	32 LINE	Tower Soudan	TWN-1	12 kV	1.03	0.21	N/A	Engineering Estimate
N	Tower	32 LINE	Tower Soudan	TWN-2	12 kV	1.67	0.33	N/A	Engineering Estimate
N	Virginia	VRG-311	Iron Bowl North	IBN-1	4 kV	0.07	0.01	N/A	Engineering Estimate
N	Virginia	VRG-311	Iron Bowl South	IBS-1	4 kV	0.07	0.01	N/A	Engineering Estimate
N	Virginia	VRG-311	Iron	INJ-1	12 kV	1.03	0.21	N/A	Engineering Estimate
N	Virginia	VRG-311	West Eveleth Hwy 101	WEH-1	4 kV	0.01	0.00	N/A	Engineering Estimate
N	Winton	33 LINE	St. Croix	STC-1	12 kV	0.39	0.08	N/A	Engineering Estimate
N	Winton	33 LINE	St. Croix	STC-2	12 kV	1.35	0.27	N/A	Engineering Estimate
N	Zemple	ZMP-337	Deer River DRR	DRR-2	4 kV	1.48	0.30	N/A	Engineering Estimate
N	Zemple	ZMP-337	Deer River DRV	DRV-1	4 kV	0.03	0.01	N/A	Engineering Estimate
N	Zemple	ZMP-337	Deer River DRW	DRW-1	4 kV	0.03	0.01	N/A	Engineering Estimate
W	Akeley	AKY-543	Akeley Dist	AKE-1	4 kV	1.10	0.22	N/A	Engineering Estimate
W	Akeley	AKY-543	Walker #1	WAK-1	12 kV	3.37	0.67	N/A	Engineering Estimate
W	Akeley	AKY-543	Walker #2	WBK-1	12 kV	3.47	0.69	N/A	Engineering Estimate
W	Akeley	AKY-543	Walker Wye	WYE-1	12 kV	0.70	0.14	N/A	Engineering Estimate
W	Akeley	AKY-544	Nevis	NEV-1	4 kV	1.63	0.33	N/A	Engineering Estimate
W	Baxter	BAX-531	Gull Lake	GLL-1	12 kV	3.73	0.75	N/A	Engineering Estimate

