APPENDIX P

Minnesota Power

Study Scope

New Tie Line Loop Flow Impact Study

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Purpose

The purpose of this study is to capture the impact of a new 500 kV Manitoba – United States tie line on the North Dakota – Manitoba loop flow phenomenon. Currently, the thermal limit associated with North Dakota – Manitoba loop flow is overload of the Roseau series capacitor banks on the Riel – Forbes 500 kV line. The two new 500 kV tie line configurations considered for this study will be compared based on their effectiveness in relieving this thermal limit and providing the most combined export capability from Manitoba and North Dakota without significantly limiting one or the other.

Configurations

Existing System (XS)

The Existing System configuration does not include a new 500 kV tie line.

Eastern Plan

The Eastern Plan involves development of a new 500 kV tie line from the Winnipeg area to the Iron Range in Northeastern Minnesota. Five Eastern Plan configurations will be considered for this study and are described below.

Eastern Plan (E1)

The basic Eastern Plan consists of the development of a single 500 kV line from the Dorsey Substation to the Iron Range (Blackberry 500 kV) Substation. The line will be 60 percent series compensated with compensation assumed to be located at the midpoint of the ~360 mile line. The Iron Range Substation will interconnect to the existing Blackberry – Forbes and Blackberry – Arrowhead 230 kV lines and is assumed to include a single 800 MVA, 500/230 kV transformer.

Eastern Plan with Bison – Monticello 345 kV Double Circuit (E1b)

In addition to the basic Eastern Plan facilities, the second circuit on the Bison – Alexandria – Quarry – Monticello 345 kV line may also be developed.

Eastern Plan Phase 2 (E2)

In addition to the basic Eastern Plan facilities, a potential second phase of the Eastern Plan consists of the development of a ~60 mile double circuit 345 kV line from the Iron Range Substation to the Arrowhead Substation. To connect to the new 345 kV lines, the Iron Range Substation would be expanded to include two 1200 MVA, 500/345 kV transformers.

Eastern Plan Phase 2 with Blackberry – Arrowhead 345 kV Single Circuit Only (E2s)

In addition to the basic Eastern Plan facilities, a potential alternative second phase of the Eastern Plan consists of the development of a ~60 mile single circuit 345 kV line from the Iron Range Substation to the Arrowhead Substation. To connect to the new 345 kV line, the Iron Range Substation would be expanded to include a single 1200 MVA, 500/345 kV transformer.

Eastern Plan Phase 2 with Bison – Monticello 345 kV Double Circuit (E2b)

In addition to the Eastern Plan Phase 2 facilities, the second circuit on the Bison – Alexandria – Quarry – Monticello 345 kV line may also be developed.

Western Plan

The Western Plan involves development of a new 500 kV tie line from the Winnipeg area to the Fargo-Moorhead area in Western Minnesota. Two Western Plan configurations will be considered for this study and are described below. The automation file used to implement the Western Plan [*XEL-4261Dorsey-BARNSVLE_NAS_Synergy_500kVOption.idv*] was obtained from model-on-demand ("MOD"). Since the file obtained from MOD appeared to install only 55 percent series compensation on the new 500 kV line, the branch impedance between bus 601061 (DBCOMPN) and bus 601062 (DBCOMPS) was modified to achieve 60 percent series compensation on the Dorsey – Barnesville 500 kV line.

Western Plan (W2)

The basic Western Plan consists of the development of a single 500 kV line from the Dorsey Substation to the Barnesville Substation. The line will be 60 percent series compensated with compensation assumed to be located at the midpoint of the ~312 mile line. The Barnesville Substation will interconnect to the existing Bison – Alexandria 345 kV line and is assumed to include a single 1200 MVA, 500/345 kV transformer.

Western Plan with Bison – Monticello 345 kV Double Circuit (W2b)

In addition to the basic Western Plan facilities, a second phase of the Western Plan consists of the development of a second circuit on the Barnesville – Alexandria – Quarry – Monticello 345 kV line. The Barnesville Substation would also be expanded to include a second 1200 MVA, 500/345 kV transformer.

