Minnesota Power

New Tie Line Loop Flow Impact

Study Report

Christian Winter and Andy Kienitz

August 28, 2014

Table of Contents

Report Structure

This study report is broken down into the following sections:

- **Study Summary** – overview of the background and results of the study, including a short Executive Summary describing broad conclusions from the study
- **Section 1: Background** – overview of relevant background information pertaining to the study
- **Section 2: Model Development** – overview of power flow model development for the study
- **Section 3: Sensitivities** – overview of the sensitivities considered as part of the study
- **Section 4: Study Methodology** – methodology & assumptions behind the study
- **Section 5: Study Results** – discussion of the results of the main part of the study
- **Section 6: Sensitivity Results** – discussion of the results from study sensitivities
- **Section 7: Conclusions** – discussion of the conclusions from the study
- **Appendices** – additional relevant information

Study Summary

Executive Summary

The results of the New Tie Line Loop Flow Impact Study support the assertion that a new 500 kV tie line from the Winnipeg area to northeastern Minnesota (Eastern Plan), such as Minnesota Power's proposed Great Northern Transmission Line, has a more favorable overall impact on North Dakota – Manitoba loop flow than a new 500 kV tie line from Winnipeg to the Barnesville area in western Minnesota (Western Plan). While it can be demonstrated that a Western Plan could provide additional outlet capability from Manitoba Hydro, this additional outlet capability would come at the expense of placing considerable limitations on North Dakota outlet capability due to the impact of the Western Plan on North Dakota – Manitoba loop flow. In contrast, the Eastern Plan provides the desired additional outlet capability from Manitoba Hydro without inherently limiting potential transmission outlet capability for current and future North Dakota generation resources due to North Dakota – Manitoba loop flow. Therefore, the results of the New Tie Line Loop Flow Impact study indicate that the Eastern Plan is the superior long-term plan for developing a new 500 kV tie line between Manitoba and the United States.

Background

Purpose

The purpose of the New Tie Line Loop Flow Impact Study is to capture and compare the impact of a new 500 kV Manitoba – United States tie line on the North Dakota – Manitoba loop flow phenomenon. Regional power system analysis has consistently shown that there is an existing North Dakota – Manitoba loop flow phenomenon where, due to the electrical configuration of the regional transmission system and the laws of physics, generation being exported out of North Dakota will flow through Manitoba on its way to load centers in Minnesota and Wisconsin. If simultaneous export levels from North Dakota and Manitoba are of a sufficient level, the combined impact of the desired Manitoba Hydro exports and incidental North Dakota – Manitoba loop flow can potentially lead to congestion on a common path, the Riel – Forbes 500 kV Line.

Transmission Configurations

A second 500 kV Manitoba – United States tie line has recently been proposed as the preferred solution for facilitating at least 750 MW of additional transfer capability from Manitoba Hydro to utilities in the United States. Depending on the electrical configuration of this new tie line, it may either mitigate or exasperate the unwanted effects of North Dakota – Manitoba loop flow. Three general transmission configurations were studied in the Loop Flow Impact Study: a benchmark ("Existing System") configuration with no new 500 kV tie line between Manitoba and the United States, an Eastern Plan configuration with a new 500 kV tie line to the Grand Rapids area in northeastern Minnesota, and a Western Plan configuration with a new 500 kV tie line to the Fargo/Moorhead area in western Minnesota. Additional Eastern and Western plan configurations include up to two additional 345 kV transmission projects, the first between Fargo, ND, and Monticello, MN, and the second between Grand Rapids, MN, and Duluth, MN. The various transmission configurations shown in the plots and figures below are abbreviated as follows:

- **XS:** Existing System
- **E1:** Eastern Plan
- **W2:** Western Plan
- **E1b:** E1 + second circuit on existing Fargo – Monticello 345 kV line
- **E2:** E1 + double circuit Grand Rapids – Duluth 345 kV line
- **E2s:** E1 + single circuit Grand Rapids – Duluth 345 kV line
- **E2b:** E2 + second circuit on existing Fargo – Monticello 345 kV line
- **W2b:** W2 + second circuit on existing Fargo – Monticello 345 kV line

Model Development & Study Methodology

Analysis was performed using four existing models which were developed and thoroughly reviewed for four very different regional studies. Models were selected from the February 2013 MISO Definitive Planning Phase (DPP) generator interconnection study, the MISO Midwest Transmission Expansion Planning (MTEP) 2013 reliability analysis performed for NERC TPL Standard compliance, the Manitoba Transmission Expansion (MANTEX) ad hoc study group, and the MISO Northern Area Study (NAS). The main methodology used for the Loop Flow Impact Study involves the calculation of distribution factors describing the percentage of the total output of conceptual new generators in Manitoba and North Dakota that will flow on each of the existing and new Manitoba – United States tie lines. An average North Dakota generation distribution factor was calculated for each tie line based on the distribution factors for individual injection points (proxy new generators) at several locations in North Dakota, which are shown in Figure 1 below.

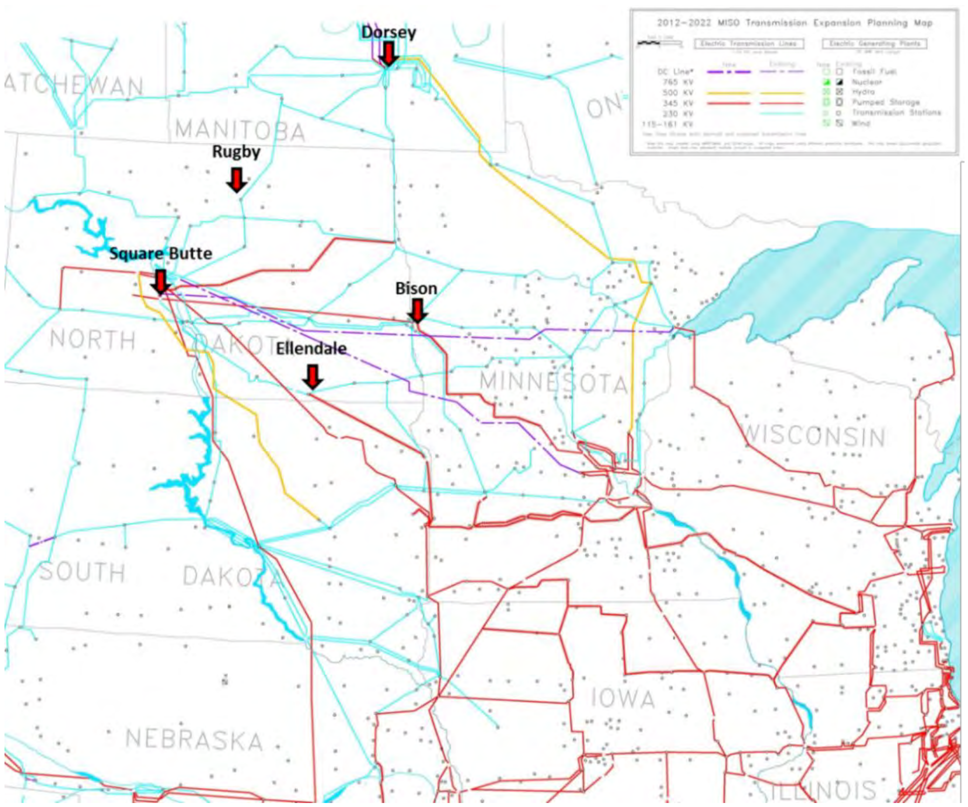


Figure 1: Transmission Map of Injection Points for Distribution Factor Analysis

Based on the results of Distribution Factor Analysis, the anticipated simultaneous North Dakota and Manitoba outlet capability based on the Riel – Forbes 500 kV Line thermal limit was determined using the nomogram calculation methodology described in Appendix B: Description of Study Methodology. The nomogram calculation methodology produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading the Riel – Forbes 500 kV Line. In some cases other constraints besides the Riel – Forbes 500 kV Line may exist that would limit simultaneous North Dakota and Manitoba outlet capability to something less than what is anticipated by the nomogram. Determination of other constraints on simultaneous outlet capability besides the Riel – Forbes 500 kV Line is outside the scope of this study.

Three general metrics were used to evaluate the relative impact of each transmission configuration on North Dakota – Manitoba loop flow:

1. The total North Dakota – Manitoba loop flow associated with the configuration, measured by calculating the sum of the North Dakota generation distribution factors on all North Dakota – Manitoba tie lines
2. The impact of North Dakota – Manitoba loop flow on the Riel – Forbes 500 kV Line, measured by calculating the North Dakota generation distribution factor on the Riel – Forbes 500 kV line
3. The level of North Dakota outlet capability that can be achieved at the expected level of Manitoba export before the Riel – Forbes 500 kV Line is overloaded, determined from the nomogram calculations described above

Results

Comparison of Benchmark Case Results

The distribution factor results from the four different benchmark cases were first compared to illustrate the defining factors behind North Dakota – Manitoba loop flow. An example of the distribution factor comparison results for a 100 MW injection at the Bison 345 kV bus is shown in Figure 2 below for the Existing System. In spite of considerable differences in the initial conditions modeled in the four different benchmark cases, the distribution factor results are remarkably similar. This illustrates the fact that North Dakota – Manitoba loop flow is fundamentally a result of the system topology that facilitates the unwanted flow of North Dakota generation through Manitoba at higher levels of North Dakota generation export. Even if interface flows, load levels, and generation dispatch are such that only very low levels of North Dakota – Manitoba loop flow are observed, the same potential for loop flow at higher North Dakota export levels will exist as long as the system topology remains unchanged.

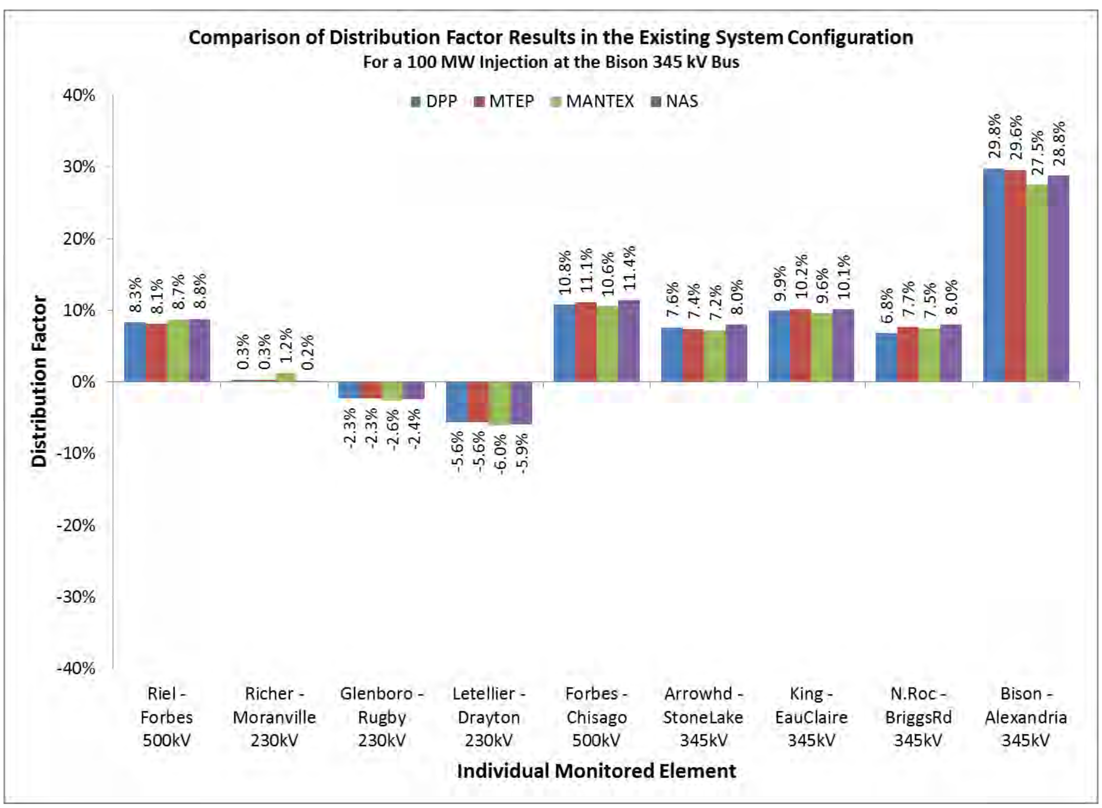


Figure 2: Comparison of Distribution Factor Results for the Bison Injection

Total Loop Flow Impact

The total North Dakota – Manitoba loop flow associated with each transmission configuration can be measured by calculating the sum of the average North Dakota generation distribution factors on all Manitoba – North Dakota tie lines present in the transmission configuration. Manitoba – North Dakota tie lines include the Glenboro – Rugby 230 kV Line (G82R), the Letellier – Drayton 230 kV Line (L20D), and the Dorsey – Barnesville 500 kV Line, if present. The total North Dakota – Manitoba loop flow associated with the various transmission configurations being studied is compared to the Existing System in Figure 3 below, from the MTEP case.

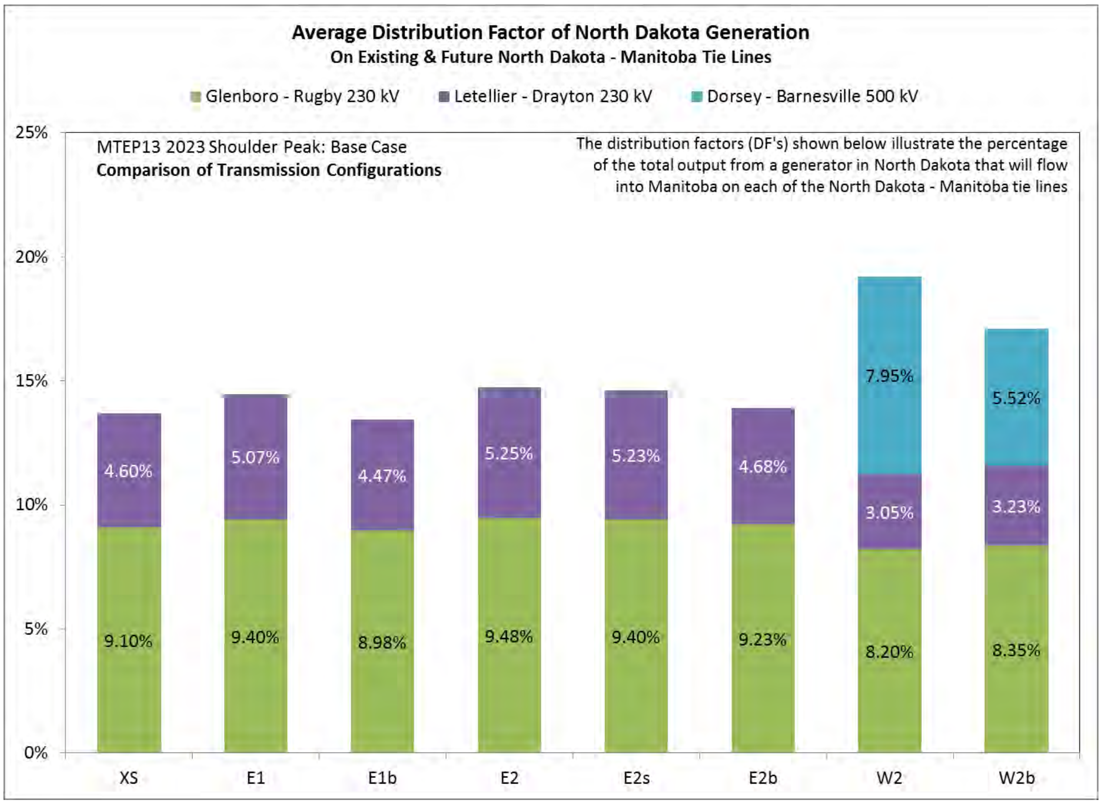


Figure 3: Comparison of Total Loop Flow Impact

In general, the Eastern Plan and associated transmission configurations cause a slight increase in the total North Dakota – Manitoba loop flow. This is due to the addition of the Dorsey – Iron Range 500 kV Line, which lowers the overall impedance of the loop flow “exit path” from Manitoba into Minnesota. The increase in total North Dakota – Manitoba loop flow is limited, however, by the higher impedance of the loop flow “entry path” from North Dakota into Manitoba on the two 230 kV tie lines. The Western Plan and associated transmission configurations cause a more significant increase in the total North Dakota – Manitoba loop flow than the Eastern Plan. This is due to the fact that the Western Plan’s Dorsey – Barnesville 500 kV Line actually lowers the overall impedance of the North Dakota – Manitoba loop flow “entry path,” connecting the North Dakota transmission system (and the generation that is interconnected to it) more tightly to the Manitoba transmission system. Comparing the Eastern Plan and the Western Plan, it is evident that the Eastern Plan has a more favorable overall impact on total North Dakota – Manitoba loop flow than the Western Plan because it does not provide an additional path for

North Dakota generation to flow into Manitoba[1]. Therefore, in a consideration of the total loop flow impact, the Eastern Plan is to be preferred over the Western Plan.

