Report R63-10

MHEB Group TSR System Impact Study Prior Outage Analysis and Incremental Transmission Capability

Prepared for

Midwest ISO

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Contents

Legal Notice ..... **iii**

Section 1 Prior Outage Thermal Analysis **1-1**

1.1 Methodology 1-1

1.2 Power Flow Cases 1-1

1.3 Thermal Screening 1-2

Section 2 Incremental Transmission Capability **2-5**

2.1 Methodology 2-5

2.2 Model Development 2-5

2.2.1 Transmission Options 2-5

2.2.2 Summer Peak Cases 2-6

2.3 Contingency Criteria 2-6

2.4 Monitored Facilities 2-7

2.5 Performance Criteria 2-7

2.6 Thermal Analysis Results 2-7

2.6.1 Injection at Bison 2-7

2.6.2 Simultaneous Injection at Bison and Brookings County 2-9

Appendix A Prior Outage Thermal Analysis **A-1**

Appendix B Incremental Transmission Capability **B-1**

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Section

1

Prior Outage Thermal Analysis

The analyses summarized in Section 1 have been performed to evaluate transfer capability on the MHEX_S interface with the Riel-Forbes-Chisago 500 kV line out of service.

1.1 Methodology

Summer peak thermal power flow models were created with the Riel-Forbes-Chisago 500 kV line out of service. The Forbes SVS is assumed to be in service.

The existing Manitoba-US transfer limit (SOL, system intact) is 2175 MW, and there is a 1420 MW difference between the system intact and prior outage SOL (2175-755). A linear analysis was performed to screen for thermal constraints at three MHEX_S transfer levels:

- 2175 MW: existing system intact SOL
- 1855 MW: existing 1420 MW differential applied to SOL (2175+1100-1420)
- 1528 MW: existing 1420 MW differential applied to firm transfer limit (1848+1100-1420)

A stability analysis was performed for Option 1 and the results are summarized in the System Impact Study performed for Option 1[1]. A stability analysis will be performed for option W1 or W2 after the transmission customers identify the preferred alternate.

1.2 Power Flow Cases

Study cases with the south bound TSRs and associated upgrade options are described in the System Impact Study for Option 1[1] and in the study for Options W1 and W2[2]. To create cases with Riel-Forbes-Chisago out of service, MH to US transfers were adjusted using a pro rata reduction of benchmark case flow and study TSRs. Benchmark case flow in the thermal case was adjusted based on confirmed firm transmission service using generation in the POD control area. Each study TSR was reduced to 74% (2175 MW case), 63% (1855 MW case), or 52% (1528 MW case) of the requested service. Diagrams of the thermal cases with Riel-Forbes-Chisago out of service are included in Appendix A.

[1] *MHEB Group TSR System Impact Study Transmission Option 1*; Siemens PTI Report R30-10
[2] *MHEB Group TSR System Impact Study Transmission Options W1 and W2*; Siemens PTI Report R20-10

Table 1-1: MHEX Transfers in Prior Outage Cases

	System Intact	Prior Outage 2175 MW Xfer	Prior Outage 1855 MW Xfer	Prior Outage 1528 MW Xfer
Benchmark Case Flow	1848 MW	1363 MW	1163 MW	958 MW
TSRs	1100 MW	812 MW	692 MW	570 MW
Total	2948 MW	2175 MW	1855 MW	1528 MW

1.3 Thermal Screening

A linear analysis was performed to screen the summer peak thermal cases for thermal constraints at the 2175 MW, 1855 MW and 1528 MW transfer levels. The screening was performed using the same contingency and performance criteria as the steady-state contingency analysis in the System Impact Study. A thermal impact is considered significant if the post-contingent loading exceeds the thermal rating and the impact of at least one TSR exceeds the applicable PTDF or OTDF threshold.

Significantly affected facilities at the 2175 MW transfer level are listed in Table 1-2. Details are provided in Appendix A.

The Roseau-Richer 230 kV line and Drayton-Letellier 230 kV line are MHEX_S facilities and may require mitigation at the 2175 MW transfer level. Other facilities that are close to the MHEX_S interface and may require mitigation include the Bison 500-345 kV transformers and the Bison-Maple River 230 kV line. Saratoga-Petenwell was previously identified as a TSR constraint; after mitigation, the line will accommodate the loading identified in the prior outage screening. Other facilities that are remote from the MHEX_S interface will be addressed using operating solutions such as market redispatch following the Riel-Forbes-Chisago contingency.

Table 1-2: 2175 MW Xfer Level, Significantly Affected Facilities [1]

Monitored Element	Owner	Rating [2] N/E	Rating [2] MVA	Option 1	Option W1	Option W2
Blue Lake-Helena 345 kV	XCEL	E	1511	105.1%		
Coon Creek-Terminal 345 kV	XCEL	E	1195		100.3%	
Bison 500-345 kV Xfmr #1		E	1500		101.2%	
Bison 500-345 kV Xfmr #2		E	1500		101.2%	
Roseau-Richer 230 kV	MH	E	229.9	113.3	119.5%	122.9%
Bison-Maple River 230 kV	OTP	E	520		112.5%	
Wilson-Wilson Tap 115 kV	XCEL	E	239		101.9%	101.2%
Nashwauk-Blackberry 115 kV	MP	E	158	100.6%	102.8%	101.8%
Maple River 345-230 kV Xfmr #1	OTP	E	420		104.3%	
Maple River 345-230 kV Xfmr #2	OTP	E	420		104.3%	

Monitored Element	Owner	Rating [2] N/E	MVA	Option 1	Option W1	Option W2
Alexandria-Alexandria Switching Station 115 kV	OTP	E	160	108.2%	112.1%	126.9%
Drayton-Letellier 230 kV	MH	E	460.5			104.5
Saratoga-Petenwell 138 kV	ATC	E	72.2	130.3%	120.8%	125.8%

Notes
1. Blank cell indicates facility is not significantly affected for transmission option
2. Loading is compared against Normal (N) and/or Emergency (E) rating

Significantly affected facilities at the 1855 MW transfer level are listed in Table 1-3. The Roseau-Richer 230 kV line is a MHEX_S facility and may require mitigation at the 1855 MW transfer level. Other facilities that are close to the MHEX_S interface and may require mitigation include the Bison-Maple River 230 kV line.

Table 1-3: 1855 MW Xfer Level, Significantly Affected Facilities [1]

Monitored Element	Owner	Rating [2] N/E	MVA	Option 1	Option W1	Option W2
Roseau-Richer 230 kV	MH	E	229.9	102.0%	107.4%	114.1%
Bison-Maple River 230 kV	OTP	E	520		102.6%	
Nashwauk-Blackberry 115 kV	MP	E	158		101.6%	
Alexandria-Alexandria Switching Station 115 kV	OTP	E	160	103.8%	110.9%	120.1%
Saratoga-Petenwell 138 kV	ATC	E	72.2	126.5%	116.8%	120.9%

Notes
1. Blank cell indicates facility is not significantly affected for transmission option
2. Loading is compared against Normal (N) and/or Emergency (E) rating

Significantly affected facilities at the 1528 MW transfer level are listed in Table 1-4. No MHEX_S facilities are significantly affected at the 1528 MW transfer level.