Scenarios

Benchmark Cases

February 2013 DPP Study – 2022 Shoulder Peak *(BaseCase-DPP-Feb13_2023SH_062613_v32.sav)*

MTEP13 – 2023 Shoulder Peak *(MTEP13-2023SShoulder-SCED_FINAL_Rev1.sav)*

MANTEX – 2021 Shoulder Peak

(15-B_2021_SH_120117_1100MWTransfer_M602FSERCOMPin_DB60Comp_R.sav)

Northern Area Study – 2022 Shoulder Peak *(NAS_MTEP12_2022SH_Import+Load_v32.sav)*

Modifications

Besides the addition of the above-mentioned facilities for each Configuration, the following modifications were made to the base DPP model:

1. Updated Bison – Alexandria – Quarry – Monticello 345 kV Line impedance based on values in Western Plan automation file obtained from MOD (for consistency)
2. Removed Dorsey – Riel 500 kV Ckt 2

Besides the addition of the above-mentioned facilities for each Configuration, the following modifications were made to the base MTEP13 model:

1. Updated Bison – Alexandria – Quarry – Monticello 345 kV Line impedance based on values in Western Plan automation file obtained from MOD (for consistency)

Besides the addition of the above-mentioned facilities for each Configuration, the following modifications were made to the base MANTEX model:

1. Updated Bison – Alexandria – Quarry – Monticello 345 kV Line impedance based on values in Western Plan automation file obtained from MOD (for consistency)

2. Removed Dorsey – Riel 500 kV Ckt 2
3. Removed Dorsey – Bison 500 kV line & 500/345 kV transformer
4. Removed Excelsior "Mesaba" generator & associated Boswell – Riverton 230 kV Line

Besides the addition of the above-mentioned facilities for each Configuration, the following modifications were made to the base Northern Area Study model:

1. Updated Bison – Alexandria – Quarry – Monticello 345 kV Line impedance based on values in Western Plan automation file obtained from MOD (for consistency)
2. Removed Dorsey – Riel 500 kV Ckt 2
3. Disconnect conceptual P2 load at Forbes 230 kV (608624)
4. Disconnect conceptual P2 load at Minntac 230 kV (608623)

Sensitivities (General)

The following sensitivity will be applied to all model series and all configurations:

Roseau Series Capacitor Upgrade *(SCupgrade)*

Increase the thermal limit of the Riel – Forbes 500 kV line from 1732 MVA to 2165 MVA, to simulate an upgrade of the Roseau Series Capacitors from 2000 A to 2500 A

Sensitivities (Model-Specific)

The following sensitivities will be applied to the base case DPP model only, to all configurations except E1b, E2s, and E2b, in the order below:

Western (North & South Dakota) MVP lines *(MVP_W)*

Disconnect North and South Dakota 345 kV MVP lines (listed below with bus numbers)

1. Ellendale – Big Stone South 345 kV (661097-620417)
2. Big Stone South – Brookings County 345 kV (620417-601031)

Southern (Iowa/Wisconsin) MVP lines *(MVP_S)*

In addition to the changes made in the MVP_W sensitivity, disconnect Wisconsin and Iowa 345 kV MVP lines (listed below with bus numbers)

1. Briggs Road – North Madison – Cardinal 345 kV (601044-699818-699829)
2. Dubuque – Spring Green – Cardinal 345 kV (631191-693863-699829)
3. Lakefield – Winnebago – Winnco – Burt 345 kV (631138-631193-631197-635369)
4. Sheldon –Burt – Webster 345 kV (635368-635369-636000)
5. Winnco – Hazelton 345 kV (631197-631198-631199-636199-631139)

Selected CapX2020 Group 1 Lines *(CapX)*

In addition to the changes made in the MVP_W and MVP_S sensitivities, disconnect selected CapX2020 Group 1 lines (listed below with bus numbers)

1. Brookings County – Lyon County 345 kV (601031-[10215]-601048)
2. Lyon County – Hazel Creek 345 kV (601048-601054)
3. Lyon County – Cedar Mountain – Helena 345 kV double ckt (601048-615643-601050)
4. Helena – Lake Marion – Hampton Corner 345 kV (601050-601052-601051)
5. Hampton Corner – North Rochester – Briggs Road 345 kV (601051-601039-601044)

The following additional sensitivities will be applied to the Base Case DPP model only, to all configurations except E1b, E2s, and E2b:

G82R Phase Shifter Set at 0 degrees *(G82Rpst-0deg)*
Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Automation file provided by MH. Set phase shifter to maintain 0 degrees phase shift.