2021 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Baxter	BAX-531	Gull Lake	GLL-2	12 kV	1.72	0.34	N/A	Engineering Estimate
W	Baxter	BAX-531	Hole in the Day	HID-11	12 kV	1.26	0.25	N/A	Engineering Estimate
W	Baxter	BAX-534	Lynch Lake	LNL-1	12 kV	0.20	0.04	N/A	Engineering Estimate
W	Baxter	BAX-534	Pillager Dist	PIL-1	12 kV	0.30	0.06	N/A	Engineering Estimate
W	Baxter	BAX-534	Pine Beach	PNB-1	12 kV	1.43	0.29	N/A	Engineering Estimate
W	Baxter	BAX-534	Pine Beach	PNB-2	12 kV	1.50	0.30	N/A	Engineering Estimate
W	Birch Lake	BLS-509	Hackensack	HCS-1	12 kV	1.48	0.30	N/A	Engineering Estimate
W	Birch Lake	BLS-509	Tenmile Lake	TML-1	12 kV	1.14	0.23	N/A	Engineering Estimate
W	Birch Lake	BLS-516	Backus	BAC-1	12 kV	2.20	0.44	N/A	Engineering Estimate
W	Blanchard	BLD-508	Camp Ripley Rural	CRS-1	12 kV	1.10	0.22	N/A	Engineering Estimate
W	Blanchard	BLD-508	Ginger Rd	GIN-1	12 kV	1.34	0.27	N/A	Engineering Estimate
W	Blanchard	BLD-511	Royalton	ROY-1	12 kV	2.02	0.40	N/A	Engineering Estimate
W	Blanchard	BLD-511	Royalton	ROY-2	12 kV	0.40	0.08	N/A	Engineering Estimate
W	Blanchard	BLD-524	Bowlus	BSD-1	12 kV	0.28	0.06	N/A	Engineering Estimate
W	Blanchard	BLD-524	Bowlus	BSD-2	12 kV	1.25	0.25	N/A	Engineering Estimate
W	Blanchard	BLD-524	Upsala	UPS-1	12 kV	0.80	0.16	N/A	Engineering Estimate
W	Blanchard	BLD-524	Upsala	UPS-2	12 kV	0.75	0.15	N/A	Engineering Estimate
W	Blueberry	BLU-552	Sebeka Nimrod	SEB-1	12 kV	1.75	0.35	N/A	Engineering Estimate
W	Blueberry	BLU-552	Spirit Lake	SLS-1	12 kV	2.40	0.48	N/A	Engineering Estimate
W	Dog Lake	DOG-503	Motley	MOT-1	12 kV	1.70	0.34	N/A	Engineering Estimate
W	Dog Lake	DOG-503	Motley	MOT-2	12 kV	0.52	0.10	N/A	Engineering Estimate
W	Dog Lake	DOG-503	Staples Rural	STR-1	12 kV	0.28	0.06	N/A	Engineering Estimate
W	Eagle Valley	EGV-513	Bertha	BER-1	12 kV	1.20	0.24	N/A	Engineering Estimate
W	Eagle Valley	EGV-513	Eagle Bend	EGB-1	12 kV	1.70	0.34	N/A	Engineering Estimate
W	Eagle Valley	EGV-517	Browerville	BRW-1	12 kV	3.03	0.61	N/A	Engineering Estimate
W	Eagle Valley	EGV-517	Browerville	BRW-2	12 kV	3.45	0.69	N/A	Engineering Estimate
W	Eagle Valley	EGV-517	Clarissa	CLR-1	12 kV	2.20	0.44	N/A	Engineering Estimate
W	Eagle Valley	EGV-517	Clarissa	CLR-2	12 kV	0.20	0.04	N/A	Engineering Estimate
W	Hubbard	HBB-523	Hubbard Dist	HUB-1	12 kV	0.33	0.07	N/A	Engineering Estimate
W	Hubbard	HBB-523	Menahga	MEN-1	12 kV	0.54	0.11	N/A	Engineering Estimate
W	Little Falls	LFL-525	Little Falls West Side	LFW-1	12 kV	1.96	0.39	N/A	Engineering Estimate
W	Little Falls	LFL-525	Little Falls West Side	LFW-2	12 kV	1.98	0.40	N/A	Engineering Estimate
W	Little Falls	LFL-525	Little Falls North Side	NTH-1	12 kV	0.85	0.17	N/A	Engineering Estimate
W	Little Falls	LFL-525	Little Falls North Side	NTH-2	12 kV	0.15	0.03	N/A	Engineering Estimate
W	Little Falls	LFL-526	Pierz-Genola	PZG-1	12 kV	2.83	0.57	N/A	Engineering Estimate
W	Little Falls	LFL-526	Pierz-Genola	PZG-2	12 kV	1.57	0.31	N/A	Engineering Estimate
W	Little Falls	LFL-526	Rich Prairie	RPR-1	12 kV	0.89	0.18	N/A	Engineering Estimate
W	Little Falls	LFL-529	Little Falls East Side	LFE-1	12 kV	1.79	0.36	N/A	Engineering Estimate
W	Little Falls	LFL-529	Little Falls Hospital	LFG-1	12 kV	1.57	0.31	N/A	Engineering Estimate
W	Little Falls	LFL-529	Little Falls South Side	LFS-1	12 kV	0.51	0.10	N/A	Engineering Estimate
W	Long Lake	LNG-540	Dorset	DOR-1	4 kV	0.32	0.06	N/A	Engineering Estimate
W	Long Lake	LNG-541	Explorer Circle	ECS-1	4 kV	0.15	0.03	N/A	Engineering Estimate
W	Long Lake	LNG-541	Long Lake Park Rapids	LGL-1	4 kV	0.75	0.15	N/A	Engineering Estimate