Table 1-4: 1528 MW Xfer Level, Significantly Affected Facilities [1]

Monitored Element	Owner	Rating [2] N/E	MVA	Option 1	Option W1	Option W2
Nashwauk-Blackberry 115 kV	MP	E	158		100.3%	
Alexandria-Alexandria Switching Station 115 kV	OTP	E	160		106.0%	112.4%
Saratoga-Petenwell 138 kV	ATC	E	72.2	121.3%	112.7%	116.4%

Notes
1. Blank cell indicates facility is not significantly affected for transmission option
2. Loading is compared against Normal (N) and/or Emergency (E) rating

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Section
2

Incremental Transmission Capability

The analyses summarized in Section 2 have been performed to estimate the incremental transmission capability for each 500 kV transmission option.

2.1 Methodology

A summer peak power flow case was used to estimate the incremental transmission capability of the transmission options shown in Table 2-1. Transmission capability is estimated subject to thermal transmission system limits and does not consider voltage or stability limitations.

2.2 Model Development

2.2.1 Transmission Options

Table 2-1 describes the transmission upgrade options. Table 2-1 includes Option W6 (a.k.a. Comprehensive Plan) in addition to the transmission options evaluated in the MHEB Group TSR System Impact Study.

Table 2-1: Transmission Upgrade Options

Option	Project
1	Dorsey-Bison 50% series compensated 500 kV line (230 miles) Bison-Helena 50% series compensated 500 kV line (286 miles) One 500/345 kV, 1200 MVA transformer at Bison Two 500/345 kV, 1200 MVA transformers at Helena
W1	Dorsey-Bison 60% series compensated 500 kV line (230 miles) Double circuit the proposed CapX Group 1 345 kV line Bison-Alexandria Switching Station-Waite Park-Monticello Two 500/345 kV, 1200 MVA transformers at Bison
W2	Dorsey-Bison 50% series compensated 500 kV line (230 miles) Bison-Brookings County 50% series compesated 500 kV line (180 miles) One 500/345 kV, 1200 MVA transformer at Bison Two 500/345 kV, 1200 MVA transformers at Brookings County
W6 (Comprehensive)	Dorsey-Bison 50% series compensated 500 kV line (230 miles) Bison-Brookings County 50% series compesated 500 kV line (180 miles) Brookings County-Split Rock 500 kV line (60 miles) Double circuit the proposed CapX Group 1 345 kV line Bison-Alexandria Switching Station-Waite Park-Monticello Double circuit the proposed CapX Group 1 345 kV line Brookings Co-

Option	Project
	Hampton Corner Corridor Project, Hazel Creek-Blue Lake double circuit 345 kV One 500/345 kV, 1200 MVA transformer at Bison Two 500/345 kV, 1200 MVA transformers at Brookings County Two 500/345 kV, 1200 MVA transformers at Split Rock

2.2.2 Summer Peak Cases

The summer peak cases were developed in the MHEB Group TSR SIS. One transmission upgrade option is modeled in each case along with the 1100 MW of requested south bound transmission service from Manitoba. Manitoba is exporting a total of 1848+1100=2848 MW in each case.

Refer to the System Impact Study report for Option 1 and the study report for Options W1 and W2 for details on case development.

2.3 Contingency Criteria

A variety of contingencies are considered for steady-state analysis:

- NERC Category A with system intact (no contingencies)
- NERC Category B contingencies
  - Outage of single element 100 kV or higher (B.2 and B.3) associated with single contingency event in the following areas: Iowa, Manitoba, Minnesota, North Dakota, South Dakota, and Wisconsin.
  - Outage of multiple-elements 100 kV or higher (B.2 and B.3) associated with single contingency event in the following areas: Iowa, Manitoba, Minnesota, North Dakota, South Dakota, and Wisconsin.
- NERC Category C contingencies
  - Outage of common tower circuits (C.5) as specified by the ad-hoc study group
  - Outage of multiple-elements (C.7-C.9) as specified by the ad-hoc study group
  - Select single element outage combinations (C.3) as specified by the ad-hoc study group

Existing 500 kV and 230 kV triggers to the Manitoba Hydro HVDC power order reduction scheme were simulated in the contingency analysis. Outage of the Dorsey-Bison 500 kV line is modeled with a 100% HVDC reduction. Outage of the Bison-Helena 500 kV line (Option 1) or the Bison-Brookings Co. 500 kV line (Option W2 and Option W6) is modeled with a 50% HVDC reduction.

2.4 Monitored Facilities

Facilities 69 kV and above were monitored in northern Illinois, Iowa, Manitoba, Minnesota, Nebraska, North Dakota, South Dakota and Wisconsin. Pre-contingent loading was compared against the normal rating (PSS®E rate A) and post-contingent loading was compared against the emergency rating (rate B).

2.5 Performance Criteria

A branch is considered a significantly affected facility if both of the following conditions are met:

1) The branch is loaded above its applicable normal or emergency rating for the post-change case, and
2) The power transfer distribution factor (PTDF) or outage transfer distribution factor (OTDF) is greater than 5%.

2.6 Thermal Analysis Results

The Linear FCITC Calculation in PSS®MUST was used to calculate the incremental transmission capability of each transmission option subject to thermal transmission system limits. Each option was evaluated by injecting power at the Bison 345 kV bus. Option W6 was also evaluated by simultaneously injecting power at both Bison and Brookings County. Power was sunk to generation in eastern MISO control areas (202 First Energy, 207 Hoosier Energy, 208 Duke Energy Midwest, 210 Southern Indiana Gas & Electric, 216 Indianapolis Power & Light, 217 Northern Indiana Public Service, 218 Michigan Electric Transmission Company, 219 International Transmission Company).

Power was injected until the pre-contingent flow on the Roseau 500 kV series capacitors reached the existing 1732 MVA rating. For this initial screen, emphasis was placed on constraints between Winnipeg and the Twin Cities. Impacts on facilities remote from the new transmission facilities were calculated but were not used to estimate incremental transfer capability.

The results in Appendix A include estimates of costs to mitigate constraints that are more restrictive than the limit imposed by the Roseau 500 kV series capacitors. These costs are estimates based on the assumptions shown in Appendix B, Table B-6.

2.6.1 Injection at Bison

Power was injected at the Bison 345 kV bus and sunk to generation in eastern MISO control areas.

Detailed results for each transmission option are shown in Appendix B, Tables B-1 through B-4, which show the two lowest injection limits associated with each limiting facility. Table 2-2 shows a comparison of incremental transfer capability without making any system improvements.

Table 2-2: Incremental Transfer Capability without Improvements - Bison Injection

	Option 1	Option W1	Option W2	Option W6
Injection Limit	1187 MW	0 MW	747 MW	1379 MW

Table 2-3 shows the estimated cost to achieve 1000 MW of incremental injection capability. These estimates do not include the cost to address regional constraints in Iowa, Illinois or Wisconsin.

The majority of the upgrades associated with Option W1 are needed to address NERC category C.5 contingencies (any two circuits of a multiple circuit towerline) for outage of sections of the Bison-Alexandria Switching Station-Waite Park-Monticello 345 kV line.

Table 2-3: Cost to Achieve 1000 MW Injection Capability - Bison Injection

	Option 1	Option W1	Option W2	Option W6
Cost of Option[1]	$1,242 million	$774 million	$987 million	$1,802 million
Incremental cost to achieve 1000 MW injection capability	$0	$155 million	$20 million	$0
Total cost to achieve 1000 MW injection capability	$1,242 million	$929 million	$1,007 million	1,802 million

Note 1: Cost estimates are for transmission lines only

Table 2-4 shows the injection at which pre-contingent flow on the 500 kV line reaches 1732 MVA in the summer peak case. With Option 1, approximately 23% of the power injected at Bison flows on the existing 500 kV line (PTDF), versus 13%-17% with the other options. The Roseau series capacitors can be upgraded to increase their rating from 2000 A to 2500 A; this increase may impact regional reserve requirements.