Riel – Forbes 500 kV Line Impact

The impact of North Dakota – Manitoba loop flow on the Riel – Forbes 500 kV Line can be determined simply by comparing the average North Dakota generation distribution factor on the Riel – Forbes 500 kV Line (M602F) obtained for each of the transmission configurations. The impact of North Dakota – Manitoba loop flow on the Manitoba – Minnesota tie lines associated with the various transmission configurations being studied is compared to the Existing System in Figure 4 below, from the MTEP case.

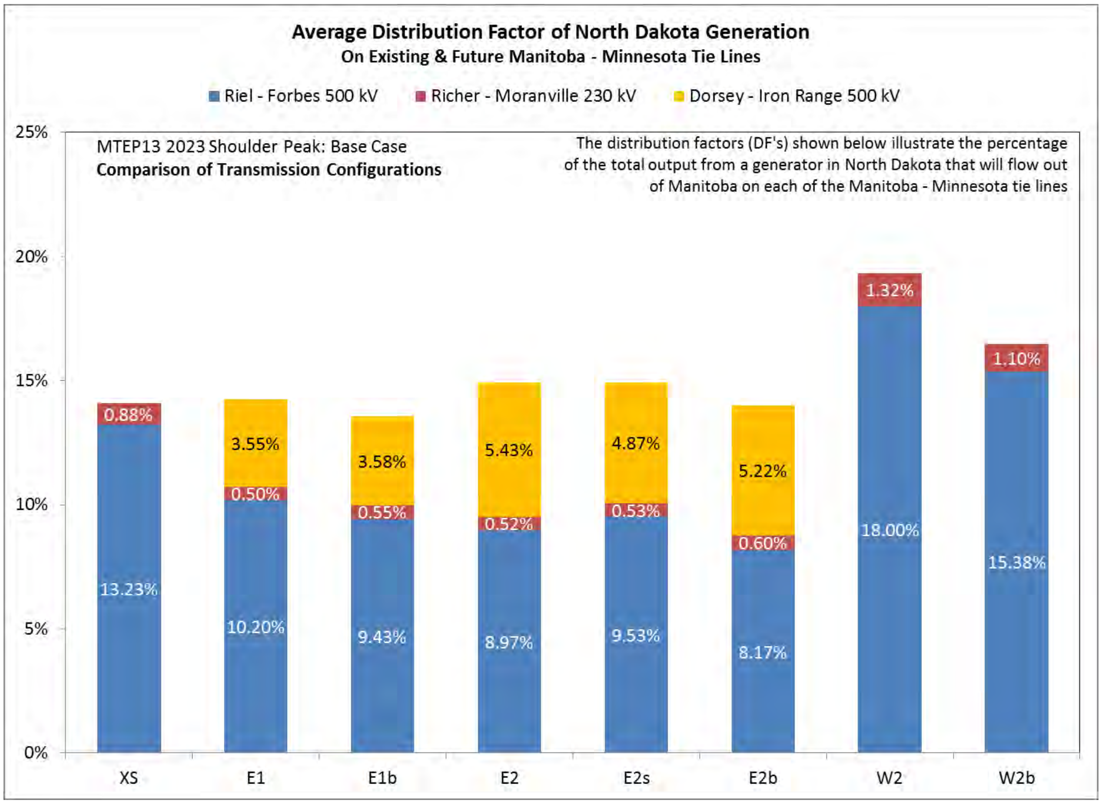


Figure 4: Comparison of Riel - Forbes 500 kV Line Impact

The Eastern Plan and the associated transmission configurations notably reduce the impact of North Dakota – Manitoba loop flow on the Manitoba – Minnesota tie lines, and particularly M602F. The Western Plan and associated transmission configurations have the opposite impact on the amount of North Dakota – Manitoba loop flow present on M602F. Comparing the Eastern Plan and the Western Plan, it is evident that the Eastern Plan improves the performance of the Riel – Forbes 500 kV Line (M602F) because the Eastern Plan Dorsey – Iron Range 500 kV Line actually carries some of the North Dakota – Manitoba loop flow that would normally flow on M602F and R50M, reducing the overall impact of North Dakota – Manitoba loop flow on M602F. In contrast, the Western Plan actually causes more North Dakota – Manitoba loop flow on M602F, arguably degrading the performance of the line. This is because the Western Plan Dorsey – Barnesville 500 kV Line actually increases the total amount of North Dakota – Manitoba loop flow by providing an additional loop flow “entry path” (as discussed in the previous section) without providing an additional transmission line “exit path” adjacent to the

[1] The conceptual impact of the electrical configuration of the two plans on total North Dakota – Manitoba loop flow is discussed in further detail in Appendix L: Conceptual Loop Flow Impact of the Western Plan

existing Manitoba – Minnesota tie lines[2]. The consequence is that nearly all of the resulting additional North Dakota – Manitoba loop flow associated with the Western Plan must flow on M602F. The end result of the Western Plan, therefore, is a significant increase in the impact of North Dakota – Manitoba loop flow on M602F. Therefore, in a consideration of the impact of North Dakota – Manitoba loop flow on the Riel – Forbes 500 kV Line, the Eastern Plan is to be preferred over the Western Plan.

Simultaneous North Dakota & Manitoba Outlet Capability

The level of North Dakota outlet capability that can be achieved at the expected level of Manitoba export before overloading the Roseau series capacitors on the Riel – Forbes 500 kV Line ("simultaneous North Dakota and Manitoba outlet capability") is a practical application of the metrics described in the previous two sections. This is because the simultaneous North Dakota and Manitoba outlet capability is a direct result of the total North Dakota – Manitoba loop flow and the specific impact of loop flow on the loading of the Riel – Forbes 500 kV Line. Using this metric provides a good indication of the relative impact of the various transmission configurations being studied on regional generation outlet capability and overall system efficiency. Two main observations, which provide useful insight into the general loop flow impact of the Eastern Plan and the Western Plan, arose from the results of the study:

1. Both the Eastern and Western plans provide increased simultaneous North Dakota and Manitoba outlet capability compared to the Existing System
2. The Eastern Plan configurations generally provide more potential simultaneous North Dakota and Manitoba outlet capability than the Western Plan configurations

Both the Eastern Plan and the Western Plan provide increased simultaneous North Dakota and Manitoba outlet capability compared to the Existing System. With the Eastern Plan, North Dakota outlet capability and Manitoba outlet capability are increased proportionally compared to the Existing System. Therefore, it can be said that the Eastern Plan provides increased Manitoba to United States transfer capability without inherently limiting potential outlet capability from North Dakota relative to the Existing System. With the Western Plan, North Dakota outlet capability and Manitoba outlet capability increase disproportionately due to the loop flow impact of the Western Plan. As a result, the greater the desired incremental Manitoba outlet capability is, the more limited the associated North Dakota outlet capability becomes due to overloads on the Riel – Forbes 500 kV Line. Therefore, it can be said that the Western Plan also provides increased Manitoba to United States transfer capability, but it does so while inherently limiting the potential simultaneous outlet capability from North Dakota.

The Eastern Plan configurations generally provide more potential simultaneous North Dakota and Manitoba outlet capability than the Western Plan configurations. The capability of the Eastern Plan (configuration E1) and the Western Plan (configuration W2) to facilitate the near-term need for 750 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is compared in Figure 5 below.

Configuration E1 is capable of facilitating at least 2200 MW of North Dakota outlet capability (today's level[3]) simultaneously with 2925 MW of Manitoba Hydro export without overloading M602F. In contrast, configuration W2 would limit North Dakota outlet capability to no more than 1112 MW simultaneously with 2925 MW of Manitoba Hydro export. Comparing the potential simultaneous North Dakota and Manitoba outlet capability afforded by the two transmission configurations at the 750 MW incremental Manitoba to United States transfer level, it is obvious that the Eastern Plan provides

[2] The conceptual impact of the electrical configuration of the two plans on total North Dakota – Manitoba loop flow is discussed in further detail in Appendix L: Conceptual Loop Flow Impact of the Western Plan
[3] Current North Dakota outlet capability was assumed to be 2200 MW based on the NDEX stability limit identified in "Impact of CapX Facilities on North Dakota Export for the Year 2016 Report"

significant additional simultaneous outlet capability compared to the Western Plan. While the Eastern Plan would at least maintain (and possibly increase) simultaneous transfer capability out of North Dakota after adding an incremental 750 MW of Manitoba to United States transfers, the Western Plan would actually put considerable limitations on North Dakota outlet capability because of the impact of North Dakota – Manitoba loop flow in overloading the Riel – Forbes 500 kV Line. Therefore, in a consideration of simultaneous North Dakota and Manitoba outlet capability at the 750 MW incremental Manitoba to United States transfer level, the Eastern Plan is to be preferred over the Western Plan.

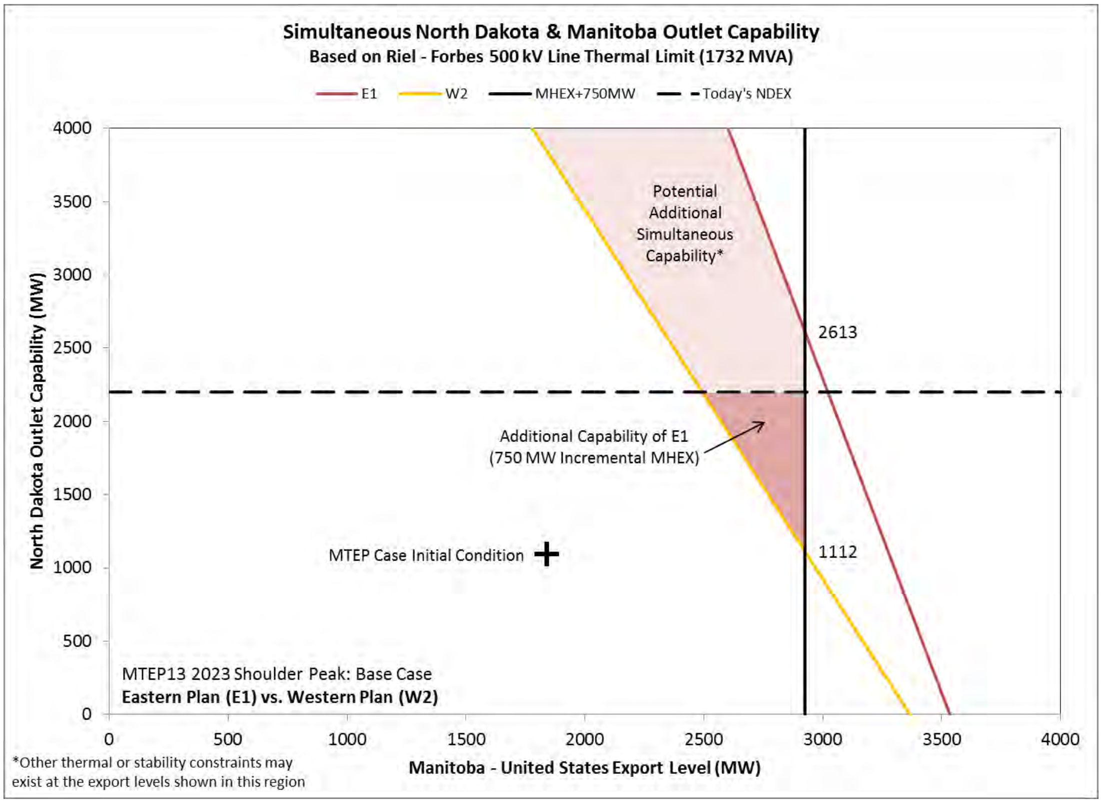


Figure 5: Simultaneous North Dakota & Manitoba Outlet Capability – E1 vs. W2

Sensitivities

Several sensitivities were applied to the various benchmark models used for the Loop Flow Impact Study. These sensitivities are meant to capture the impact that various conceptual or planned changes to the transmission system in the upper Midwest have on the results of the Loop Flow Impact Study for the transmission configurations being studied.

The Roseau Series Capacitor Upgrade sensitivity consisted of increasing the thermal limit of the Riel – Forbes 500 kV line from 1732 MVA to 2165 MVA. The sensitivity results indicate that the series capacitor upgrade exhibits similar relative benefits for all transmission configurations. Since the Eastern Plan configurations by themselves facilitate significantly more simultaneous outlet capability than the Western Plan configurations, as demonstrated in the base case results, and since the Roseau series capacitor upgrade provides more or less the same incremental outlet capability for both plans, the Roseau Series Capacitor Upgrade sensitivity results confirm that the Eastern Plan configurations are to be preferred over the Western Plan configurations.

The Glenboro Phase Shifter sensitivities consisted of adding a new phase shifting transformer at the Glenboro Substation as proposed by Manitoba Hydro to limit North Dakota – Manitoba loop flow on the

Glenboro – Rugby 230 kV Line. To capture the impact of the Glenboro phase shifter on the Loop Flow Impact Study, five different phase shifter control modes were analyzed. The sensitivity results indicate that the Glenboro phase shifter shows benefit for all transmission configurations when used to limit North Dakota – Manitoba loop flow or force power flow south on G82R, but the greatest benefits from this facility are realized by the Eastern Plan configurations.

The MVP & CapX2020 Lines sensitivities consisted of cumulatively removing several planned and proposed 345 kV transmission lines in the upper Midwest that have the potential to alter the bias of power flow out of North Dakota in such a way that there is less North Dakota – Manitoba loop flow. The sensitivity results indicate that the MISO MVP and CapX2020 345 kV lines in North and South Dakota, southern Minnesota, northern Iowa, and southern Wisconsin cumulatively reduce the total North Dakota – Manitoba loop flow by drawing more power south and east out of North Dakota. The impact of these lines appears to be similar for both the Eastern Plan and the Western Plan.

The Western Plan Alternative Endpoints sensitivities consisted of moving the endpoint of the Western Plan away from North Dakota to the south and/or east in order to capture the impact of the alternative endpoints on the amount and impact of North Dakota – Manitoba loop flow associated with the Western Plan. Six alternative endpoints were considered, including two that involve the development of a second 500 kV line from the Fargo area to the south. The sensitivity results indicate that, in order for the Western Plan configurations to produce simultaneous North Dakota and Manitoba outlet capability that is comparable to or better than the Eastern Plan configurations, the endpoint of the Western Plan must be moved far to the southeast, away from North Dakota generation and toward large load centers in the Twin Cities. At a minimum, it appears that a comparable Western Plan project must extend from Winnipeg to the St. Cloud, MN area.