G82R Phase Shifter Set at 0 MW *(G82Rpst-0mw)*
Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Automation file provided by MH. Set phase shifter to maintain 0 MW power flow on G82R.

G82R Phase Shifter Set at 80 degrees *(G82Rpst-80deg)*
Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Automation file provided by MH. Set phase shifter to maintain +80 degrees phase shift (maximum south flow).

G82R Phase Shifter Set at 250 Import *(G82Rpst-250i)*
Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Automation file provided by MH. Set phase shifter to maintain 250 MW north flow on G82R.

The following sensitivities will be applied to the Base Case MTEP13 model, configuration W2b only:

Western Plan Alexandria Endpoint *(W2alx)*
Move 500 kV endpoint to Alexandria 345 kV Substation:

- Dorsey – Alexandria 500 kV line ~392 Miles (60% series compensated)
- Two 500/345 kV transformers (1200 MVA) at Alexandria
- Alexandria – Quarry – Monticello double circuit 345 kV

Western Plan Quarry Endpoint *(W2qry)*
Move 500 kV endpoint to Quarry 345 kV Substation:

- Dorsey – Quarry 500 kV line ~457 Miles (60% series compensated)
- Two 500/345 kV transformers (1200 MVA) at Quarry
- Quarry – Monticello double circuit 345 kV

Western Plan Monticello Endpoint *(W2mnt)*
Move 500 kV endpoint to Monticello 345 kV Substation:

- Dorsey – Monticello 500 kV line ~487 Miles (60% series compensated)
- Two 500/345 kV transformers (1200 MVA) at Monticello

Western Plan Bison Endpoint *(W2bis)*
Move 500 kV endpoint to Bison 345 kV Substation (based on MTEP Project #3398):

- Dorsey – Bison 500 kV line ~245 Miles (60% series compensated)
- Two 500/345 kV transformers (1200 MVA) at Bison
- Bison – Alexandria – Quarry – Monticello double circuit 345 kV

Western Plan Helena Endpoint *(W2hln)*
Add Bison – Helena 500 kV line instead of Bison – Alexandria – Quarry – Monticello double circuit 345 kV line (based on MTEP Project #3398 & Option 1 Facility Study):

- Dorsey – Bison 500 kV line ~245 miles (60% series compensated)

- Bison – Helena 500 kV line ~313 Miles (60% series compensated)
- One 500/345 kV transformer (1200 MVA) at Bison
- Two 500/345 kV transformers (1200 MVA) at Helena

Western Plan Brookings Endpoint *(W2brk)*

Add Bison – Brookings 500 kV line in addition to Bison – Alexandria – Quarry – Monticello double circuit 345 kV line (based on MTEP Project #3398):

- Dorsey – Bison 500 kV line ~245 miles (60% series compensated)
- Two 500/345 kV transformers (1200 MVA) at Bison
- Bison – Alexandria – Quarry – Monticello double circuit 345 kV
- Bison – Brookings 500 kV line ~205 Miles (60% series compensated)
- One 500/345 kV transformer (1200 MVA) at Brookings

The following sensitivity will be applied to the Base Case MANTEX model only, to all configurations except E1b, E2s, and E2b:

Excelsior Online *(Excelsior)*

Do not remove the Excelsior "Mesaba" generation facility or the associated Boswell – Riverton 230 kV line from the original MANTEX model:

1. Excelsior scheduled at 556.8 MW in the base case (buses 608619-608620-608621-608622)
2. Boswell – Riverton 230 kV line in service (608626-608612)

The following sensitivities will be applied to the Base Case Northern Area Study model only, to all configurations except E1b, E2s, and E2b:

Minnesota Power Load Pocket *(MPLoad)*

Do not remove conceptual northern Minnesota load pocket from the original Northern Area Study model:

- Reconnect 225 MW load ("P2") at Forbes 230 kV (608624)
- Reconnect 225 MW load ("P2") at Minntac 230 kV (608623)

Essar Phase 2 Delayed *(Essar)*

Simulate delay or removal of Essar Phase 2, a large taconite project near Blackberry:

- Scale total Essar load to 120 MW, 0.98 power factor (bus numbers 608628 & 608629)
- Disconnect Blackberry – McCarthy Lake 230 kV Line (608625-608628)

Study Methodology

Distribution Factor Analysis

PSSE will be used to perform distribution factor (DF) analysis on each of the configurations described above for an incremental 100 MW injection at various locations in Manitoba, North Dakota, Minnesota, and Iowa. The buses to be used for these locations are shown in the table below:

Bus Name	Bus #	Voltage	Area
667500	DORSEY 2	500 kV	667-MH
601067	BISON 3	345 kV	600-XEL
661097	ELLENDLMVP3	345 kV	661-MDU
601048	LYON CO 3	345 kV	600-XEL
631198	LIMECREEK3	345 kV	627-ALTW
657756	SQBUTTE4	230 kV	620-OTP
620379	RUGBY 4	230 kV	620-OTP

The 100 MW injection will be modeled as a 100 MW negative load. The following steps will be taken to obtain a distribution factor for each injection point:

1. The *PSSE* DC Contingency Checking (DCCC) function will be used to obtain the real power flow on each monitored element prior to the 100 MW injection *(Pre Injection Flow)*
2. The 100 MW negative load *(Total Injection)* will be added to the model and the model solved
3. The *PSSE* DC Contingency Checking (DCCC) function will be used to obtain the real power flow on each monitored element after the 100 MW injection *(Post Injection Flow)*
4. Distribution factors will be calculated for each of the monitored elements according to the formula below:

$$Distribution\ Factor\ (\%) = \frac{(Post\ Injection\ Flow) - (Pre\ Injection\ Flow)}{(Total\ Injection)}$$

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Nomogram Development

Once distribution factors (DF's) have been obtained for each of the injection locations, the following steps will be taken to obtain a nomogram illustrating the relationship between incremental North Dakota generation additions and incremental Manitoba generation additions:

1. Calculate composite North Dakota DF (DF_{ND}) for each monitored element from the average DF of the four North Dakota injection locations (Bison, Ellendale, Square Butte, and Rugby)
2. Using DF_{ND} for the Riel – Forbes 500 kV line, increment North Dakota injection in 100 MW steps until the thermal limit on Riel – Forbes is exceeded
3. Using DF_{ND} for NDEX and MHEX (interfaces defined as described in the monitored elements below) calculate equivalent NDEX and MHEX at the level of incremental North Dakota injection when the Riel – Forbes thermal limit is exceeded ($NDEX_{ND}$, $MHEX_{ND}$)
4. Repeat Steps 1-3 using a Manitoba DF equal to the DF of the Dorsey injection (DF_{MH}) and incrementing Manitoba injection until the Riel – Forbes thermal limit is exceeded to obtain corresponding NDEX and MHEX levels ($NDEX_{MH}$, $MHEX_{MH}$)
5. Develop a formula ($y = mx + b$) for the line that connects ($NDEX_{ND}$, $MHEX_{ND}$) and ($NDEX_{MH}$, $MHEX_{MH}$) using the formulas and definitions below:

$$\Delta NDEX = NDEX_{ND} - NDEX_{MH}$$

$$\Delta MHEX = MHEX_{ND} - MHEX_{MH}$$

$$m\ (slope) = \frac{\Delta NDEX}{\Delta MHEX}$$

$$b\ (y\ intercept) = NDEX_{MH} - m * MHEX_{MH}$$

6. Using the equation below, calculate the level of NDEX that can be achieved prior to overloading the Riel – Forbes 500 kV line for MHEX ranging from 0 to 5000 MW:

$$(NDEX) = m * (MHEX) + b$$

7. Results will be plotted in the form of a nomogram with NDEX on the vertical axis and MHEX on the horizontal axis to allow for quick comparison of the various cases and scenarios under study

Monitored Elements

In addition to the individual branches that make up the MHEX and MWEX interfaces defined below, the power flow on each of the following branches will be monitored:

Frm Bus #	From Bus Name	To Bus #	To Bus Name	Voltage	Ckt	Owner
608910	IRONRNG3	699449	ARROWHD	345 kV	1	608-MP 691-ATC
608910	IRONRNG3	699449	ARROWHD	345 kV	2	608-MP 691-ATC
601067	BISON 3	601081	BARNESVILLE3	345 kV	1	CapX2020
601081	BARNESVILLE3	658047	ALEX SS 3	345 kV	1	CapX2020
601081	BARNESVILLE3	658047	ALEX SS 3	345 kV	2	CapX2020
601001	FORBES 2	601017	CHIS-N 2	500 kV	1	600-XEL 615-GRE 608-MP
601039	NROC 3	601044	BRIGGS RD 3	345 kV	1	600-XEL

The total MHEX will be calculated as the sum of the power flows on the branches below. The measurement location is indicated by an asterisk (*). As indicated below, the corresponding new 500 kV tie line will be included in the MHEX calculation for the Eastern Plan and the Western Plan cases.