Table 2-4: Injection Limit Imposed by 500 kV Line - Bison Injection

	Option 1	Option W1	Option W2	Option W6
Injection limit imposed by 500 kV line	1932 MW	1008 MW	1145 MW	2292 MW
Cost of Option[1]	$1,242 million	$774 million	$987 million	$1,802 million
Incremental cost to achieve limit imposed by 500 kV line	$49 million	$155 million	$20 million	$91 million
Total cost to achieve limit imposed by 500 kV line	$1,291 million	$929 million	$1,007 million	$1,893 million

Note 1: Cost estimates are for transmission lines only

2.6.2 Simultaneous Injection at Bison and Brookings County

A second analysis was performed with Option W6 with power injected simultaneously at the Bison 345 kV bus and Brookings County 345 kV bus and sunk to generation in eastern MISO control areas. Detailed results are in Appendix B, Table B-5, which shows the two lowest injection limits associated with each limiting facility.

The Split Rock 345-115 kV transformers are the only local facilities that would require mitigation to achieve a total injection of 3000 MW (1500 MW at each location). Additional upgrades may be required to address regional constraints in Iowa, Illinois and Wisconsin.

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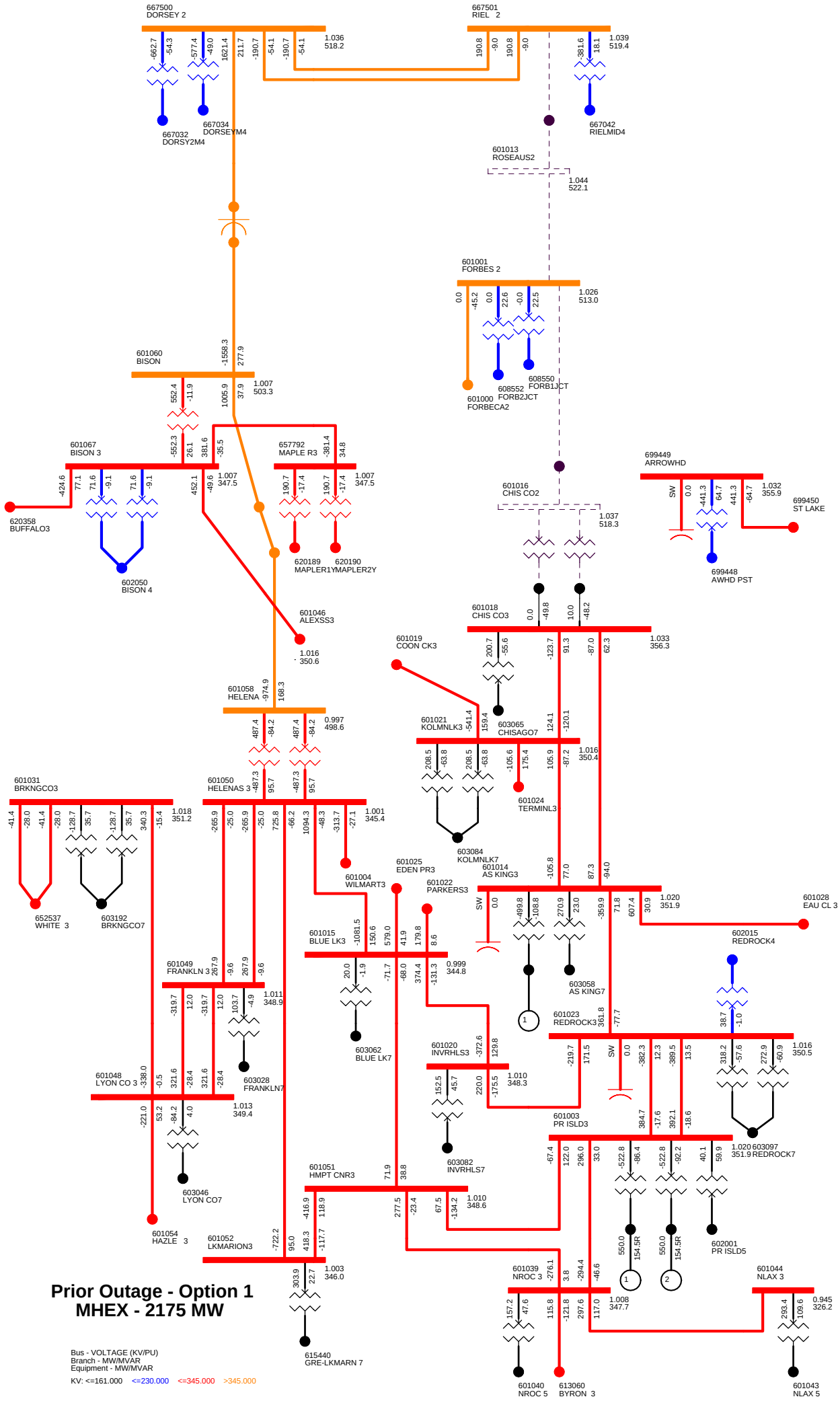
Appendix