The Northeastern Minnesota Generation sensitivity consisted of adding approximately 600 MW of generation interconnected directly to the Blackberry Substation and an associated 230 kV transmission line, in order to capture the impact that large new generation development in northeastern Minnesota has on the results of the Loop Flow Impact Study. The sensitivity results indicate that the new generation in northeastern Minnesota generally reduces the impact of North Dakota – Manitoba loop flow on M602F for the Western Plan, increasing the potential simultaneous North Dakota and Manitoba outlet capability. For the Eastern Plan, the impact of new generation in northeastern Minnesota is highly dependent on the location of the generator. In the worst case, with a new generator interconnected directly to the Blackberry Substation, simultaneous North Dakota and Manitoba outlet capability could be limited significantly as more power is forced to flow on the Riel – Forbes 500 kV Line. However, if a new generator were interconnected just 30 miles away at the Forbes Substation, it could have the opposite impact, actually improving simultaneous North Dakota and Manitoba outlet capability by reducing loading on the Riel – Forbes 500 kV Line.

The Northeastern Minnesota Load sensitivities consisted of adding a conceptual 450 MW load pocket in northeastern Minnesota or reducing the anticipated total plant load of a taconite mine that is currently under development near Nashwauk, MN. The purpose of these sensitivities was to capture the impact that significant load additions or reductions in northeastern Minnesota have on the results of the Loop Flow Impact Study. In general, the sensitivity results indicate that significant load growth that is electrically near to the endpoint of one of the Manitoba – United States tie lines will draw more power down the line. If that line is M602F, the resulting increase in loading will limit simultaneous North Dakota and Manitoba outlet capability. If it is a different tie line, simultaneous outlet capability may be increased.

Conclusions

The purpose of the New Tie Line Loop Flow Impact Study is to capture and compare the impact of a new 500 kV Manitoba – United States tie line on the North Dakota – Manitoba loop flow phenomenon. Specifically, the study is meant to compare the loop flow impact of an Eastern (Grand Rapids area) 500 kV tie line configuration and a Western (Fargo area) 500 kV tie line configuration. The results of the study and the various sensitivities also provide insight into the nature of North Dakota – Manitoba loop flow as well as the various factors that influence the level and impact of the loop flow.

The results of the study illustrate the fact that North Dakota – Manitoba loop flow is fundamentally a result of the system topology that facilitates the unwanted flow of North Dakota generation through Manitoba at higher levels of North Dakota generation export. Even if interface flows, load levels, and generation dispatch are such that only very low levels of North Dakota – Manitoba loop flow are observed, the same potential for loop flow at higher North Dakota export levels will exist as long as the system topology remains unchanged.

The results of the study support the assertion that the Eastern Plan has a more favorable overall impact on North Dakota – Manitoba loop flow than the Western Plan. The Western Plan introduces a new, very low impedance path for North Dakota generation to flow from North Dakota into Manitoba (the Dorsey – Barnesville 500 kV Line) and then back into the United States, primarily on the Riel – Forbes 500 kV Line. This has the impact of significantly increasing the total amount of North Dakota – Manitoba loop flow as well as the amount of loop flow that ends up on the Riel – Forbes 500 kV Line. In practice, the result would be that, the higher the North Dakota export is, the less power a new Dorsey – Barnesville 500 kV Line would carry from Manitoba to the United States. This would cause more power to flow on the existing Riel – Forbes 500 kV Line, overloading the line at much lower levels of simultaneous Manitoba and North Dakota export levels than would otherwise be possible if the new tie line did not connect North Dakota and Manitoba. While it can be demonstrated that the Western Plan provides additional outlet capability from Manitoba Hydro, this additional outlet capability would come at the expense of placing considerable limitations on North Dakota outlet capability absent any additional upgrades or new transmission developments.

The Eastern Plan, on the other hand, does not directly connect North Dakota generation to Manitoba. Instead, the Eastern Plan provides a new, very low impedance transmission path parallel to the Riel – Forbes 500 kV Line, alleviating the main thermal constraint associated with North Dakota – Manitoba loop flow and thereby facilitating less interaction between North Dakota generation and Manitoba Hydro exports. While it is true that the Eastern Plan facilitates slightly more total North Dakota – Manitoba loop flow than the existing system, it also reduces the overall impact of loop flow on the Riel – Forbes 500 kV Line by carrying some of the North Dakota – Manitoba loop flow that would normally flow on the line. The result is that the Eastern Plan provides the desired additional outlet capability from Manitoba Hydro without inherently limiting potential transmission outlet capability for current and future North Dakota generation resources. In fact, the Eastern Plan is not only capable of maintaining North Dakota outlet capability at existing levels or better simultaneous with increased exports from Manitoba, it actually offers significant potential for increased North Dakota outlet capability without restrictions due to North Dakota – Manitoba loop flow.

In conclusion, the results of the New Tie Line Loop Flow Impact study indicate that the Eastern Plan is the superior long-term plan for developing a new 500 kV tie line between Manitoba and the United States when compared to the Western Plan based on the impact of the two transmission configurations on North Dakota – Manitoba loop flow.

(This page intentionally left blank)

Section 1: Background

Purpose

The purpose of the New Tie Line Loop Flow Impact Study is to capture and compare the impact of a new 500 kV Manitoba – United States tie line on the North Dakota – Manitoba loop flow phenomenon. Regional power system analysis has consistently shown that there is an existing North Dakota – Manitoba loop flow phenomenon where, due to the electrical configuration of the regional transmission system and the laws of physics, generation being exported out of North Dakota will flow through Manitoba on its way to load centers in Minnesota and Wisconsin. If simultaneous export levels from North Dakota and Manitoba are of a sufficient level, the combined impact of the desired Manitoba Hydro exports and incidental North Dakota – Manitoba loop flow can potentially lead to congestion on a common path, the Riel – Forbes 500 kV Line. The capability of the Riel – Forbes 500 kV Line is limited to 2000 Amps (1732 MVA) by the Roseau series capacitor banks, an electrical component of the line required for its reliable and efficient operation. A second 500 kV Manitoba – United States tie line has recently been proposed as the preferred solution for facilitating at least 750 MW of additional transfer capability from Manitoba Hydro to utilities in the United States. Depending on the electrical configuration of this new tie line, it may either mitigate or exasperate the unwanted effects of North Dakota – Manitoba loop flow. For the Loop Flow Impact Study, two general configurations for this new 500 kV tie line were compared based on the total amount of North Dakota – Manitoba loop flow associated with each configuration, their effectiveness in relieving the impact of North Dakota – Manitoba loop flow on the Riel – Forbes 500 kV Line, and their efficiency in providing the most combined generation outlet capability from Manitoba and North Dakota without significantly limiting one or the other due to overloading of the Riel – Forbes 500 kV Line.

Regional Power System

On a regional level, power has historically flowed from major generation centers in Manitoba and North Dakota to load centers on the Iron Range and in the Twin Cities, and further east into Wisconsin. Some of the most stressed conditions, among those with the most serious reliability and economic impacts, have been those with high simultaneous export levels from Manitoba and North Dakota causing massive amounts of power to flow from those areas to load centers on the Iron Range, in the Twin Cities, and in Wisconsin. This trend is shown in Figure 6, below.

Three interfaces, also shown in Figure 6, have historically been used to measure the level of stress in a power flow case and identify regional power flow limits. First, the Manitoba Hydro Export ("MHEX") interface is a measure of the sum of the power flowing on the four existing Manitoba – United States tie lines. The existing interface between Manitoba and the United States consists of three 230 kV lines and one 500 kV line. The three 230 kV lines from Manitoba to the United States are G82R from Glenboro to Rugby (North Dakota), L20D from Letellier to Drayton (North Dakota), and R50M from Richer to Moranville (Minnesota). The Dorsey – Forbes 500 kV Line, known as D602F, originates at the Dorsey Substation near Winnipeg, Manitoba, and connects to the Forbes Substation on Minnesota's Iron Range. A second 500 kV line then then continues on from Forbes to the Chisago Substation near the Twin Cities. The Riel Station Reliability Project, which will sectionalize the Dorsey – Forbes 500 kV Line, is scheduled to be in service in late 2014, resulting in a Dorsey – Riel 500 kV Line and a Riel – Forbes 500 kV Line. Throughout this Report, wherever the Riel – Forbes 500 kV Line is referred to, the new designator for the line – "M602F" – will be used. Current total firm transfer capability on MHEX is 2175 MW southward and 700 MW northward. A new 500 kV tie line is needed to increase firm transfer capability on MHEX to at least 2925 MW southward and 1450 MW northward while preserving system reliability at existing levels or better.

Second, the North Dakota Export ("NDEX") interface has traditionally been defined by the sum of the power flowing on the tie lines extending from North Dakota to the north (Manitoba), south (South Dakota), and east (Minnesota). Today, this includes 19 high voltage (115+ kV) tie lines, with two additional components located in Minnesota that must be netted out. NDEX currently has a studied limit of 2080 MW for simultaneous high transfer cases, though recent studies have suggested that planned system improvements will modify the nature of the NDEX limit and potentially increase it to 2200 MW or more.[4] The NDEX interface represents the location where North Dakota historically separated from the rest of the regional power system. While recent and anticipated changes on the system, including two new tie lines across the historical NDEX boundary, have largely eliminated the need for the historical NDEX as a stability interface, NDEX remains a good proxy for measuring the total generation export (or import) from North Dakota to the rest of the system as well as the impact of this export on other interfaces like MHEX and the Minnesota-Wisconsin Export (described below). It is in this context that the NDEX interface will be referred to throughout the rest of this Report. More information on the history of NDEX, as well as its current and potential future significance is provided in Appendix N: History and Significance of NDEX.

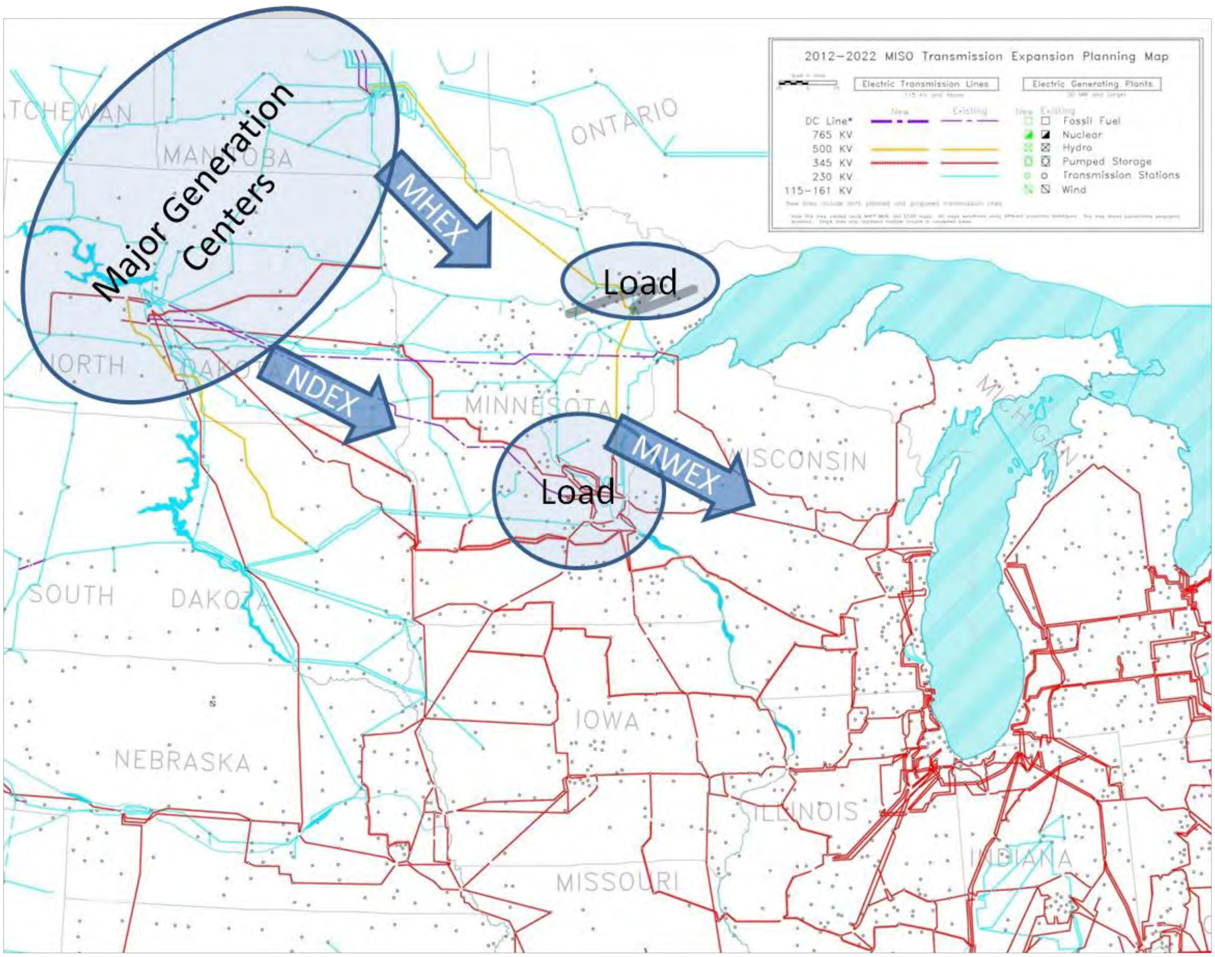


Figure 6: Historical Trend of Regional Power Flow

Third, the Minnesota-Wisconsin Export ("MWEX") interface is currently defined by the sum of the power flowing on two lines: the King – Eau Claire – Arpin 345 kV line and the Arrowhead – Stone Lake –

[4] Impact of CapX Facilities on North Dakota Export for the Year 2016 Report, June 2012.

Gardner Park 345 kV line. Currently, export capability from Minnesota to Wisconsin on the MWEX interface is limited to 1665 MW; beyond this MWEX level, system instability is likely to occur for certain fault events on the King – Eau Claire 345 kV line. The future construction of the Hampton Corners (southeast Twin Cities) – North Rochester – Briggs Road (Lacrosse, WI) 345 kV line and the Briggs Road – North Madison – Cardinal (Madison, WI) 345 kV line will likely improve the stability performance of the MWEX interface and increase export capability from Minnesota to Wisconsin.

North Dakota – Manitoba Loop Flow

Regional power system analysis has consistently shown that there is an existing North Dakota – Manitoba loop flow phenomenon where, due to the electrical configuration of the regional transmission system and the laws of physics, generation being exported out of North Dakota will flow through Manitoba on its way to load centers in Minnesota and Wisconsin. Unlike most commodities, electric power cannot be shipped from its point of origin to its destination along a prescribed transmission path. Rather, due the laws of physics, electric power will be subdivided among all possible paths based on the impedance of the power system as it flows from the location where it is generated to the location where it is used. For that reason, a portion of the power generated in and exported from North Dakota will always flow into Manitoba on the two 230 kV lines between Manitoba and North Dakota (Glenboro – Rugby/G82R and Letellier – Drayton/L20D) and then back down into the United States, primarily on the Dorsey – Forbes 500 kV Line (D602F), which is a very low impedance path relative to the surrounding transmission system. This concept is illustrated in Figure 7, below.