2021 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Long Lake	LNG-541	Mud Lake Stepdown	MSD-1	4 kV	0.07	0.01	N/A	Engineering Estimate
W	Long Lake	LNG-541	Park Rapids Hospital	PRH-1	4 kV	0.61	0.12	N/A	Engineering Estimate
W	Long Lake	LNG-542	Park Rapids Dist #2	PKD-1	4 kV	2.13	0.43	N/A	Engineering Estimate
W	Long Lake	LNG-542	Park Rapids Dist #1	PKR-1	4 kV	2.61	0.52	N/A	Engineering Estimate
W	Long Prairie	LPR-501	Long Prairie Rural	LGP-1	12 kV	0.81	0.16	N/A	Engineering Estimate
W	Long Prairie	LPR-527	Gutches Grove	GGR-1	12 kV	2.69	0.54	N/A	Engineering Estimate
W	Long Prairie	LPR-527	Long Prairie Dist	LPD-1	4 kV	2.56	0.51	N/A	Engineering Estimate
W	Long Prairie	LPR-527	Long Prairie Dist	LPD-2	4 kV	0.58	0.12	N/A	Engineering Estimate
W	Long Prairie	LPR-535	Big Bear	BBR-1	12 kV	1.20	0.24	N/A	Engineering Estimate
W	Long Prairie	LPR-535	Harts Press	HPS-1	12 kV	0.51	0.10	N/A	Engineering Estimate
W	Long Prairie	LPR-535	Lake Charlotte	LCH-1	12 kV	0.65	0.13	N/A	Engineering Estimate
W	Long Prairie	LPR-535	Long Prairie North	LPN-1	12 kV	0.05	0.01	N/A	Engineering Estimate
W	Pepin Lake	PPL-514	Flensburg	FLN-1	12 kV	0.15	0.03	N/A	Engineering Estimate
W	Pepin Lake	PPL-514	Flensburg	FLN-2	12 kV	0.65	0.13	N/A	Engineering Estimate
W	Pepin Lake	PPL-514	Long Lake Stepdown	LLK-1	12 kV	0.72	0.14	N/A	Engineering Estimate
W	Pepin Lake	PPL-514	Swanville	SWN-1	12 kV	2.27	0.45	N/A	Engineering Estimate
W	Pepin Lake	PPL-539	Grey Eagle	GES-1	12 kV	2.05	0.41	N/A	Engineering Estimate
W	Pequot Lakes	PQT-507	Pequot Lakes Dist	PQL-1	12 kV	3.40	0.68	N/A	Engineering Estimate
W	Pequot Lakes	PQT-507	Pequot Lakes Dist	PQL-2	12 kV	3.34	0.67	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Nisswa Pumping Station	NPS-1	12 kV	1.95	0.39	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Nisswa	NSW-1	12 kV	1.69	0.34	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Nisswa	NSW-2	12 kV	3.38	0.68	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Northwest Gull Lake	NWG-1	12 kV	0.82	0.16	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Northwest Gull Lake	NWG-2	12 kV	1.39	0.28	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Round Lake	RDL-1	12 kV	0.80	0.16	N/A	Engineering Estimate
W	Pequot Lakes	PQT-531	Round Lake	RDL-2	12 kV	1.61	0.32	N/A	Engineering Estimate
W	Pine River	PNV-549	Jenkins	JKS-1	12 kV	0.55	0.11	N/A	Engineering Estimate
W	Pine River	PNV-549	South Pine River	SPR-1	12 kV	1.56	0.31	N/A	Engineering Estimate
W	Pine River	PNV-550	Pine River Dist	PNR-1	12 kV	1.70	0.34	N/A	Engineering Estimate
W	Pine River	PNV-550	Pine River Dist	PNR-2	12 kV	1.50	0.30	N/A	Engineering Estimate
W	Platte River	PLA-547	Rice	RIC-1	12 kV	1.34	0.27	N/A	Engineering Estimate
W	Riverton	RVT-505	Crosby	CSB-1	4 kV	3.20	0.64	N/A	Engineering Estimate
W	Riverton	RVT-505	Crosby	CSB-2	4 kV	2.40	0.48	N/A	Engineering Estimate
W	Riverton	RVT-505	Ironton	IRN-1	4 kV	0.46	0.09	N/A	Engineering Estimate
W	Riverton	RVT-506	Cotton Tail Drive	CTD-1	12 kV	0.15	0.03	N/A	Engineering Estimate
W	Riverton	RVT-506	Cuyuna	CUY-1	4 kV	0.28	0.06	N/A	Engineering Estimate
W	Riverton	RVT-506	Deerwood	DER-1	12 kV	2.40	0.48	N/A	Engineering Estimate
W	Riverton	RVT-506	Deerwood	DER-2	12 kV	1.90	0.38	N/A	Engineering Estimate
W	Riverton	RVT-506	Deerwood Highway	DHY-1	12 kV	2.40	0.48	N/A	Engineering Estimate
W	Riverton	RVT-506	Trommald	TRM-1	4 kV	0.14	0.03	N/A	Engineering Estimate
W	Riverton	RVT-530	Sylvan Dist	SYN-1	12 kV	0.30	0.06	N/A	Engineering Estimate
W	Riverton	RVT-532	Riverton Dist	RVD-1	12 kV	0.47	0.09	N/A	Engineering Estimate
W	Sylvan	SYL-502	Fort Ripley	FTR-1	4 kV	0.25	0.05	N/A	Engineering Estimate