A

Prior Outage Thermal Analysis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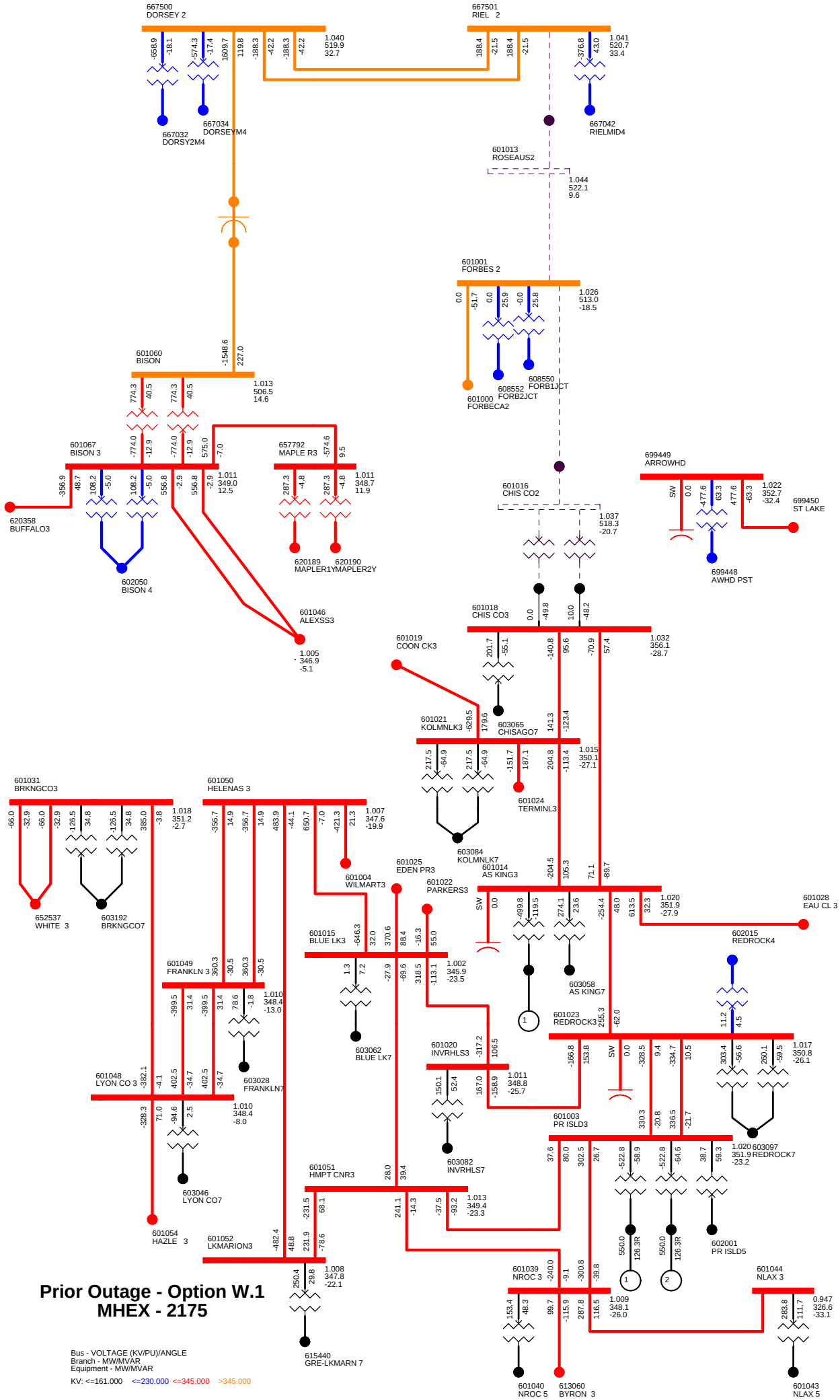
BYRON 3
601044
NLAX 3
0.945
326.2
601043
NLAX 5
Prior Outage - Option 1
MHEX - 2175 MW
Bus - VOLTAGE (KV/PU)
Branch - MW/MVAR
Equipment - MW/MVAR
KV: <=161.000 <=230.000 <=345.000 >345.000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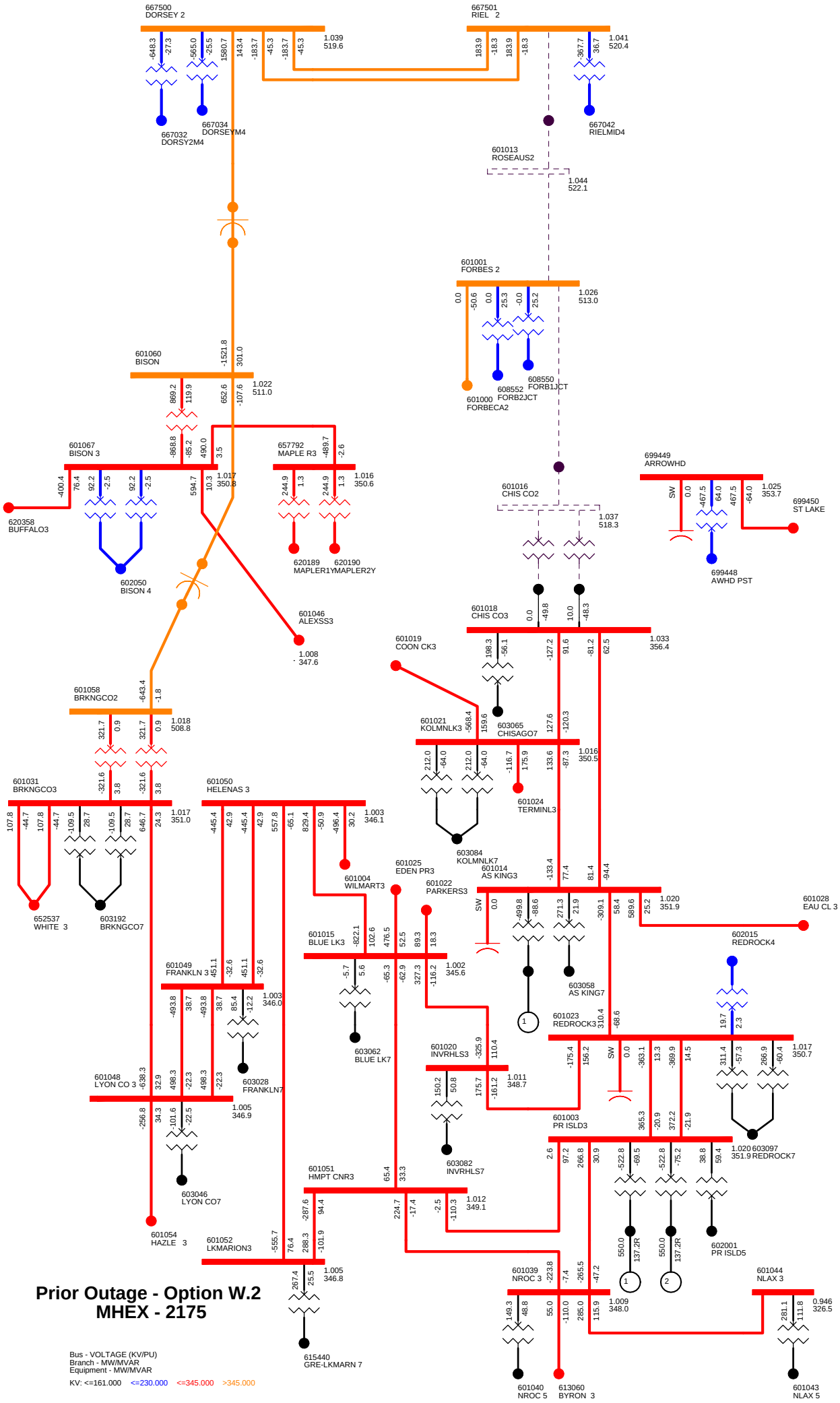
Prior Outage - Option W.1
MHEX - 2175
Bus - VOLTAGE (KV/PU)/ANGLE
Branch - MW/MVAR
Equipment - MW/MVAR
KV: <=161.000
<=230.000
<=345.000
>345.000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601039
NROC 3
601040
NROC 5
613060
BYRON 3
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NLAX 3
601043
NLAX 5
Prior Outage - Option W.2
MHEX - 2175
Bus - VOLTAGE (KV/PU)
Branch - MW/MVAR
Equipment - MW/MVAR
KV: <=161.000 <=230.000 <=345.000 >345.000

Table A-1: Option 1, Riel-Forbes-Chisago Prior Outage
Thermal Violations, Significantly Affected Facilities