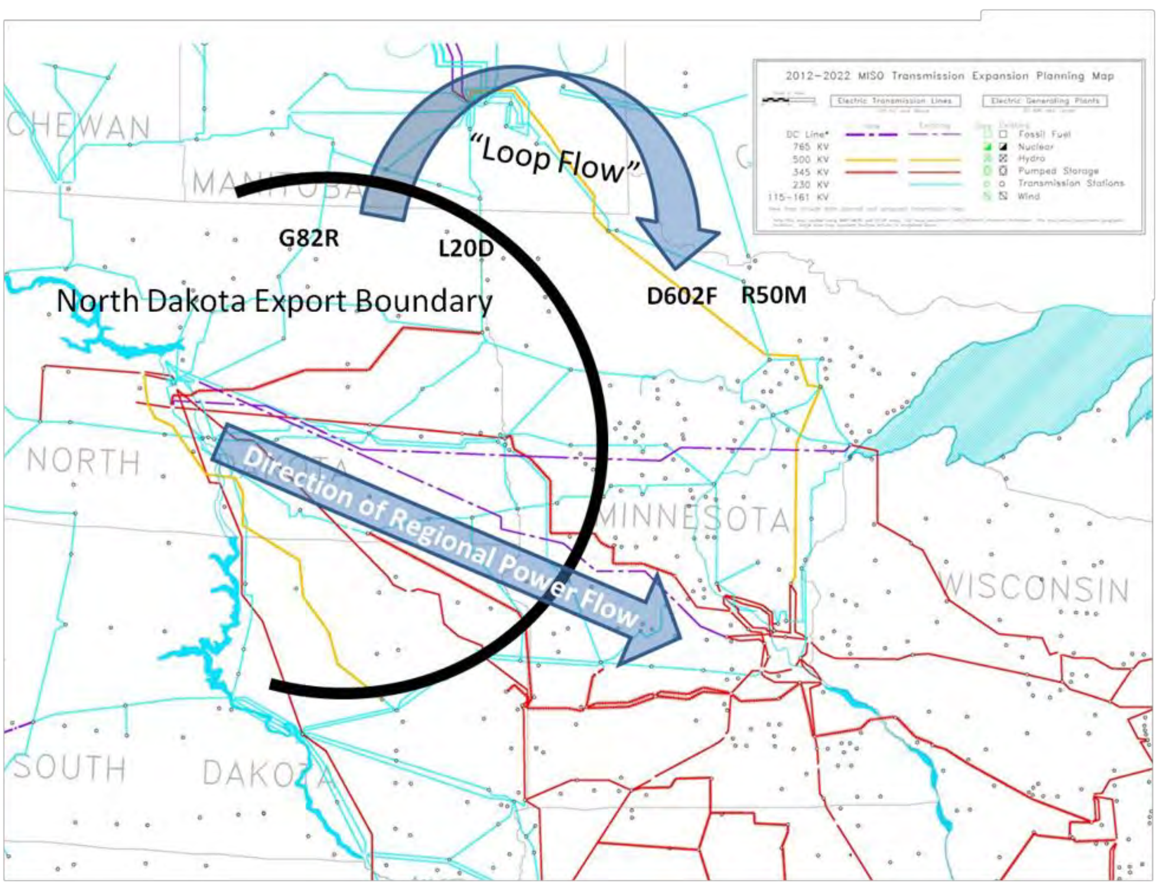


Figure 7: North Dakota - Manitoba Loop Flow

Because generation and load levels on the power system are constantly changing, the amount of North Dakota – Manitoba loop flow present at any given time varies depending on the load and generation levels in North Dakota and Manitoba. At very low NDEX levels, there is very little North Dakota – Manitoba loop flow due to low North Dakota generation levels. As the amount of generation being exported from North Dakota increases, North Dakota loop flow through Manitoba increases proportionately. In practice, North Dakota – Manitoba loop flow does not typically result in large power flows north on the North Dakota – Manitoba tie lines (G82R and L20D). Rather, when loop flow from North Dakota is superimposed onto Manitoba – United States exports, the typical result is a reduction in the total power flow south into North Dakota on G82R and L20D and an increase in the total power flow south into Minnesota on D602F and R50M. This is illustrated in Figure 8 and Figure 9, below.

Figure 8 shows the separate power flows on the Manitoba interface due to Manitoba export and North Dakota loop flow.

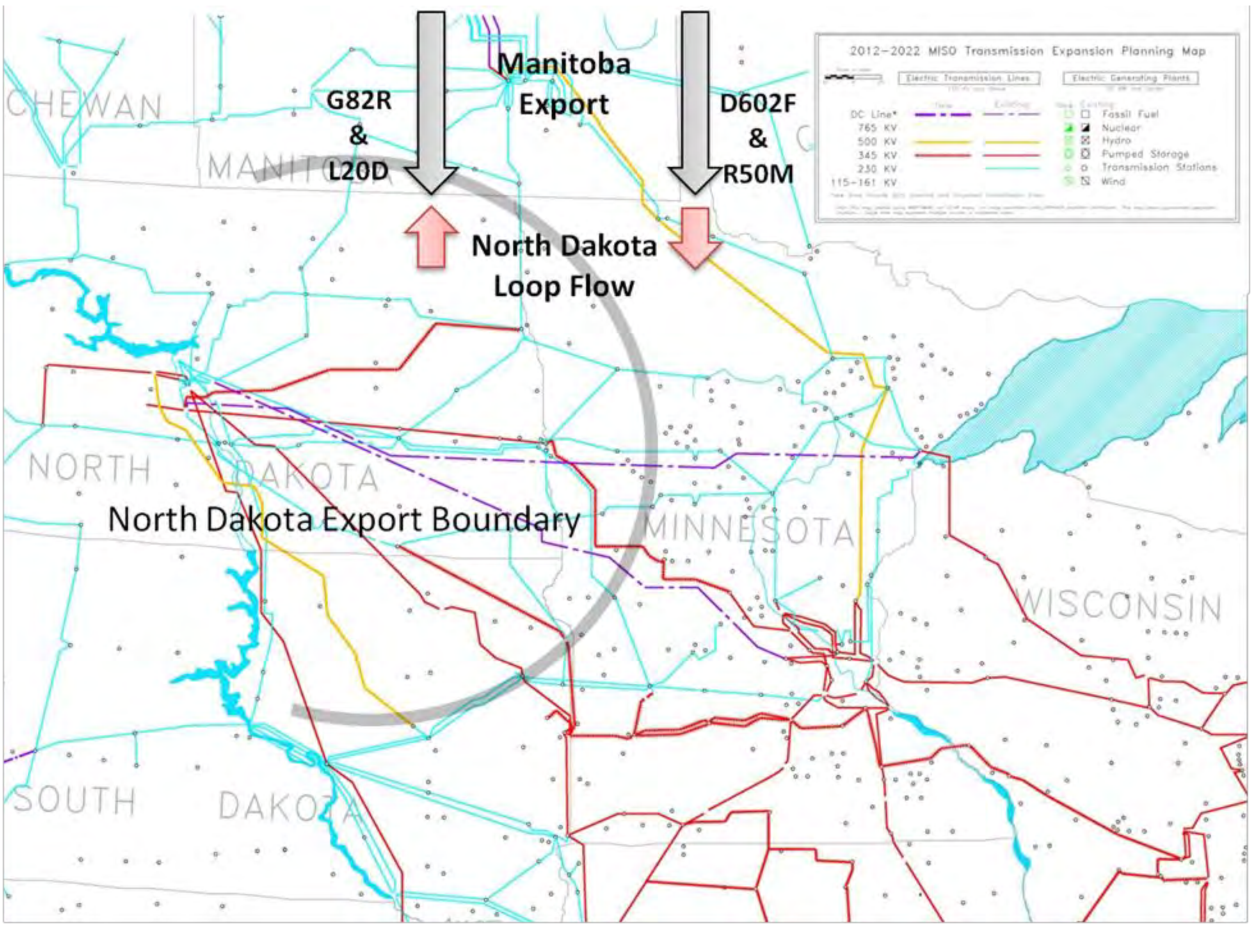


Figure 8: Power Flows on the Manitoba/U.S. Interface

Figure 9 shows the net effect of North Dakota loop flow: Less power flow south on G82R and L20D, and more power flow south on D602F and R50M.

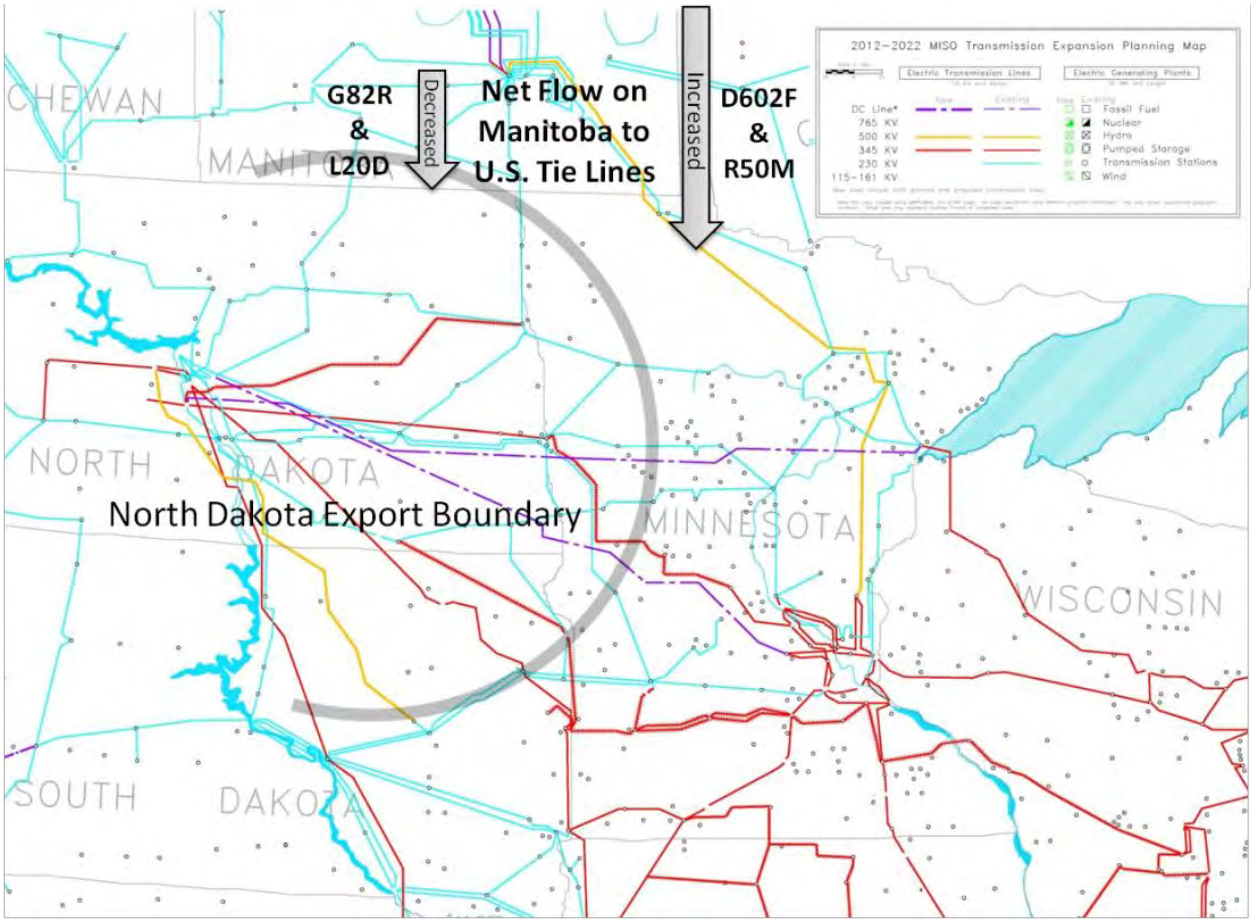


Figure 9: Net Effect of Loop Flow on the North Dakota/U.S. Interface

This North Dakota – Manitoba Loop Flow phenomenon was recently documented in the CapX2020 study report "Impact of CapX Facilities on North Dakota Export for the Year 2016," where it was found that even with the new Phase 1 CapX2020 facilities in service, thermal and stability constraints on NDEX exist due to North Dakota – Manitoba loop flow. The study found that the simultaneous NDEX stability limit, with MHEX at 2175 MW, MWEX at 1665 MW, and the new CapX2020 lines in service, is established at approximately 2200 MW by transient undervoltages on the 161 kV system in northwestern Wisconsin. The next limitation on NDEX was encountered in the study at approximately 2500 MW when the Roseau series capacitors on D602F overloaded.[5] Both of these constraints are directly attributable to North Dakota – Manitoba loop flow, as generation from North Dakota flows through Manitoba and down into Minnesota on D602F, pushing more power through northeastern Minnesota into northwestern Wisconsin, causing stability issues on the MWEX interface and eventually exceeding the thermal capability of the Roseau series capacitor banks.

[5] Impact of CapX Facilities on North Dakota Export for the Year 2016 Report, June 2012.

Section 2: Model Development

Power Flow Models

Analysis was performed using four existing models which were developed and thoroughly reviewed for four very different regional studies. Models were selected from the February 2013 MISO Definitive Planning Phase (DPP) generator interconnection study, the MISO Midwest Transmission Expansion Planning (MTEP) 2013 reliability analysis performed for NERC TPL Standard compliance, the Manitoba Transmission Expansion (MANTEX) ad hoc study group, and the MISO Northern Area Study (NAS). To ensure consistency on key assumptions that could impact study results, a minimal number of modifications were made to the benchmark cases. These modifications are listed below. A detailed comparison of some of the key indicators from the four benchmark cases is provided in Appendix A: Detailed Comparison of Benchmark Cases.

Benchmark Cases

February 2013 DPP Study – 2023 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 transmission facilities specific to each of the Transmission Configurations described below, the following modifications were made to the benchmark 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 transmission facilities specific to each of the Transmission Configurations described below, the following modifications were made to the benchmark MTEP 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 transmission facilities specific to each of the Transmission Configurations described below, the following modifications were made to the benchmark 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 transmission facilities specific to each of the Transmission Configurations described below, the following modifications were made to the benchmark NAS 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. Disconnected conceptual P2 load at Forbes 230 kV (608624)
4. Disconnected conceptual P2 load at Minntac 230 kV (608623)

Transmission Configurations

Three general transmission configurations were studied in the Loop Flow Impact Study: a benchmark ("Existing System") configuration with no new 500 kV tie line between Manitoba and the United States, an Eastern Plan configuration with a new 500 kV tie line to the Grand Rapids area in northeastern Minnesota, and a Western Plan configuration with a new 500 kV tie line to the Fargo/Moorhead area in western Minnesota. Additional Eastern and Western plan configurations include up to two additional 345 kV transmission projects, the first between Fargo, ND, and Monticello, MN, and the second between Grand Rapids, MN, and Duluth, MN. All three transmission configurations, and the associated additional configurations, are described in further detail below.

Existing System Configuration

The Existing System (XS) configuration does not include a new 500 kV tie line. The existing transmission system is shown in Figure 10 below.