2021 Stepdown Feeder Loading Summary[NOTE1,NOTE2]

Area	Substation	Parent Feeder	Stepdown	Stepdown Feeder	Voltage Class	Peak Load (MW)	Daytime Min (MW)[NOTE3]	Avg Load (MW)	Data Source[NOTE4]
W	Verndale	VRD-503	Aldrich	ALD-1	4 kV	0.32	0.06	N/A	Engineering Estimate
W	Verndale	VRD-510	Blue Grass	BLG-1	4 kV	0.08	0.02	N/A	Engineering Estimate
W	Verndale	VRD-510	Verndale Dist	VND-1	4 kV	1.22	0.24	N/A	Engineering Estimate
W	Verndale	VRD-519	Hewitt	HEW-1	12 kV	0.70	0.14	N/A	Engineering Estimate

NOTES

1. Values in table are non-coincident and shouldn't be added together

2. Values represent real power loading (MW) only; apparent power loading (MVA) will generally be slightly higher

3. Daytime Minimum corresponds to minimum hourly load between 0800-1800 where available or 20% of peak load where direct data is not available

4. Except as noted, values are based on hourly load data from the MP eDNA Data Historian

October 16, 2023

VIA E-FILING
Will Seuffert
Executive Secretary
Minnesota Public Utilities Commission
121 7th Place East, Suite 350
St. Paul, MN 55101-2147

Re: Compliance Filing In the Matter of a Commission Investigation on Grid and Customer Security Issues Related to Public Display or Access to Electric Distribution Grid Data
Docket No. E015/M-20-800

Dear Mr. Seuffert:

On October 20, 2020 the Minnesota Public Utilities Commission ("PUC") issued a Notice of Comment to address the following question:

What, if any, action by the Commission is needed to address electric distribution grid and customer security issues related to public display or access to grid data; including, but not limited to, distribution grid mapping, aggregated load data, and critical infrastructure?

On January 30, 2021 Dakota Electric issued a proposal to provide "discrete sets of information on-demand" to Distributed Energy Resource ("DER") developers "necessary for the orderly, efficient, and cost-effective deployment of DER…while also limiting risks that may be created by widely disseminating potentially sensitive grid data."

While Minnesota Power ("Company") initially expressed concern that adoption of Dakota Electric's proposal would cause unnecessary complications for its own interconnection process, upon further discussion before the Commission the Company clarified that Dakota Electric's Proposal was consistent with current practices and supported its adoption.

In the PUC's order of June 7, 2023 Minnesota Power was ordered to provide a narrative report on the implementation of this policy in it's next Integrated Distribution Plan ("IDP").

Dakota Electric's Proposal:

In its Initial Comments in this docket filed January 29, 2020 and subsequently in its June 30, 2021 Reply Comments Dakota Electric set forth a proposal to share interconnection data with prospective DER developers that provided both ease of access to that information and protected the integrity and security of the electrical grid as well as customer privacy. Dakota Electric proposed that DER developers would obtain a Pre-Application Report from Dakota Electric, to be followed with a meeting with a distribution engineer knowledgeable about the area. The developer would be billed for the meeting
at a level that would compensate the utility for the engineering labor and preparation time.
Dakota Electric further proposed that the report contain the following information which was readily available from its Geographic Information System ("GIS") and does not compromise sensitive grid information:

- Distribution transformer, kVA rating, total DER already interconnected or proposed, percent capacity utilized;

- At all upstream devices (e.g., fuses, breakers, reclosers, regulators) Rating, total DER proposed or interconnected, percent capacity utilized;
- Substation capacity, total DER proposed or interconnected, min load from last study, percent of minimum load utilized; and
- Conductor size(s) and footage between distribution transformer and substation.