Monitored Element	Owner	Rating N/E	Rating MVA	2175 Xfer Loading (%)	1855 Xfer Loading (%)	1528 Xfer Loading (%)	Contingency Detail
601015 BLUE LK3 345 601050 HELENAS 3 345 1	XCEL	E	1511	105.1%	99.0%	92.2%	CAPX7 HELENAS 3 345 - LKMARION3 345 1 LKMARION3 345 - GRE-LKMARN 7115 1 LKMARION3 345 - HMPT CNR3 345 1
602013 ROSEAU 4 230 667046 RICHER 4 230 1	MH	E	229.9	113.3%	102.0%	92.0%	726L INTPHAS7 118 - FT FRANC 118 1 INTPHAS7 118 - I.FALLS7 118 1
602013 ROSEAU 4 230 667046 RICHER 4 230 1	MH	E	229.9	104.5%	93.2%	83.1%	LIL FORK 1T RUNNING4 230 - LITLFRK7 118 1 RUNNING4 230 - RUNSWCP4 230 1
608737 NASHWAK7 115 608739 BLCKBRY7 115 1	MP	E	158	100.6%	99.8%	98.6%	FORBES 4 230 - BLCKBRY4 230 1
620222 ALEXAND7 115 658050 ALEXSS 7 115 1	OTP	E	160	108.2%	103.8%	97.2%	ALEXSS3 345 - WAITEPK3 345 1
659120 BRDLAND3 345 659204 BRDLNDTY 345 1	BEPC	N (E)	400 (480)	102.9% (85.8%)	100.1% (83.4%)	97.4% (81.1%)	FTTHOMP3 345 - LELANDO3 345 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	130.3%	126.5%	121.3%	ATC-ZN1-2 AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	122.0%	118.4%	113.5%	ATC-ARP-0G2 EAU CL 3 345 - ARP 345 345 1 COC 69 69.0 - TIMBERWOLF 69.0 1 HLT 69 69.0 - MAUSTON 69.0 1 LUBLIN 69.0 - LAKEHEAD 69.0 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	120.2%	116.5%	111.6%	ATC-ARP-0G1 AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1 COC 69 69.0 - TIMBERWOLF 69.0 1 HLT 69 69.0 - MAUSTON 69.0 1 LUBLIN 69.0 - LAKEHEAD 69.0 1

Notes

1. Loading is compared against Normal (N) and/or Emergency (E) rating

Table A-2: Option W1, Riel-Forbes-Chisago Prior Outage
Thermal Violations, Significantly Affected Facilities

Monitored Element	Owner	Rating N/E	Rating MVA	2175 Xfer Loading (%)	1855 Xfer Loading (%)	1528 Xfer Loading (%)	Contingency Detail
601019 COON CK3 345 601024 TERMINL3 345 1	XCEL	E	1195	100.3%	98.0%	93.3%	B_XEL_COON_CK-KOLMNLK COON CK3 345 - KOLMNLK3 345 1 KOLMNLK3 345 - KOLMNLK7 115 9
601060 BISON 500 601067 BISON 3 345 1		E	1500	101.2%	87.8%	57.5%	BISON 500 - BISON 3 345 2
601060 BISON 500 601067 BISON 3 345 2		E	1500	101.2%	87.8%	57.5%	BISON 500 - BISON 3 345 1
602013 ROSEAU 4 230 667046 RICHER 4 230 1	MH	E	229.9	119.5%	107.4%	92.0%	726L INTPHAS7 118 - FT FRANC 118 1 INTPHAS7 118 - I.FALLS7 118 1
602013 ROSEAU 4 230 667046 RICHER 4 230 1	MH	E	229.9	110.7%	100.1%	83.1%	LIL FORK 1T RUNNING4 230 - LITLFRK7 118 1 RUNNING4 230 - RUNSWCP4 230 1
602050 BISON 4 230 657754 MAPLE R4 230 1	OTP	E	520	112.5%	102.6%	79.7%	BISON 3 345 - MAPLE R3 345 1
603116 WILSON 7 115 603204 WILSON TAP7 115 1	XCEL	E	239	101.9%	99.7%	95.4%	BLK DOG7 115 - WILSON 7 115 1
608737 NASHWAK7 115 608739 BLCKBRY7 115 1	MP	E	158	102.8%	101.6%	100.3%	FORBES 4 230 - BLCKBRY4 230 1
608737 NASHWAK7 115 608739 BLCKBRY7 115 1	MP	E	158	100.2%	98.7%	95.6%	20L BLANDIN7 115 - 20L TAP7 115 1 BLCKBRY7 115 - 20L TAP7 115 1 GR RPDS7 115 - 20L TAP7 115 1
620189 MAPLER1Y 345 657792 MAPLE R3 345 1	OTP	E	420	104.3%	95.1%	73.9%	MAPLER2Y 345 - MAPLE R3 345 1
620190 MAPLER2Y 345 657792 MAPLE R3 345 1	OTP	E	420	104.3%	95.1%	73.8%	MAPLER1Y 345 - MAPLE R3 345 1
620222 ALEXAND7 115 658050 ALEXSS 7 115 1	OTP	E	160	112.1%	110.9%	106.0%	552 ALEXSS 7 115 - ALEXSWM7 115 1 ALEXSWM7 115 - ALEXPLDM 115 1
659120 BRDLAND3 345 659204 BRDLNDTY 345 1	BEPC	N (E)	400 (480)	110.2% (91.8%)	106.7% (88.9%)	102.7% (85.6%)	FTTHOMP3 345 - LELANDO3 345 1
659120 BRDLAND3 345 659204 BRDLNDTY 345 1	BEPC	N (E)	400 (480)	106.6% (88.9%)	103.3% (86.0%)	99.5% (82.9%)	LELANDO3 345 - GROTON 3 345 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	76	120.8%	116.8%	112.7%	ATC-ZN1-2 AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	76	113.2%	109.3%	105.3%	ATC-ARP-OG2 EAU CL 3 345 - ARP 345 345 1 COC 69 69.0 - TIMBERWOLF 69.0 1 HLT 69 69.0 - MAUSTON 69.0 1 LUBLIN 69.0 - LAKEHEAD 69.0 1

Table A-3: Option W2, Riel-Forbes-Chisago Prior Outage
Thermal Violations, Significantly Affected Facilities

Monitored Element	Owner	Rating N/E	Rating MVA	2175 Xfer Loading (%)	1855 Xfer Loading (%)	1528 Xfer Loading (%)	Contingency Detail
602013 ROSEAU 4 230 667046 RICHER 4 230 1	MH	E	229.9	122.9%	114.1%	99.1%	726L INTPHAS7 118 - FT FRANC 118 1 INTPHAS7 118 - I.FALLS7 118 1
602013 ROSEAU 4 230 667046 RICHER 4 230 1	MH	E	229.9	114.0%	105.3%	90.3%	LIL FORK 1T RUNNING4 230 - LITLFRK7 118 1 RUNNING4 230 - RUNSWCP4 230 1
603116 WILSON 7 115 603204 WILSON TAP7 115 1	XCEL	E	239	101.2%	99.1%	95.0%	BLK DOG7 115 - WILSON 7 115 1
608737 NASHWAK7 115 608739 BLCKBRY7 115 1	MP	E	158	101.8%	100.0%	99.6%	FORBES 4 230 - BLCKBRY4 230 1
620222 ALEXAND7 115 658050 ALEXSS 7 115 1	OTP	E	160	126.9%	120.1%	112.4%	ALEXSS3 345 - WAITEPK3 345 1
657752 DRAYTON4 230 667048 LETELER4 230 1	MH	E	460.5	104.5%	93.3%	81.1%	BISON 500 - BISON 3 345 1
659120 BRDLAND3 345 659204 BRDLNDTY 345 1	BEPC	N (E)	400 (480)	105.4% (87.8%)	103.6% (86.3%)	101.1% (84.3%)	FTTHOMP3 345 - LELANDO3 345 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	125.8%	120.9%	116.4%	ATC-ZN1-2 AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	117.7%	113.0%	108.7%	ATC-ARP-OG2 EAU CL 3 345 - ARP 345 345 1 COC 69 69.0 - TIMBERWOLF 69.0 1 HLT 69 69.0 - MAUSTON 69.0 1 LUBLIN 69.0 - LAKEHEAD 69.0 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	115.9%	111.2%	106.9%	ATC-ARP-OG1 AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1 COC 69 69.0 - TIMBERWOLF 69.0 1 HLT 69 69.0 - MAUSTON 69.0 1 LUBLIN 69.0 - LAKEHEAD 69.0 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	109.4%	106.8%	104.0%	ARP 345 345 - ARP 138 138 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	72.2	108.9%	106.1%	103.3%	SGL 138 138 - ARP 138 138 1