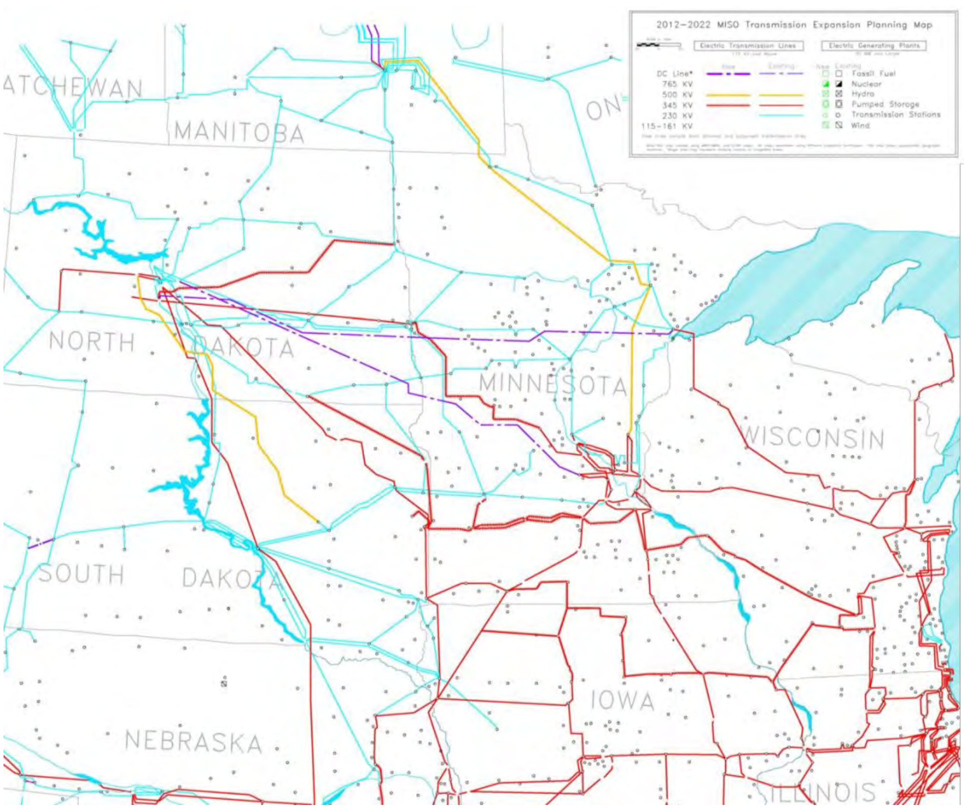


Figure 10: Conceptual Transmission Map of Existing System Configuration

Eastern Plan Configurations

The Eastern Plan involves development of a new 500 kV tie line from the Winnipeg area to the Grand Rapids area in northeastern Minnesota. Five transmission configurations involving the Eastern Plan were studied and are described below. A conceptual transmission map for each of the Eastern Plan configurations is also provided on the following pages.

Eastern Plan (E1)

Transmission configuration "E1" (the Eastern Plan) is shown in Figure 11 below. It consists of the development of a single 500 kV line from the Dorsey Substation to the Iron Range (Blackberry 500 kV) Substation. The line is assumed to be 60 percent series compensated with compensation located at the midpoint of the line. For this study, the Dorsey – Iron Range 500 kV Line was assumed to be ~360 miles long. Line-end shunt reactor sizes at Dorsey and Iron Range are assumed to be the same as those on the existing Riel – Forbes 500 kV Line. The Iron Range Substation interconnects 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)

Transmission configuration "E1b" is shown in Figure 12 below. It consists of the combination of the Eastern Plan and a second circuit on the Bison – Alexandria – Quarry – Monticello 345 kV line

Eastern Plan with Iron Range – Arrowhead 345 kV Double Circuit (E2)

Transmission configuration "E2" is shown in Figure 13 below. It consists of the combination of the Eastern Plan and a new ~60 mile double circuit 345 kV line from the Iron Range Substation to the Arrowhead Substation near Duluth, Minnesota. 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 with Iron Range – Arrowhead 345 kV Single Circuit Only (E2s)

Transmission configuration "E2s" is shown in Figure 14 below. It consists of the combination of the Eastern Plan and a new ~60 mile single circuit 345 kV line from the Iron Range Substation to the Arrowhead Substation near Duluth, Minnesota. 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, Iron Range – Arrowhead 345 kV, and Bison – Monticello 345 kV Double Circuit (E2b)

Transmission configuration "E2b" is shown in Figure 15 below. It consists of the combination of the Eastern Plan, the new double circuit Iron Range – Arrowhead 345 kV line, and a second circuit on the Bison – Alexandria – Quarry – Monticello 345 kV line.

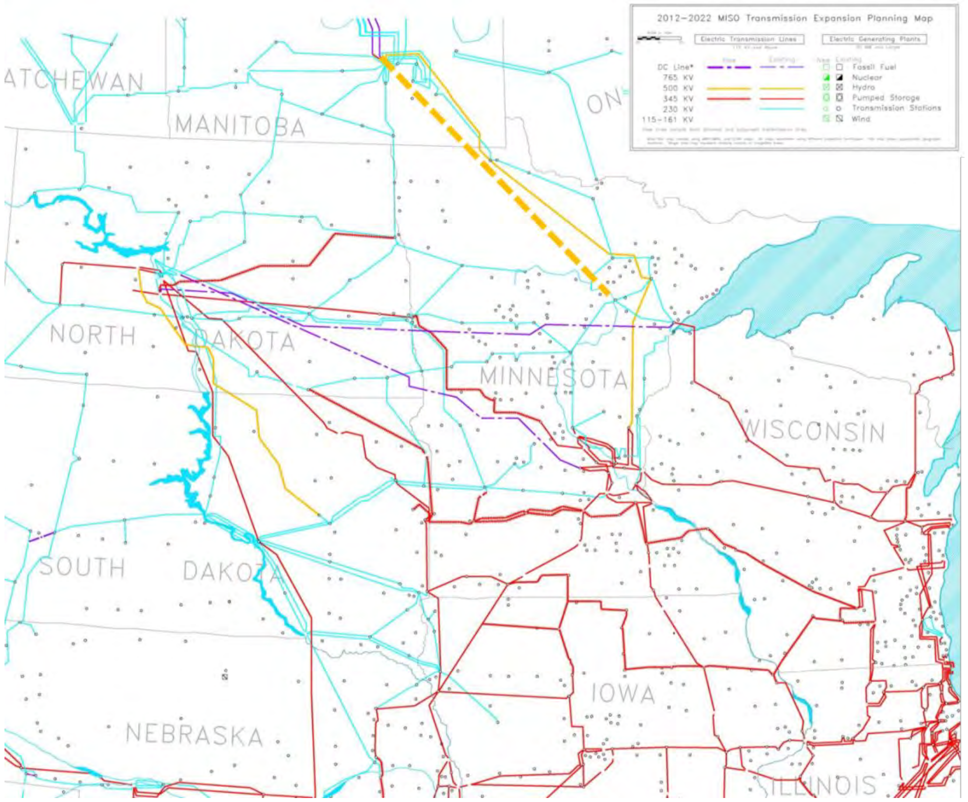


Figure 11: Conceptual Transmission Map of Configuration E1

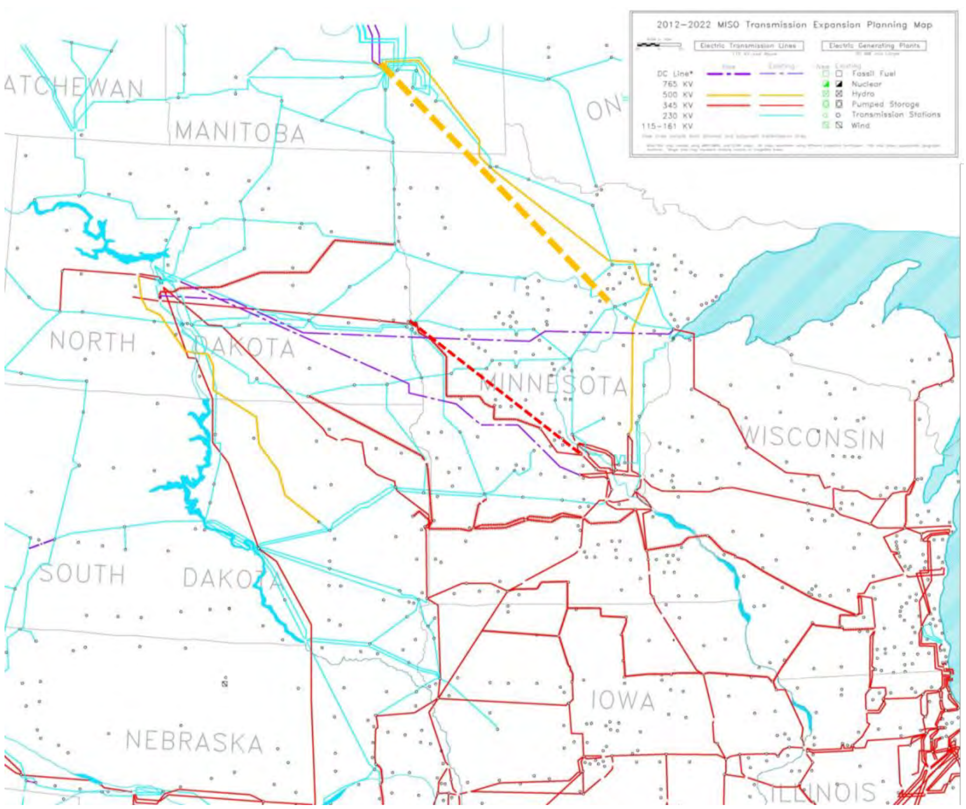


Figure 12: Conceptual Transmission Map of Configuration E1b

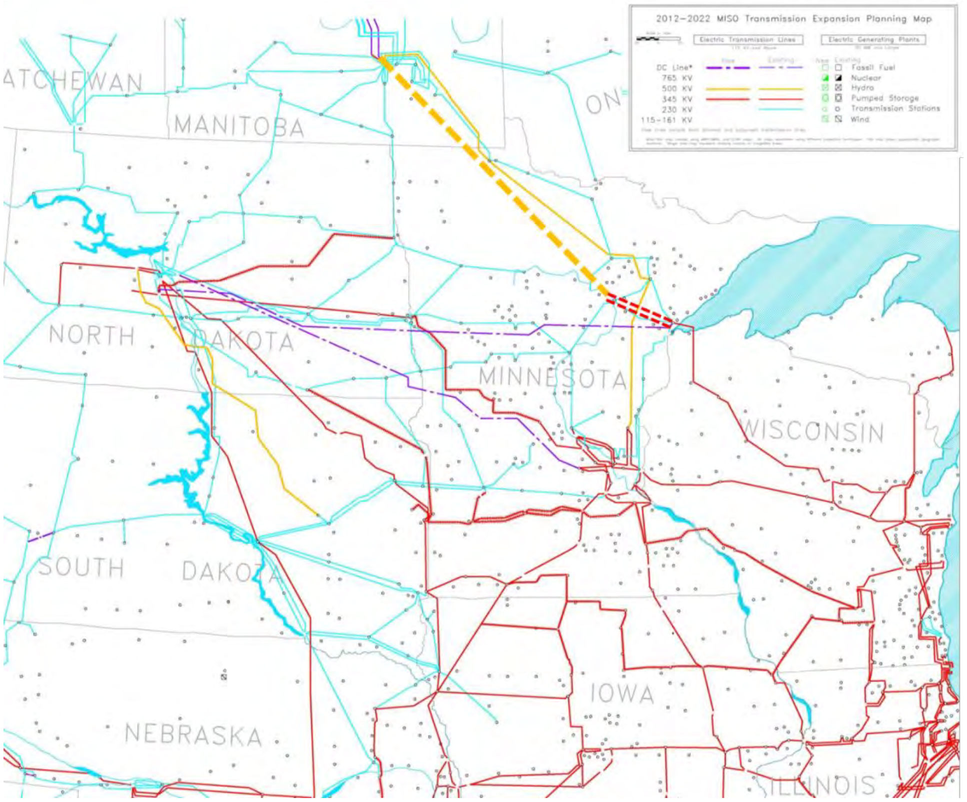


Figure 13: Conceptual Transmission Map of Configuration E2

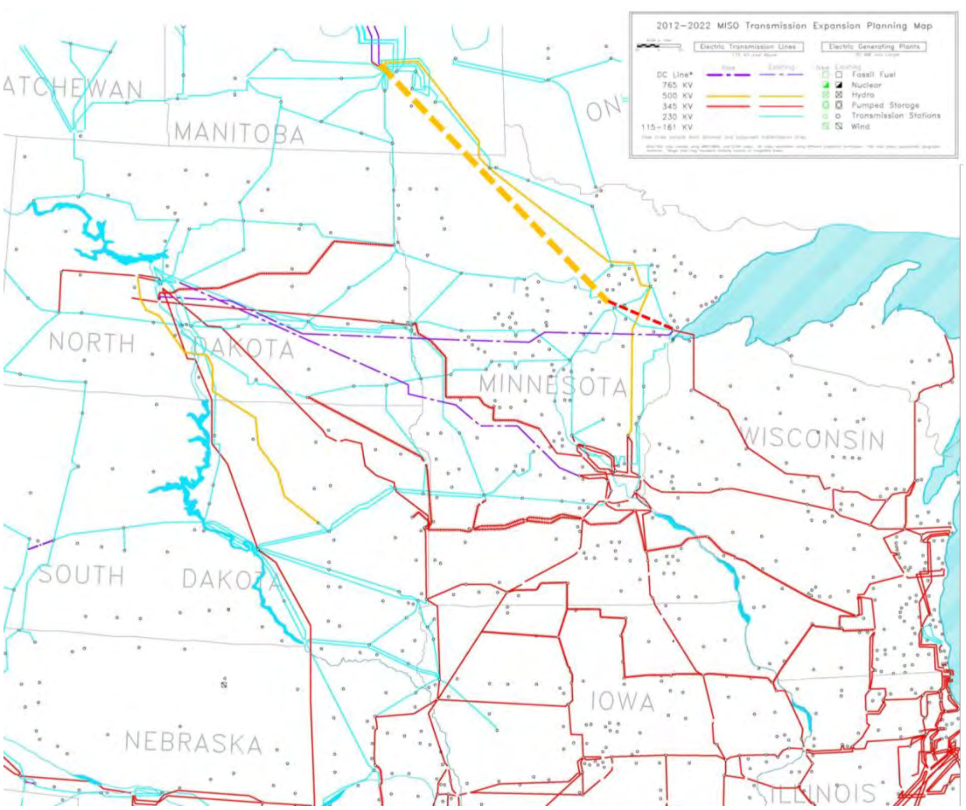


Figure 14: Conceptual Transmission Map of Configuration E2s

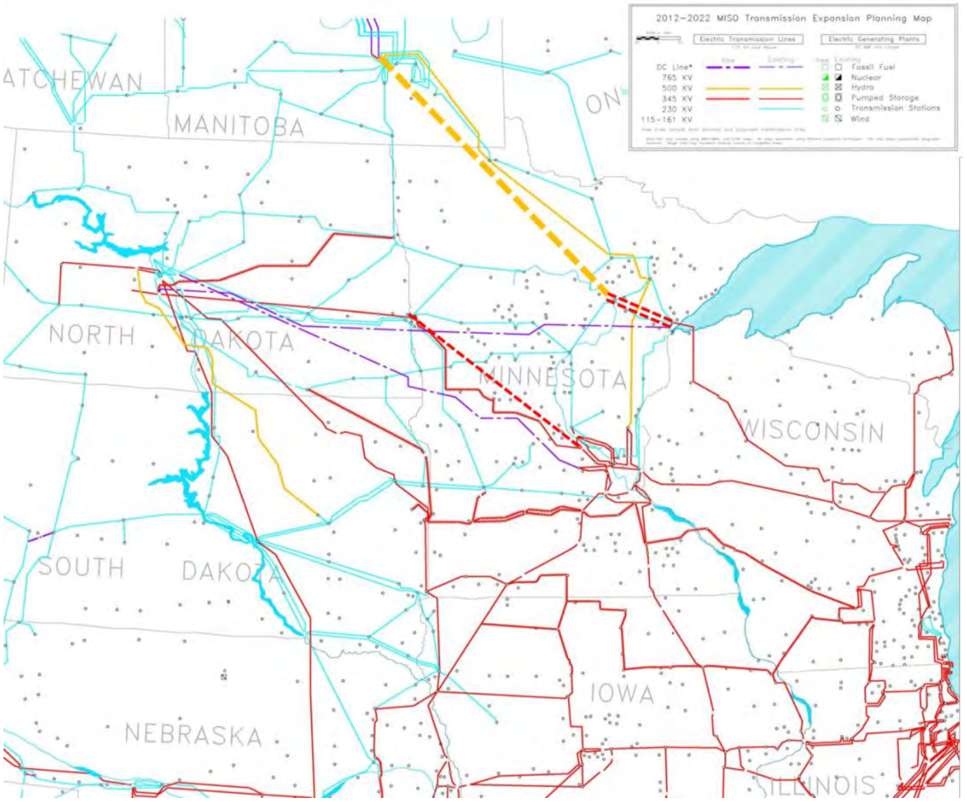


Figure 15: Conceptual Transmission Map of Configuration E2b

Western Plan Configurations

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 transmission configurations involving the Western Plan were studied and are described below. The automation file used to implement the Western Plan [*XEL-4261Dorsey-BARNSVLE_NAS_Synergy_500kVOption.idv*] was obtained from the regional model building database 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 new 500 kV tie line. A conceptual transmission map for each of the Western Plan configurations is also provided on the following page.