Frm Bus #	From Bus Name	To Bus #	To Bus Name	Voltage	Ckt	Owner
667501	RIEL 2*	601012	ROSEAUN2	500 kV	1	667-MH 600-XEL
667046	RICHER 4*	602013	ROSEAU 4	230 kV	1	667-MH 600-XEL
667048	LETELER4*	657752	DRAYTON4	230 kV	1	667-MH 657-MPC
667052	GLENBOR4*	620379	RUGBY 4	230 kV	1	667-MH 620-OTP
667500	DORSEY 2*	601061	MIDCOMPN	500 kV	1	667-MH 608-MP
667500	DORSEY 2*	601061	DBCOMPN	500 kV	1	unknown

The total MWEX will be calculated as the sum of the power flows on the branches below. The measurement location is indicated by an asterisk (*). Note that the MWEX boundary was moved from the Arrowhead Phase Shifting Transformer to the Arrowhead – Stone Lake 345 kV line due to the addition of the Blackberry – Arrowhead 345 kV line(s) in some cases.

Frm Bus #	From Bus Name	To Bus #	To Bus Name	Voltage	Ckt	Owner
699449	ARROWHD*	699450	ST LAKE	345 kV	1	691-ATC
601014	AS KING3*	601028	EAU CL 3	345 kV	1	600-XEL

The total NDEX will be calculated as the sum of the power flows on the branches below. The measurement location is indicated by an asterisk (*). Where applicable, the three additional lines at the bottom of the list may be included in the NDEX calculation.

Frm Bus #	From Bus Name	To Bus #	To Bus Name	Voltage	Ckt	Owner
659105	LELANDO3*	652506	FTTHOMP3	345 kV	1	659-BEPC
659105	LELANDO3*	659160	GROTON 3	345 kV	1	659-BEPC
659101	ANTELOP3*	659120	BRDLAND3	345 kV	1	659-BEPC
658047	ALEX SS 3*	601047	QUARRY 3	345 kV	1	CapX2020
620447	CASS LK4*	608611	DEER RV4	230 kV	1	CapX2020
652521	SULLYBT4*	652519	OAHE 4	230 kV	1	652-WAPA
652470	BISON 4*	652497	MAURINE4	230 kV	1	652-WAPA
620314	BIGSTON4*	652503	BLAIR 4	230 kV	1	620-OTP 660-NWPS
652554	MORRIS 4*	652550	GRANITF4	230 kV	1	652-WAPA
615300	GRE-INMAN*	615566	GRE-WINGRIV4	230 kV	1	615-GRE
620336	AUDUBON4*	615341	GRE-HUBBARD4	230 kV	1	620-OTP 600-XEL 608-MP
657752	DRAYTON4*	667048	LETELER4	230 kV	1	667-MH 657-MPC
620379	RUGBY 4*	667052	GLENBOR4	230 kV	1	667-MH 620-OTP
661027	ELLENDL7*	660000	ABDNJCT7	115 kV	1	660-NWPS
652432	EDGELEY7*	652534	ORDWAY7	115 kV	1	652-WAPA
652438	FORMAN 7*	652522	SUMMIT-7	115 kV	1	652-WAPA
620211	CANBY 7*	652551	GRANITF7	115 kV	1	620-OTP
620222	ALEXAND7*	619112	GRE-HUDSON7	115 kV	1	620-OTP 600-XEL
657716	LAPORTE7*	608638	AKELEY7	115 kV	1	608-MP 657-MPC
616005	GRE-KERKHO 7*	616004	GRE-KERKHOT7	115 kV	1	615-GRE
615365	GRE-BENSON7*	603185	FIBROMN7	115 kV	1	615-GRE
615366	GRE-BENSON7*	615365	GRE-BENSON8	115/69 kV	1	615-GRE
601080	BARNESVILLE2*	601062	DBCOMPS	500 kV	1	unknown
658047	ALEX SS 3*	601047	QUARRY 3	345 kV	2	CapX2020
620417	BSSOUTH3*	601031	BRKNGCO3	345 kV	1	CapX2020