Notes

1. Loading is compared against Normal (N) and/or Emergency (E) rating

Monitored Element	Owner	Rating N/E	Rating MVA	2175 Xfer Loading (%)	1855 Xfer Loading (%)	1528 Xfer Loading (%)	Contingency Detail
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	76	111.3%	107.5%	103.5%	ATC-ARP-OG1 AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1 COC 69 69.0 - TIMBERWOLF 69.0 1 HLT 69 69.0 - MAUSTON 69.0 1 LUBLIN 69.0 - LAKEHEAD 69.0 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	76	103.7%	101.7%	99.3%	ARP 345 345 - ARP 138 138 1
699240 SAR 138 138 699808 PETENWEL 138 1	ATC	E	76	103.4%	101.2%	98.7%	SGL 138 138 - ARP 138 138 1

Notes

1. Loading is compared against Normal (N) and/or Emergency (E) rating

Appendix

B

Incremental Transmission Capability

Table B-1: Option 1 Summer Peak Thermal Results

Monitored Element	Rating (MVA)	Contingency	FCITC (MW)	Bison DF	Required Rating (MVA)	Remedy	Cost (M$)
602050 BISON 4 230 657754 MAPLE R4 230 1	520	BISON 3 345 - MAPLE R3 345 1	1187.3	18.6%	659	Rebuild 10 mile (est) line with 795 ACSS	15.0
601067 BISON 3 345 657792 MAPLE R3 345 1	792	BISON-HELENA-50 MIDCOMP-W 500 - BISON 500 1 MIDCOMP-E 500 - MIDCOMP-W 500 1 MIDCOMP-E 500 - HELENA 500 1 Change bus DORSEY 4 230 load by 562.0 MW	1349.5	27.1%	950	Replace terminal equipment to achieve conductor rating 1560 MVA	1.5
620189 MAPLER1Y 345 657792 MAPLE R3 345 1	420	MAPLER2Y 345 - MAPLE R3 345 1	1361.0	14.1%	501	Add 3rd 336/420 MVA transformer	10.0
620190 MAPLER2Y 345 657792 MAPLE R3 345 1	420	MAPLER1Y 345 - MAPLE R3 345 1	1361.7	14.1%	501	Remedy listed above	
36310 ELECT; B 345 36362 NELSO; B 345 1	1234	ATC_B2_2221_GD ZION ; R 345 - PLS PR2 345 1 ZION ; 138 - LAKEVIEW 138 1	1367.4	14.4%	1315	IL constraint	
601015 BLUE LK3 345 601050 HELENAS 3 345 1	1511	HELENAS 3 345 - LKMARION3 345 1	1384.0	15.8%	1598	Rebuild 15 mile (est) line with twin bundled 954 ACSS	22.5
698871 GRANVL3 345 699328 GRANVL 6 138 1	478	GRANVL2 345 - GRANVL1 345 1	1403.1	5.2%	506	WI constraint	
36310 ELECT; B 345 36362 NELSO; B 345 1	1234	ZION ; R 345 - PLS PR2 345 1	1484.5	14.1%	1297	IL constraint	
601067 BISON 3 345 657792 MAPLE R3 345 1	792	BISON 4 230 - MAPLE R4 230 1	1646.4	24.3%	862	Remedy listed above	
601012 ROSEAUN2 500 601013 ROSEAUS2 500 1	1732	Base Case	1932.5	15.8%			

Table B-2: Option W1 Summer Peak Thermal Results

Monitored Element	Rating	Contingency	FCITC (MW)	Bison DF	Required Rating (MVA)	Remedy	Cost (M$)
620222 ALEXAND7 115 658050 ALEXSS 7 115 1	160	C5_XEL_Alex-Waite_345 ALEXSS3 345 - WAITEPK3 345 1 ALEXSS3 345 - WAITEPK3 345 2	-958.2	5.6%	269	Replace terminal equipment to achieve conductor rating 310 MVA	1.0
603032 SAUK RV7 115 615560 GRE-WST CLD7 115 1	201	C5_XEL_Waite-Montic_345 WAITEPK3 345 - MNTCELO3 345 1 WAITEPK3 345 - MNTCELO3 345 2	-549.7	7.3%	315	Rebuild 3 mile line with twin 795 ACSR and replace terminal equipment	3.1
601045 WAITEPK7 115 603032 SAUK RV7 115 1	239	C5_XEL_Waite-Montic_345 WAITEPK3 345 - MNTCELO3 345 1 WAITEPK3 345 - MNTCELO3 345 2	-534.6	7.3%	352	Rebuild 10 mile line with twin 795 ACSR and replace terminal equipment	8.0
601067 BISON 3 345 657792 MAPLE R3 345 1	792	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	208.0	33.8%	1063	Replace terminal equipment to achieve 1560 MVA conductor rating	1.5
620189 MAPLER1Y 345 657792 MAPLE R3 345 1	420	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	349.8	16.9%	532	Add 3rd 336/420 MVA transformer	10.0
620190 MAPLER2Y 345 657792 MAPLE R3 345 1	420	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	351.0	16.9%	531	Remedy listed above	
602050 BISON 4 230 657754 MAPLE R4 230 1	520	BISON 3 345 - MAPLE R3 345 1	370.4	22.4%	663	Rebuild 10 mile (est) line with 954 ACSS	10.0
601045 WAITEPK7 115 601047 WAITEPK3 345 1	515	C5_XEL_Waite-Montic_345 WAITEPK3 345 - MNTCELO3 345 1 WAITEPK3 345 - MNTCELO3 345 2	484.4	15.5%	596	Add 2nd 448/515 MVA transformer	7.5
620189 MAPLER1Y 345 657792 MAPLE R3 345 1	420	MAPLER2Y 345 - MAPLE R3 345 1	528.1	16.9%	501	Remedy listed above	
620190 MAPLER2Y 345 657792 MAPLE R3 345 1	420	MAPLER1Y 345 - MAPLE R3 345 1	528.7	16.9%	501	Remedy listed above	
657750 FRONTER4 230 657754 MAPLE R4 230 1	292	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	558.4	12.9%	350	Rebuild 4 mile line with 795 ACSS	4.0
620329 WAHPETN4 230 657750 FRONTER4 230 1	292	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	567.0	12.9%	349	Rebuild 50 mile line with 795 ACSS	50.0
602006 SHEYNNE4 230 657754 MAPLE R4 230 1	637	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	685.2	23.5%	713	Rebuild 7 mile line with 954 ACSS and replace terminal equiipment	8.2
601067 BISON 3 345 657792 MAPLE R3 345 1	792	C5_XEL_Alex-Waite_345 ALEXSS3 345 - WAITEPK3 345 1 ALEXSS3 345 - WAITEPK3 345 2	764.8	28.8%	862	Remedy listed above	
615560 GRE-WST CLD7 115 619402 GRE-WESTWD 7 115 1	214	C5_XEL_Waite-Montic_345 WAITEPK3 345 - MNTCELO3 345 1 WAITEPK3 345 - MNTCELO3 345 2	848.1	7.1%	225	Rebuild 3.5 mile line with 795 ACSS and replace terminal equipment	3.5
603042 MEI INT7 115 619402 GRE-WESTWD 7 115 1	214	C5_XEL_Waite-Montic_345 WAITEPK3 345 - MNTCELO3 345 1 WAITEPK3 345 - MNTCELO3 345 2	909.0	7.1%	221	Remedy listed above	