Western Plan (W2)

Transmission configuration "W2" (the Western Plan) is shown in Figure 16 below. It consists of the development of a single 500 kV line from the Dorsey Substation to a new Barnesville Substation southeast of Moorhead, Minnesota. The line is assumed to be 60 percent series compensated with compensation located at the midpoint of the line. For this study, the Dorsey – Barnesville 500 kV Line was assumed to be ~312 miles long. The new Barnesville Substation interconnects to the existing Bison – Alexandria 345 kV line and is assumed to include a single 1200 MVA, 500/345 kV transformer.

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

Transmission configuration "W2b" is shown in Figure 17 below. It consists of the combination of the Western Plan and 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.

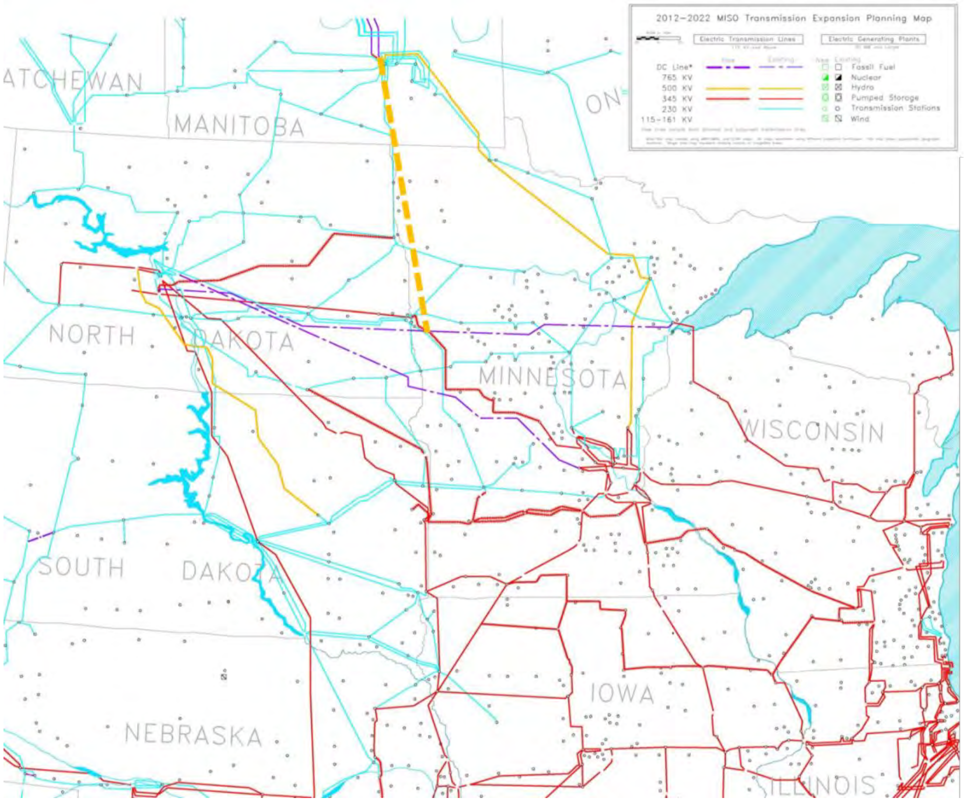


Figure 16: Conceptual Transmission Map of Configuration W2

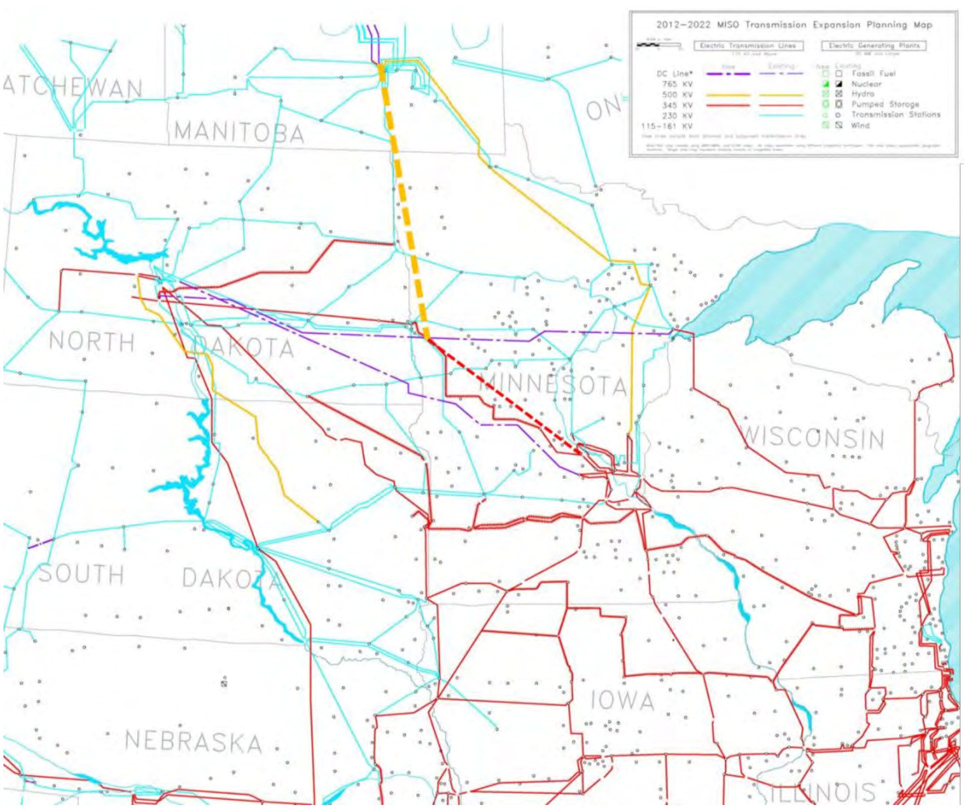


Figure 17: Conceptual Transmission Map of Configuration W2b

Section 3: Sensitivities

Several sensitivities, described below, were considered for the Loop Flow Impact Study. The sensitivities were meant to capture the impact that various conceptual or planned changes to the transmission system in the upper Midwest have on the results of the Loop Flow Impact Study for each of the transmission configurations being studied. Unless otherwise noted, sensitivities were only applied to the Existing System (XS), Eastern Plan (E1), Eastern Plan with double circuit Iron Range – Arrowhead 345 kV Line (E2), Western Plan (W2), and Western Plan with second circuit on the Barnesville – Monticello 345 kV Line (W2b).

Roseau Series Capacitor Upgrade

The series capacitor banks located at the Roseau County Station limit the maximum continuous rating of the Riel – Forbes 500 kV Line to 2000 Amps (1732 MVA). Since the basic premise of the Loop Flow Impact Study is that the limit associated with the Roseau series capacitor banks constrains simultaneous North Dakota and Manitoba outlet capability due to North Dakota – Manitoba loop flow, the following sensitivity was applied to all four benchmark cases:

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 Amps to 2500 Amps

Glenboro Phase Shifter

In connection with the development of a new 500 kV tie line from Manitoba to the United States, Manitoba Hydro has proposed to install a new phase shifting transformer (PST) on the Glenboro – Rugby 230 kV Line (G82R). The new PST will be located at the Glenboro Substation in Manitoba, and its main purpose is to limit loop flow on G82R, which is the main path that power flows on from North Dakota into Manitoba. To capture the impact of the Glenboro phase shifter on the results of the Loop Flow Impact Study, the following sensitivities were applied to the DPP case:

Glenboro Phase Shifter Set at +80 degrees (PST_80deg+)

Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Phase shifter maintaining +80 degrees phase shift (maximum south flow).

Glenboro Phase Shifter Set at 0 MW (PST_0MW)

Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Phase shifter maintaining power flow on G82R at 0 MW.

Glenboro Phase Shifter Set at 0 degrees (PST_0deg)

Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Phase shifter maintaining 0 degrees phase shift.

Glenboro Phase Shifter Set at 250 MW Import (PST_250i)

Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Phase shifter maintaining power flow on G82R at 250 MW north flow.

Glenboro Phase Shifter Set at -80 degrees (PST_80deg-)

Add a +/- 80 degrees phase shifting transformer on G82R rated at 300 MW. Phase shifter maintaining -80 degrees phase shift (maximum north flow).

MVP & CapX2020 Lines

The MISO Multi-Value Project (MVP) portfolio and the CapX2020 Brookings County – Hampton (part of the MVP portfolio) and Hampton – Rochester – Lacrosse (not part of the MVP portfolio) 345 kV lines represent a significant transmission expansion in the upper Midwest. Because of their electrical configuration, several of these projects have the potential to alter the bias of power flow out of North Dakota in such a way that there is more power flowing south and east out of North Dakota and less loop flow through Manitoba. To that end, the following sensitivities, which are cumulative, were applied to the DPP case only:

North & South Dakota ("Western") 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)

Iowa & Wisconsin ("Southern") 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. Lacrosse – 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 Lines (CapX)

In addition to the changes made in the MVP_W and MVP_S sensitivities, disconnect selected CapX2020 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 – Lacrosse 345 kV (601051-601039-601044)

The MVP and CapX2020 transmission lines listed above are shown in Figure 18 below.

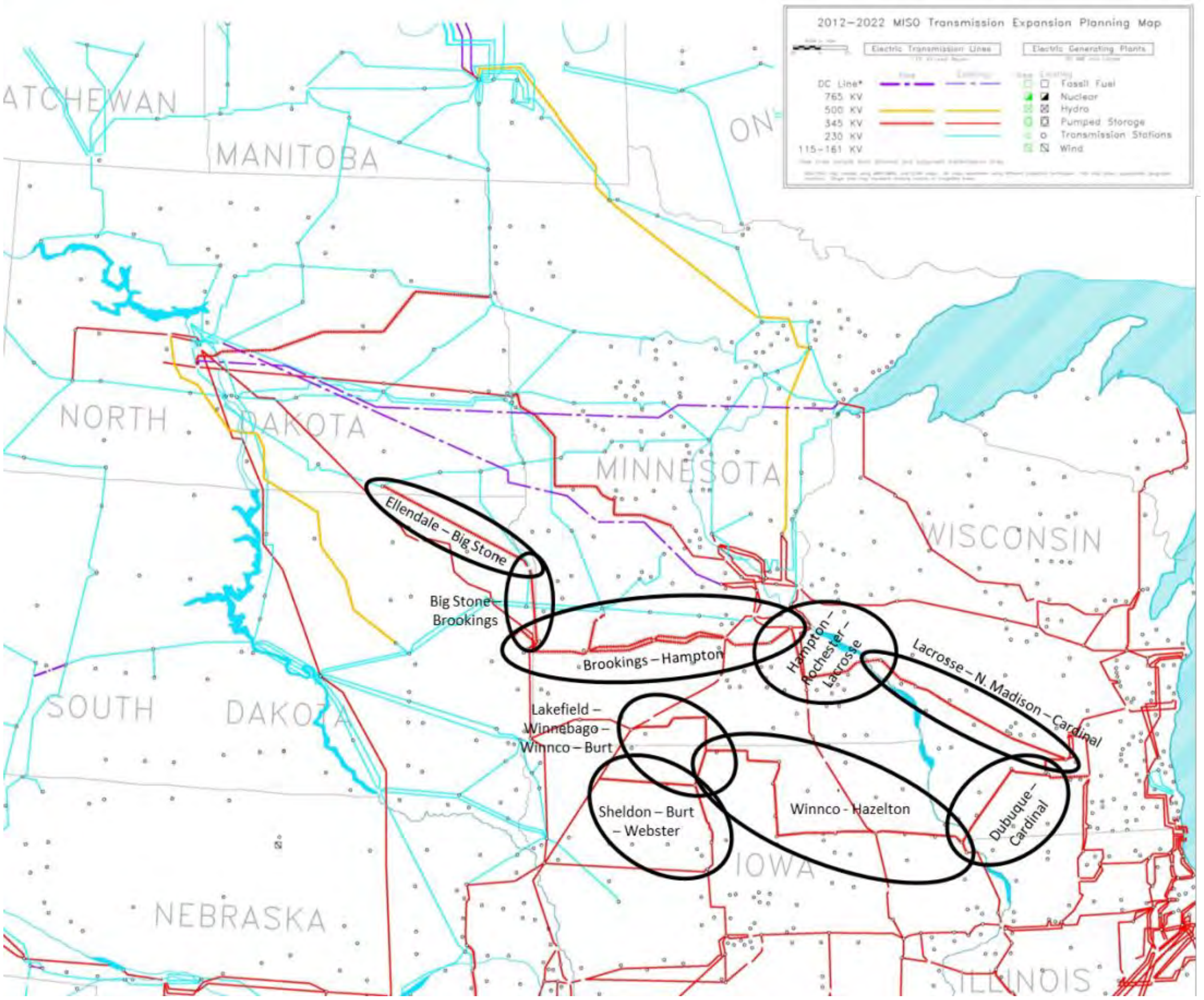


Figure 18: Transmission Map of MVP & CapX2020 Lines Sensitivity

Western Plan Alternative Endpoints

The endpoint for the Western Plan lies within the traditional North Dakota export boundary, creating a new transmission path for North Dakota – Manitoba loop flow. To capture the impact that moving the endpoint of the Western Plan away from North Dakota to the south and/or east has on the amount and impact of North Dakota – Manitoba loop flow associated with the Western Plan, the following sensitivities were applied to the MTEP case, configuration W2b only. A conceptual transmission map for each alternative endpoint configuration is also provided in the following pages.