In its order of June 7, 2023 the Commission adopted Dakota Electric's proposal and applied it to Dakota Electric, Otter Tail Power, and Minnesota Power "provide discrete sets of information on-demand, in the context of other existing DER interconnection tools and improvements being considered to maintain an orderly, efficient, and cost-effective deployment of DER in Minnesota."

Minnesota Power's Process:

Dakota Electric's proposal is similar to the existing interconnection process at Minnesota Power. Minnesota Power follows guidelines set forth in the Minnesota Distributed Energy Resources Interconnection Process (MnDIP) for answering questions regarding current hosting capacity and other data for potential customers and developers. The Pre-Application Report is offered for a $300 flat fee.

The Pre-Application report (MnDIP Section 1.4.2) offers valuable information for potential projects. The application does not require in-depth engineering or proof of site control. An applicant must simply indicate a system size and point of proposed interconnection. The resulting report gives high level site specific and feeder level data which may then be used to assess the viability of a project.
The data supplied includes:

- Total capacity in megawatts ("MW") of substation/area bus, bank or circuit based on normal or operating ratings likely to serve the proposed Point of Common Coupling.
- Existing aggregate generation capacity (in MW) interconnected to a substation/area bus, bank or circuit (i.e., amount of generation online) likely to serve the proposed Point of Common Coupling.
- Aggregate queued generation capacity (in MW) for a substation/area bus, bank or circuit (i.e., amount of generation in the queue) likely to serve the proposed Point of Common Coupling.
- Available capacity (in MW) of substation/area bus or bank and circuit likely to serve the proposed Point of Common Coupling (i.e., total capacity less the sum of existing aggregate generation capacity and aggregate queued generation capacity).
- Substation nominal distribution voltage and/or transmission nominal voltage if applicable.
- Nominal distribution circuit voltage at the proposed Point of Common Coupling.
- Approximate circuit distance between the proposed Point of Common Coupling and the substation.
- Relevant line section(s) actual or estimated peak load and minimum load data, including daytime minimum load as described in section 3.4.4.1 below and absolute minimum load, when available.
- Whether the Point of Common Coupling is located behind a line voltage regulator.
- Number and rating of protective devices and number and type (standard, bi-directional) of voltage regulating devices between the proposed Point of Common Coupling and the substation/area. Identify whether the substation has a load tap changer.

- Number of phases available on the Minnesota Power medium voltage system at the proposed Point of Common Coupling. If a single phase, distance from the three-phase circuit.
- Limiting conductor ratings from the proposed Point of Common Coupling to the distribution substation.
- Whether the Point of Common Coupling is located on a spot network, grid network, or radial supply.
- Based on the proposed Point of Common Coupling, existing or known constraints such as, but not limited to, electrical dependencies at that location, short circuit interrupting capacity issues, power quality or stability issues on the circuit, capacity constraints, or secondary networks.

The Pre-Application report is a cost effective, up to date, and expedient way for project developers to understand potential project viability. Minnesota Power has seen an uptick in Pre-Applications in 2023. Feedback has been positive from applicants as to the usefulness of the data they receive. Additionally, the process inis an opportunity for both Minnesota Power, customers, and developers to engage in follow up questions and answers.

Conclusion:

It is the Company's position that its Interconnection Process meets the letter and spirit of the Commission's adoption of the Dakota Electric proposal. That said, the Company may consider adjustments based on those set forth in the proposal, such as formalizing scheduling and fee structure for interconnection projects requiring additional direct meetings with Minnesota Power Distribution personnel.
If you have any questions regarding this filing, please contact me at (218) 428-9846 or jmccullough@mnpower.com.

Yours truly,

Jess McCullough
Public Policy Advisor

STATE OF MINNESOTA)
) ss
COUNTY OF ST. LOUIS)

AFFIDAVIT OF SERVICE VIA
ELECTRONIC FILING

Tiana Heger of the City of Duluth, County of St. Louis, State of Minnesota, says that on the 16th day of October, 2023, she served Minnesota Power's Compliance Filing of its 2023 Integrated Distribution Plan in **Docket No. E015/M-23-258** on the Minnesota Public Utilities Commission and the Energy Resources Division of the Minnesota Department of Commerce via electronic filing. The persons on E-Docket's Official Service List for this Docket were served as requested.

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Tiana Heger