Monitored Element	Rating	Contingency	FCITC (MW)	Bison DF	Required Rating (MVA)	Remedy	Cost (M$)
601045 WAITEPK7 115 603035 STCLOUD7 115 1	239	C5_XEL_Waite-Montic_345 WAITEPK3 345 - MNTCELO3 345 1 WAITEPK3 345 - MNTCELO3 345 2	961.0	8.2%	243	Rebuild 3.5 mile line with 795 ACSS and replace terminal equipment	3.5
602006 SHEYNNE4 230 620336 AUDUBON4 230 1	385	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	986.4	8.7%	387	Rebuild 44 mile line with 795 ACSS and replace Audubon terminal equipment	44.6
601012 ROSEAUN2 500 601013 ROSEAUS2 500 1	1732.0	Base Case	1008.8	23.3%			

Table B-3: Option W2 Summer Peak Thermal Results

Monitored Element	Rating	Contingency	FCITC (MW)	Bison DF	Required Rating (MVA)	Remedy	Cost (M$)
602050 BISON 4 230 657754 MAPLE R4 230 1	520	BISON 3 345 - MAPLE R3 345 1	747.5	17.1%	588	Rebuild 10 mile (est) line with 795 ACSS	10.0
620189 MAPLER1Y 345 657792 MAPLE R3 345 1	420	MAPLER2Y 345 - MAPLE R3 345 1	922.1	13.1%	449	Add 3rd 336/420 MVA transformer	10.0
620190 MAPLER2Y 345 657792 MAPLE R3 345 1	420	MAPLER1Y 345 - MAPLE R3 345 1	922.9	13.1%	449	Remedy listed above	
601012 ROSEAUN2 500 601013 ROSEAUS2 500 1	1732	Base Case	1145.4	17.3%			

Table B-4: Comprehensive Plan Summer Peak Thermal Results - Bison Injection

Monitored Element	Rating	Contingency	FCITC (MW)	Bison DF	Required Rating (MVA)	Remedy	Cost (M$)
36310 ELECT; B 345 36362 NELSO; B 345 1	1234	ATC_B2_2221_GD ZION ; R 345 - PLS PR2 345 1 ZION ; 138 - LAKEVIEW 138 1	1379.7	14.3%	1364	IL Constraint	
602050 BISON 4 230 657754 MAPLE R4 230 1	520	BISON 3 345 - MAPLE R3 345 1	1429.1	14.4%	644	Rebuild 10 mile (est) line with 795 ACSS	10.0
36310 ELECT; B 345 36362 NELSO; B 345 1	1234	WPS-ARP2eA EAU CL 3 345 - ARP 345 345 1 T-CRNRS7 115 - WIEN 115 1 COC 69 69.0 - TIMBERWOLF 69.0 1 MAUSTON 69.0 - HLT 69 69.0 1	1539.5	14.1%	1340	IL Constraint	
620189 MAPLER1Y 345 657792 MAPLE R3 345 1	420	MAPLER2Y 345 - MAPLE R3 345 1	1562.5	13.9%	496	Add 3rd 336/420 MVA transformer	10.0
620190 MAPLER2Y 345 657792 MAPLE R3 345 1	420	MAPLER1Y 345 - MAPLE R3 345 1	1562.5	13.9%	496	Remedy listed above	
601067 BISON 3 345 657792 MAPLE R3 345 1	792	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	1562.5	13.9%	923	Replace terminal equipment to achieve 1560 MVA conductor rating	1.5
601043 NLAX 5 161 601044 NLAX 3 345 1	448	NROC 3 345 - BYRON 3 345 1	1679.8	7.2%	492	WI Constraint	
601043 NLAX 5 161 601044 NLAX 3 345 1	448	825 C ADAMS 3 345 - GRE-PL VLLY3345 1 ADAMS 3 345 - ADAMS 5 161 1 ADAMS 3 345 - G172_WF3 345 1 HAZLTON3 345 - G172_WF3 345 1	1700.5	7.3%	491	WI Constraint	
601045 WAITEPK7 115 601047 WAITEPK3 345 1	515	C5_XEL_Waite-Montic_345 WAITEPK3 345 - MNTCELO3 345 1 WAITEPK3 345 - MNTCELO3 345 2	1796.0	10.1%	565	Add 2nd 448/515 MVA transformer	7.5
620189 MAPLER1Y 345 657792 MAPLE R3 345 1	420	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	1874.5	10.0%	462	Remedy listed above	
620190 MAPLER2Y 345 657792 MAPLE R3 345 1	420	C5_OTP_Bison-Alex_345 BISON 3 345 - ALEXSS3 345 1 BISON 3 345 - ALEXSS3 345 2	1876.5	10.0%	462	Remedy listed above	
601067 BISON 3 345 657792 MAPLE R3 345 1	792	BISON 4 230 - MAPLE R4 230 1	1966.5	19.0%	854	Remedy listed above	
601006 SPLT RK3 345 605588 SPLTRK1Y 110 10	450	B_XEL_SPLIT_R1B SPLT RK3 345 - SPLTRTB3 345 1 SPLT RK3 345 - SPLTRK2Y 110 11 SPLT RK7 115 - SPLTRK2Y 110 11 SPK13.82 13.8 - SPLTRK2Y 110 11	2133.6	8.5%	463	Add 3rd 448/515 MVA Transformer	7.5
601006 SPLT RK3 345 605588 SPLTRK1Y 110 10	450	C2_XEL_SPLIT_R_5X32 SPLT RK3 345 - SPLTRTB3 345 1 LAWRENC7 115 - SPLT RK7 115 1 SPLT RK3 345 - SPLTRK2Y 110 11 SPLT RK7 115 - SPLTRK2Y 110 11 SPK13.82 13.8 - SPLTRK2Y 110 11 LAWRENC7 115 - LAWRENC8 69.0 1	2235.7	8.5%	455	Remedy listed above	
601012 ROSEAUN2 500 601013 ROSEAUS2 500 1	1732	Base Case	2292.0	13.3%			

Table B-5: Comprehensive Plan Summer Peak Thermal Results - Bison+Brookings County Simultaneous Injection