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:

- 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 – Monticello double circuit 345 kV line:

- 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 – Monticello double circuit 345 kV line:

- 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

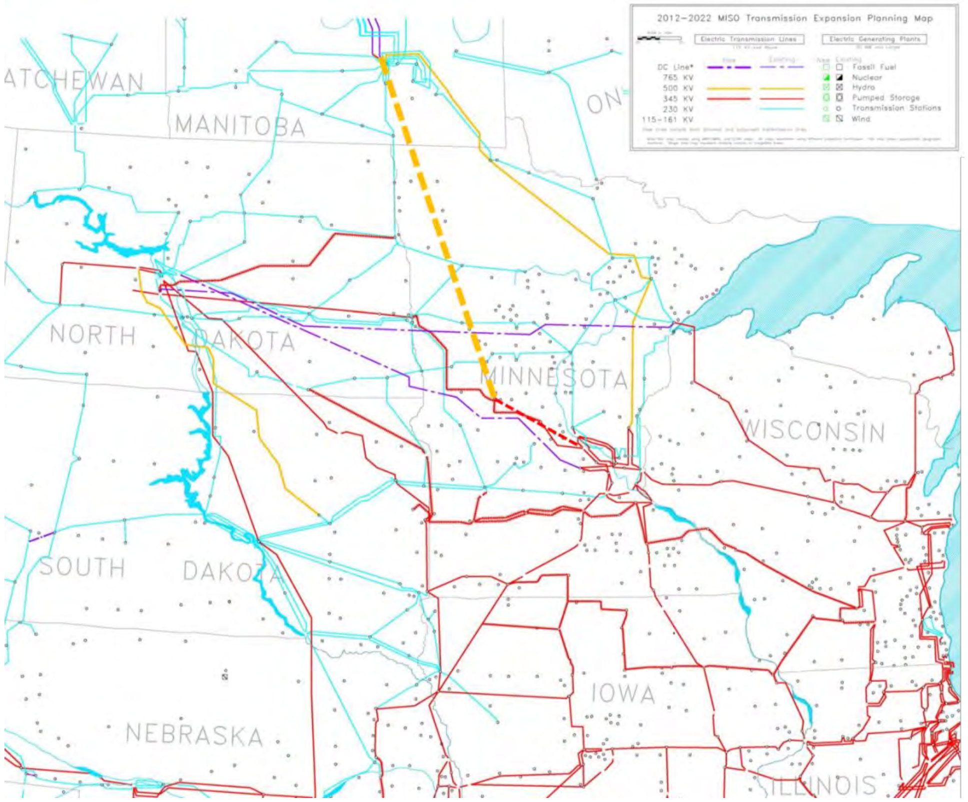


Figure 19: Western Plan Alexandria Endpoint Sensitivity (W2alx)

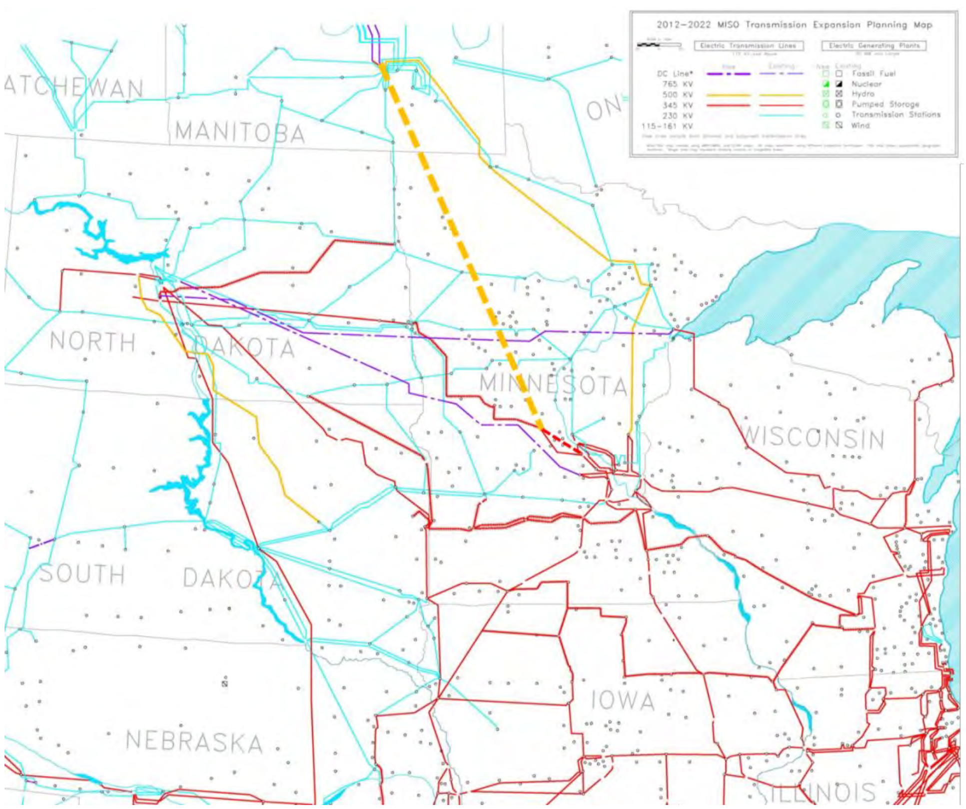


Figure 20: Western Plan Quarry Endpoint Sensitivity (W2qry)

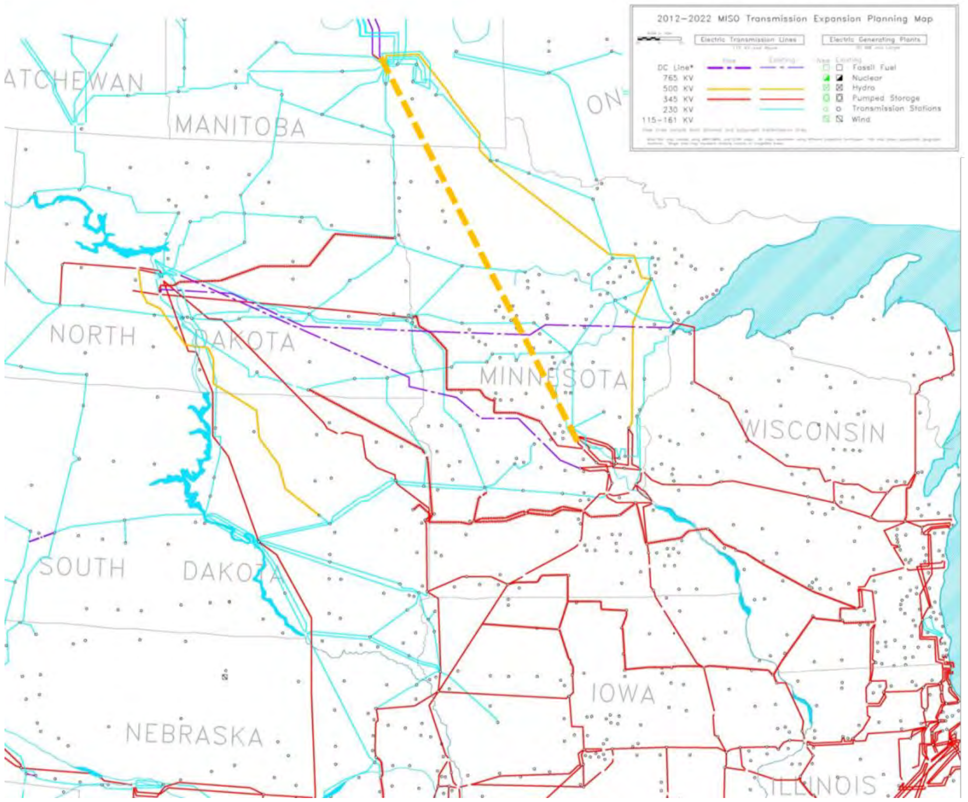


Figure 21: Western Plan Monticello Endpoint Sensitivity (W2mnt)

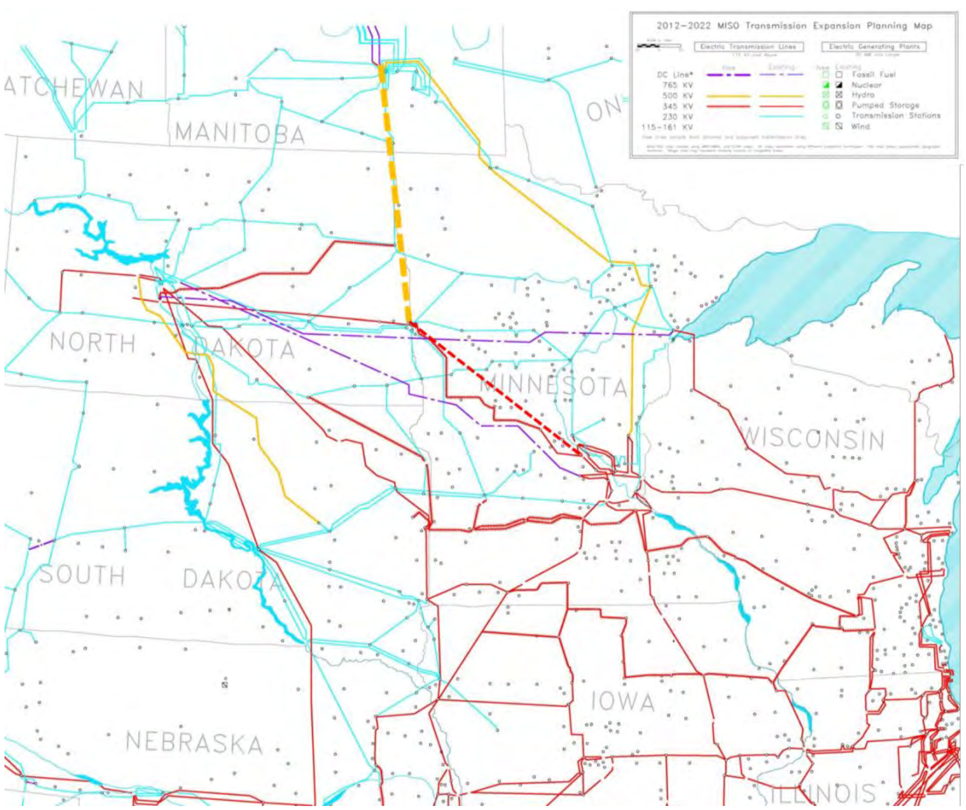


Figure 22: Western Plan Bison Endpoint Sensitivity (W2bis)

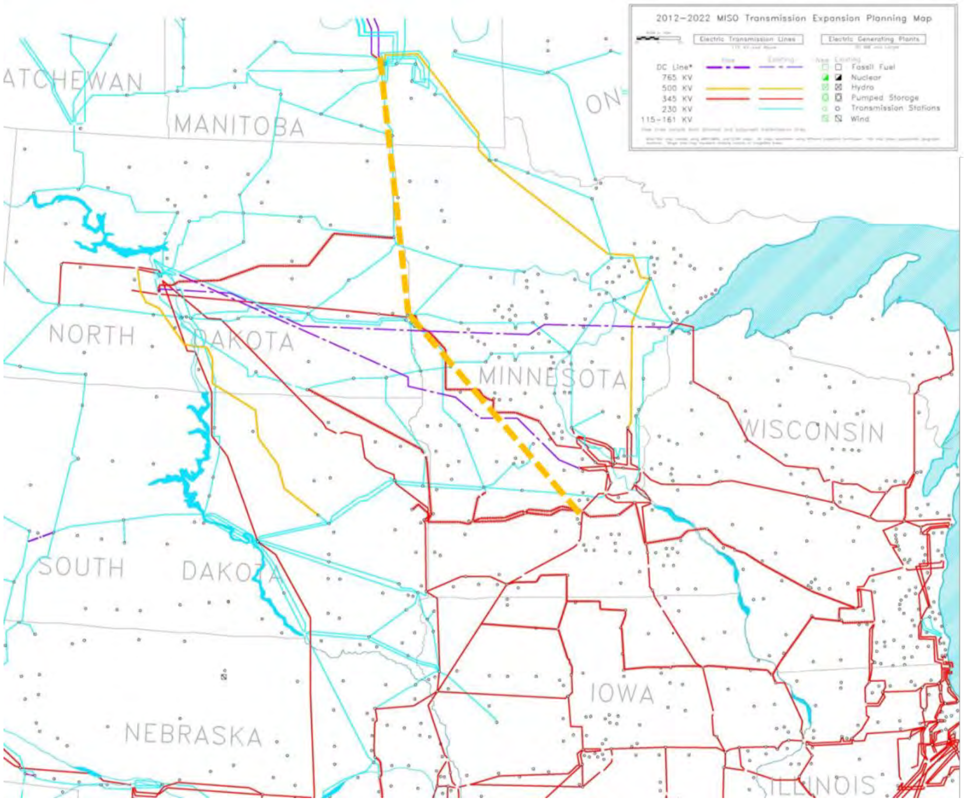


Figure 23: Western Plan Helena Endpoint Sensitivity (W2hln)

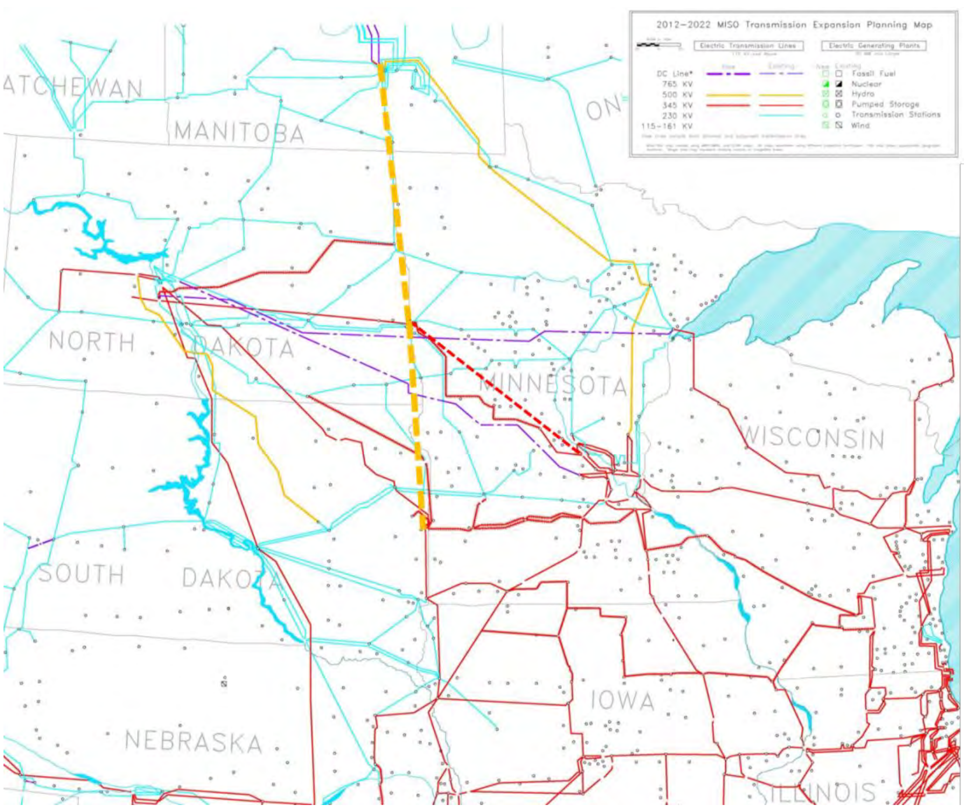


Figure 24: Western Plan Brookings Endpoint Sensitivity (W2brk)

Northeastern Minnesota Generation

The "Excelsior" project represents an approximately 600 MW thermal generation unit originally proposed to be interconnected to Minnesota Power's Blackberry 230 kV Substation by an independent power producer. While this particular project has since been removed from the MISO generator interconnection queue, it was included in the benchmark case from the MANTEX study and is a reasonable proxy for considering the impact that large new generation development in northeastern Minnesota has on the results of the Loop Flow Impact Study. The following sensitivity will be applied to the MANTEX case:

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)

Northeastern Minnesota Loads

The purpose of the MISO Northern Area Study was to identify economic opportunities for transmission expansion in the upper Midwest after development of the MISO MVP projects and a new 500 kV interconnection between Manitoba and the United States. Several pockets of potential load expansion were considered in the Northern Area Study, including a conceptual 450 MW load pocket in northeastern Minnesota. Adding the northeastern Minnesota load pocket back in to the Northern Area Study model is a reasonable way to capture the impact that significant load additions in northeastern Minnesota have on the results of the Loop Flow Impact Study.