Monitored Element	Rating	Contingency	FCITC (MW)	Bison DF	Brkng County DF	Required Rating (MVA)	Remedy	Cost (M$)
36310 ELECT; B 345 36362 NELSO; B 345 1	1234	ATC_B2_2221_GD ZION ; R 345 - PLS PR2 345 1 ZION ; 138 - LAKEVIEW 138 1	1379.4	14.3%	14.3%	1507	IL Constraint	
36310 ELECT; B 345 36362 NELSO; B 345 1	1234	WPS-ARP2eA EAU CL 3 345 - ARP 345 345 1 T-CRNRS7 115 - WIEN 115 1 COC 69 69.0 - TIMBERWOLF 69.0 1 MAUSTON 69.0 - HLT 69 69.0 1	1538.1	14.1%	14.1%	1481	IL Constraint	
601043 NLAX 5 161 601044 NLAX 3 345 1	448	NROC 3 345 - BYRON 3 345 1	1688.4	7.2%	7.1%	561	WI Constraint	
601043 NLAX 5 161 601044 NLAX 3 345 1	448	825 C ADAMS 3 345 - GRE-PL VLLY3345 1 ADAMS 3 345 - ADAMS 5 161 1 ADAMS 3 345 - G172_WF3 345 1 HAZLTON3 345 - G172_WF3 345 1	1703.8	7.3%	7.2%	562	WI Constraint	
601006 SPLT RK3 345 605588 SPLTRK1Y 110 10	450	B_XEL_SPLIT_R1B SPLT RK3 345 - SPLTRTB3 345 1 SPLT RK3 345 - SPLTRK2Y 110 11 SPLT RK7 115 - SPLTRK2Y 110 11 SPK13.82 13.8 - SPLTRK2Y 110 11	1812.4	8.5%	12.1%	626	Add 3rd 448/515 MVA Transformer	7.5
601006 SPLT RK3 345 605588 SPLTRK1Y 110 10	450	C2_XEL_SPLIT_R_5X32 SPLT RK3 345 - SPLTRTB3 345 1 LAWRENC7 115 - SPLT RK7 115 1 SPLT RK3 345 - SPLTRK2Y 110 11 SPLT RK7 115 - SPLTRK2Y 110 11 SPK13.82 13.8 - SPLTRK2Y 110 11 LAWRENC7 115 - LAWRENC8 69.0 1	1899.2	8.5%	12.1%	617	Remedy listed above	
36421 ZION ; R 345 698849 PLS PR2 345 1	1069	ATC_B2_2222_GD ZION ; B 345 - ARCADN3 345 1 ZION ; 138 - LAKEVIEW 138 1	2415.2	18.7%	17.8%	1224	WI/IL Constraint	
601002 ADAMS 3 345 631144 G172_WF3 345 1	956	WPS-ARP1eA AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1 T-CRNRS7 115 - WIEN 115 1 COC 69 69.0 - TIMBERWOLF 69.0 1 MAUSTON 69.0 - HLT 69 69.0 1	2430.3	28.1%	26.9%	1186	IA Constraint	
631139 HAZLTON3 345 631144 G172_WF3 345 1	956	WPS-ARP1eA AS KING3 345 - EAU CL 3 345 1 EAU CL 3 345 - ARP 345 345 1 T-CRNRS7 115 - WIEN 115 1 COC 69 69.0 - TIMBERWOLF 69.0 1 MAUSTON 69.0 - HLT 69 69.0 1	2431.0	28.1%	26.9%	1186	IA Constraint	
601002 ADAMS 3 345 631144 G172_WF3 345 1	956	WPS-ARP2eA EAU CL 3 345 - ARP 345 345 1 T-CRNRS7 115 - WIEN 115 1 COC 69 69.0 - TIMBERWOLF 69.0 1 MAUSTON 69.0 - HLT 69 69.0 1	2468.9	28.0%	26.8%	1174	IA Constraint	

Monitored Element	Rating	Contingency	FCITC (MW)	Bison DF	Brkng County DF	Required Rating (MVA)	Remedy	Cost (M$)
631139 HAZLTON3 345 631144 G172_WF3 345 1	956	WPS-ARP2eA EAU CL 3 345 - ARP 345 345 1 T-CRNRS7 115 - WIEN 115 1 COC 69 69.0 - TIMBERWOLF 69.0 1 MAUSTON 69.0 - HLT 69 69.0 1	2469.3	28.0%	26.8%	1174	IA Constraint	
36289 CHERR; R 345 36389 SILVE; R 345 1	1234	Base Case	2572.6	9.3%	9.2%	1300	IL Constraint	
601002 ADAMS 3 345 631046 ADAMS 5 161 1	335	ADAMS 3 345 - GRE-PL VLLY3 345 1	2687.6	11.4%	11.1%	401	IA Constraint	
601040 NROC 5 161 625415 N HILLS 161 1	302	NROC 3 345 - BYRON 3 345 1	2808.4	5.6%	5.3%	326	MN Constraint	
631122 ADAMS_N5 161 681537 ROCHSTR5 161 1	200	BYRON 3 345 - GRE-PL VLLY3 345 1	2819.8	6.8%	6.2%	228	MN Constraint	
601014 AS KING3 345 601028 EAU CL 3 345 1	1195	ARROWHD4 230 - AWHD PST 230 1	2838.8	14.0%	12.8%	1250	WI Constraint	
601014 AS KING3 345 601028 EAU CL 3 345 1	1195	ARROWHD 345 - ST LAKE 345 1	2839.6	14.0%	12.8%	1250	WI Constraint	
698928 WERNER W 345 699785 ROCKY RN 345 1	829	HIWAY 22 345 - GARDR PK 345 1	2856.7	17.2%	16.0%	895	WI Constraint	
681521 SENECA 5 161 681523 GENOA 5 161 1	302	ADAMS 3 345 - G172_WF3 345 1	2858.0	6.0%	5.8%	326	WI Constraint	
681521 SENECA 5 161 681523 GENOA 5 161 1	302	HAZLTON3 345 - G172_WF3 345 1	2859.7	6.0%	5.8%	326	WI Constraint	
601006 SPLT RK3 345 605589 SPLTRK2Y 110 11	450	C2_XEL_SPLIT_R_5X29 SPLT RK3 345 - SPLTRTA3 345 1 SPLT RK7 115 - ANSON 7 115 1 SPLT RK3 345 - SPLTRK1Y 110 10 SPLT RK7 115 - SPLTRK1Y 110 10 SPK13.81 13.8 - SPLTRK1Y 110 10 ANSON 7 115 - ANS TR2Y 90.0 2	2897.9	4.2%	6.2%	486	Remedy listed above	
36421 ZION ; R 345 698849 PLS PR2 345 1	973	Base Case	2902.8	12.7%	12.1%	1018	WI/IL Constraint	
699244 ARP 345 345 699785 ROCKY RN 345 1	883	ST LAKE 345 - GARDR PK 345 1	2920.0	16.1%	15.1%	936	WI Constraint	
699214 EDG 345 345 699396 CEDRSAUK 345 1	653	GRANVL2 345 - SEC 345 1	3007.1	5.6%	5.4%	667	WI Constraint	
36421 ZION ; R 345 698849 PLS PR2 345 1	1069	KENOSH45 138 - LAKEVIEW 138 1	3067.6	13.7%	13.0%	1095	WI/IL Constraint	
601028 EAU CL 3 345 699244 ARP 345 345 1	1165	ST LAKE 345 - GARDR PK 345 1	3166.2	17.0%	15.9%	1180	WI Constraint	
601003 PR ISLD3 345 601039 NROC 3 345 1	1281	NROC 3 345 - HMPT CNR3 345 1	3187.2	22.7%	21.3%	1297	Rebuild 33 mile (est) line with twin 954 ACSS	49.5
693580 CYPRESS 345 699247 ARCADN3 345 1	488	GRANVL2 345 - SEC 345 1	3213.0	7.1%	6.7%	491	WI Constraint	
601012 ROSEAUN2 500 601013 ROSEAUS2 500 1	1732	Base Case	3286.1	13.3%	7.1%			

Table B-6: Cost Assumptions for Facility Upgrades

Facility	Cost
Replace 345 kV Terminal Equipment	$750,000/terminal
Replace 230 kV Terminal Equipment	$600,000/terminal
Replace 115 kV Terminal Equipment	$500,000/terminal
Rebuild 345 kV circuit	$1,500,000/mile
Rebuild 230 kV circuit	$1,000,000/mile
Rebuild 115 kV circuit	$700,000/mile
345/230 kV 336/420 MVA Transformer	$10,000,000 each
345/115 kV 448/515 MVA Transformer	$7,500,000 each

Note: Costs are in year 2018 dollars