The Essar Steel Minnesota project is a staged project involving a traditional taconite mine, a direct reduced iron pellet plant, and eventually a fully integrated steel mill. Essar is included in the Northern Area Study at its full potential load level. Reducing the total load at Essar and removing the transmission associated with the steel mill expansion is a reasonable way to capture the impact of delayed or reduced load growth in northeastern Minnesota on the results of the Loop Flow Impact Study.

To capture the impact of changing northeastern Minnesota load on the results of the Loop Flow Impact Study, the following sensitivities were applied to the NAS case:

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)

Summary of Sensitivities

Several sensitivities were applied to the various benchmark models used for the Loop Flow Impact Study. A summary of the sensitivities applied to each benchmark case is given in the table below. These sensitivities are meant to capture the impact that various conceptual or planned changes to the transmission system in the upper Midwest have on the results of the Loop Flow Impact Study for the transmission configurations being studied.

Sensitivity	Benchmark Case			
	DPP	MTEP	MANTEX	NAS
Roseau Series Capacitor Upgrade	X	X	X	X
Glenboro Phase Shifter	X			
MVP & CapX2020 Lines	X			
Western Plan Alternative Endpoints		X		
Northeastern Minnesota Generation			X	
Northeastern Minnesota Loads				X

Table 1: Summary of Sensitivities

Section 4: Study Methodology

Background

A common way of determining the impact that incremental changes in generation or power transfers have on the transmission system is to calculate the fraction of the incremental generation that will flow on each transmission line in the system. The resulting percentage is called the "distribution factor" of the generator on the transmission line. If the incremental generation has a high impact on a transmission line, it will have a higher distribution factor. If it has a low or negligible impact on the transmission line, it will have a low distribution factor. If incremental generation causes counter flows – power flow in the opposite direction of the pre-injection flow on a transmission line – the result will be a negative distribution factor on the line.

Distribution Factor Analysis

The main methodology used for the Loop Flow Impact Study involves the calculation of distribution factors describing the percentage of the total output of conceptual new generators in Manitoba and North Dakota that will flow on each of the existing and new Manitoba – United States tie lines. An average North Dakota generation distribution factor was calculated for each tie line based on the distribution factors for individual injection points (proxy new generators) at several locations in North Dakota. The methodology for calculating these distribution factors is described in further detail in Appendix B: Description of Study Methodology.

The power system analysis software package *PSSE* was used to perform distribution factor (DF) analysis on each of the configurations described above for an incremental 100 MW injection at the Manitoba and North Dakota locations shown in Figure 25 below.

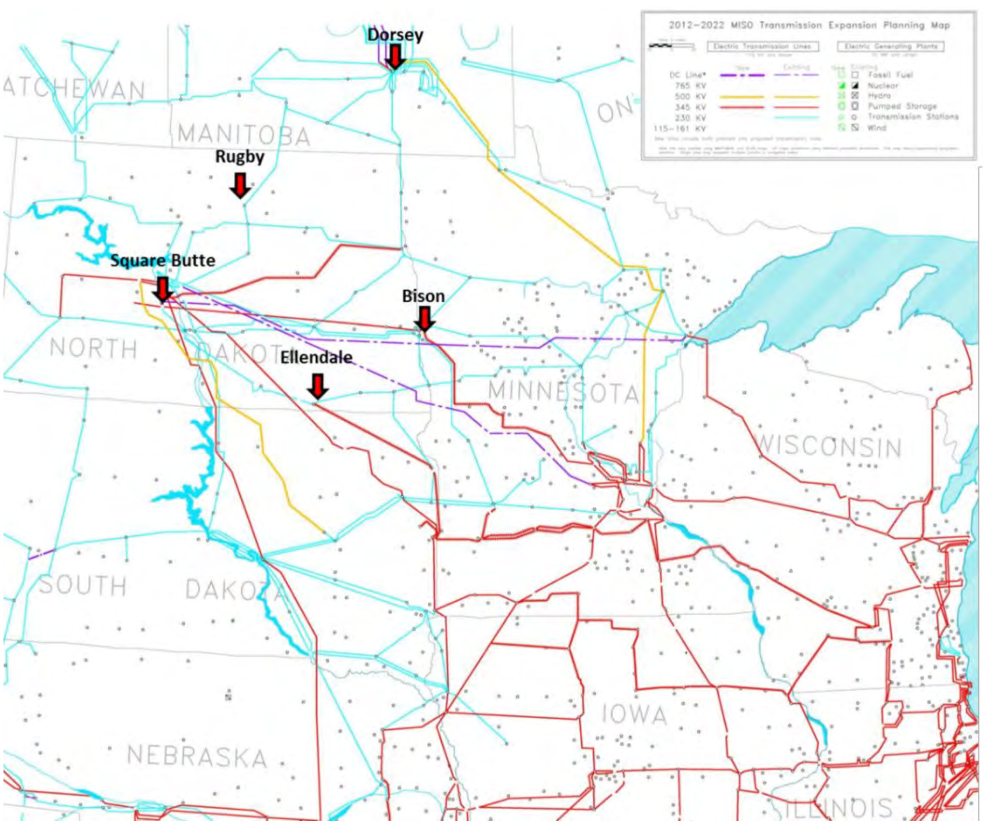


Figure 25: Transmission Map of Injection Points for Distribution Factor Analysis

In Manitoba, the Dorsey 500 kV bus, which is located near Winnipeg, was selected because it is the terminus of two of the three HVDC bipoles that move power from hydroelectric stations in far northern Manitoba to southern Manitoba. Dorsey is also a natural injection point for distribution factor analysis because it is the Manitoba endpoint for both new 500 kV tie line configurations being studied. In North Dakota, the Bison 345 kV, Ellendale 345 kV, Square Butte 230 kV, and Rugby 230 kV buses were selected. As shown in Figure 25 above, these four buses are evenly distributed geographically and are electrically located in four very different areas of the North Dakota transmission system. Therefore, the combination of results from these four North Dakota buses should provide a reasonable representation of the average impact of generic incremental generation anywhere in North Dakota on the transmission system outside of North Dakota.

The names and numbers of the buses from the *PSSE* model that were used for these injection points are provided in Table 2 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
657756	SQBUTTE4	230 kV	620-OTP
620379	RUGBY 4	230 kV	620-OTP

Table 2: Injection Points for Distribution Factor Analysis

Nomogram Development

Based on the results of Distribution Factor Analysis, the anticipated simultaneous North Dakota and Manitoba outlet capability based on the Riel – Forbes 500 kV Line thermal limit was determined using the nomogram calculation methodology described in Appendix B: Description of Study Methodology. The nomogram calculation methodology produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading the Riel – Forbes 500 kV Line. The accuracy of this nomogram calculation methodology was verified using the Existing System configuration MTEP model. Validation of the study methodology is discussed further in Appendix C: Validation of Study Methodology.

The approximate North Dakota outlet capability will be calculated based on the historical NDEX definition plus planned or recently built transmission lines that cross the historical NDEX boundary. Manitoba outlet capability will be calculated based on the historical MHEX definition plus the additional 500 kV tie line. A list of the transmission lines included in the calculation of North Dakota outlet capability and Manitoba outlet capability is given in the “Monitored Elements” section below.

Evaluation Metrics

Three general metrics were used to evaluate the relative impact of each transmission configuration on North Dakota – Manitoba loop flow:

4. The total North Dakota – Manitoba loop flow associated with the configuration, measured by calculating the sum of the North Dakota generation distribution factors on all North Dakota – Manitoba tie lines (G82R, L20D, and the Dorsey – Barnesville 500 kV line)
5. The impact of North Dakota – Manitoba loop flow on the Riel – Forbes 500 kV Line, measured by calculating the North Dakota generation distribution factor on the Riel – Forbes 500 kV line
6. The level of North Dakota outlet capability that can be achieved at the expected level of Manitoba export before the Riel – Forbes 500 kV Line is overloaded, determined from the nomogram calculations described above

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, primarily as a matter of interest:

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

Table 3: Miscellaneous Monitored Branches

The total Manitoba Hydro Export (MHEX) will be calculated as the sum of the power flows on the branches below. 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

Table 4: MHEX Monitored Branches

The total Minnesota – Wisconsin Export (MWEX) will be calculated as the sum of the power flows on the branches below. 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 Iron Range – 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

Table 5: MWEX Monitored Branches

The total North Dakota Export (NDEX) will be calculated as the sum of the power flows on the branches below. Where applicable, the two additional lines at the bottom of the list, which are associated with the studied transmission configurations, 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
620417	BSSOUTH3	601031	BRKNGCO3	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

Table 6: NDEX Monitored Branches

While recent and anticipated changes on the system, including two new tie lines across the historical NDEX boundary, have largely eliminated the need for the historical NDEX as a stability interface, NDEX remains a good proxy for measuring the total generation export from North Dakota to the rest of the system as well as the impact of this export on other interfaces like MHEX and MWEX. It is in this context that NDEX will be referred to throughout the rest of this report. More information on the history of NDEX, as well as its current and potential future significance is provided in Appendix N: History and Significance of NDEX.

Section 5: Study Results

Comparison of Benchmark Case Results

The distribution factor results from the four different benchmark cases were first compared to illustrate the defining factors behind North Dakota – Manitoba loop flow. A detailed comparison of key model parameters, which vary widely among the four benchmark cases in some instances, is provided in Appendix A: Detailed Comparison of Benchmark Cases.

The results of distribution factor analysis are given for the Existing System configuration, for each of the five injection points, in Figure 26 – Figure 30 below. Additional distribution factor analysis results are provided for the basic Eastern Plan (E1) and Western Plan (W2) configurations in Appendix D: Additional Distribution Factor Analysis Results. In spite of considerable differences in the initial conditions modeled in the four different benchmark cases, the distribution factor results are remarkably similar. For example, the distribution factor results for a 100 MW injection at the Bison 345 kV bus are shown in Figure 27 below. In nearly all cases, the difference in the calculated distribution factor of a 100 MW injection at the Bison 345 kV bus on each monitored element is less than 1 percent across the four benchmark cases used for the study.

This clearly demonstrates that distribution factors for incremental generation or transfers are primarily impacted by system topology and impedances – how the transmission system is interconnected and its physical characteristics – and only secondarily impacted by the modeled interface flows, load levels, and generation dispatch. In other words, the distribution factor for an incremental amount of generation at a particular location should be similar regardless of which model is used, as long as the modeled system topology is similar. This illustrates the fact that North Dakota – Manitoba loop flow is fundamentally a result of the system topology that facilitates the unwanted flow of North Dakota generation through Manitoba at higher levels of North Dakota generation export. Even if interface flows, load levels, and generation dispatch are such that only very low levels of North Dakota – Manitoba loop flow are observed, the same potential for loop flow at higher North Dakota export levels will exist as long as the system topology remains unchanged.

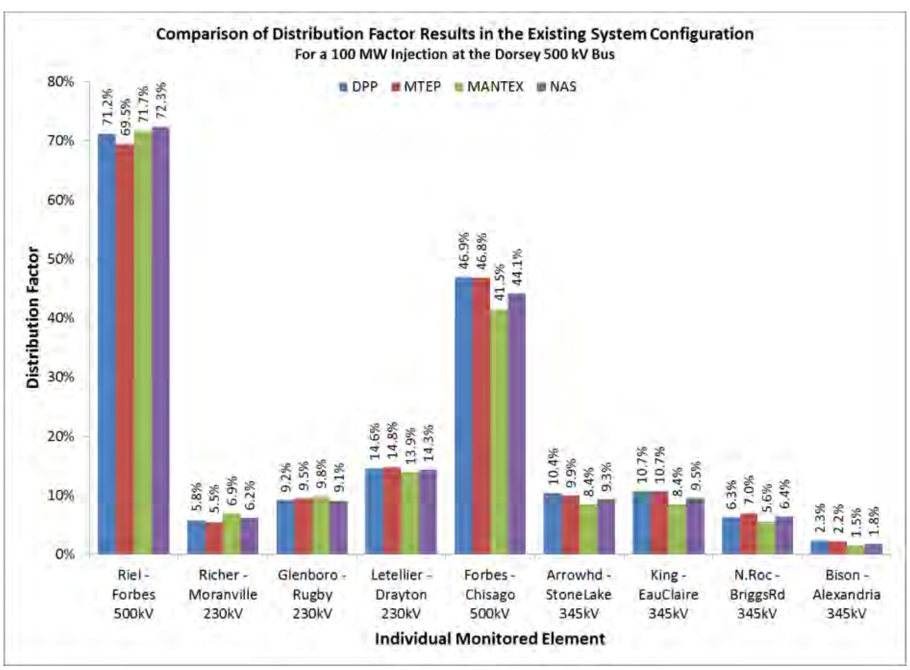


Figure 26: Comparison of Distribution Factor Results for the Dorsey Injection (XS)

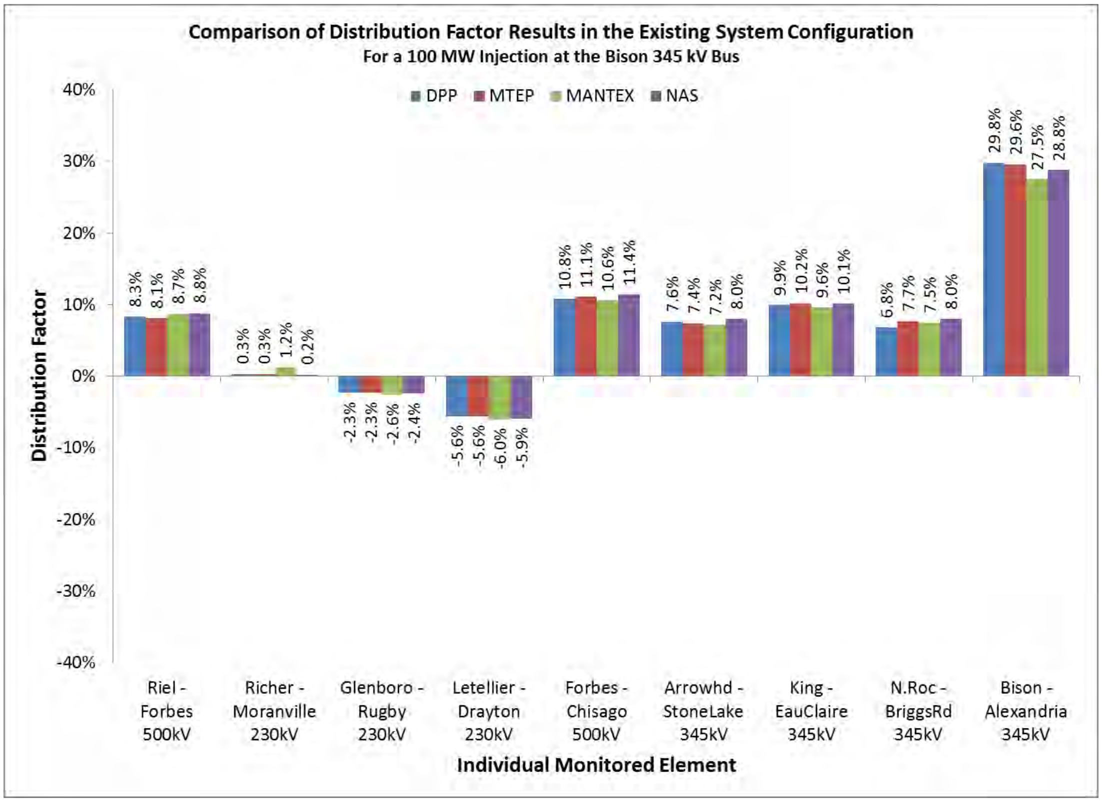


Figure 27: Comparison of Distribution Factor Results for the Bison Injection (XS)

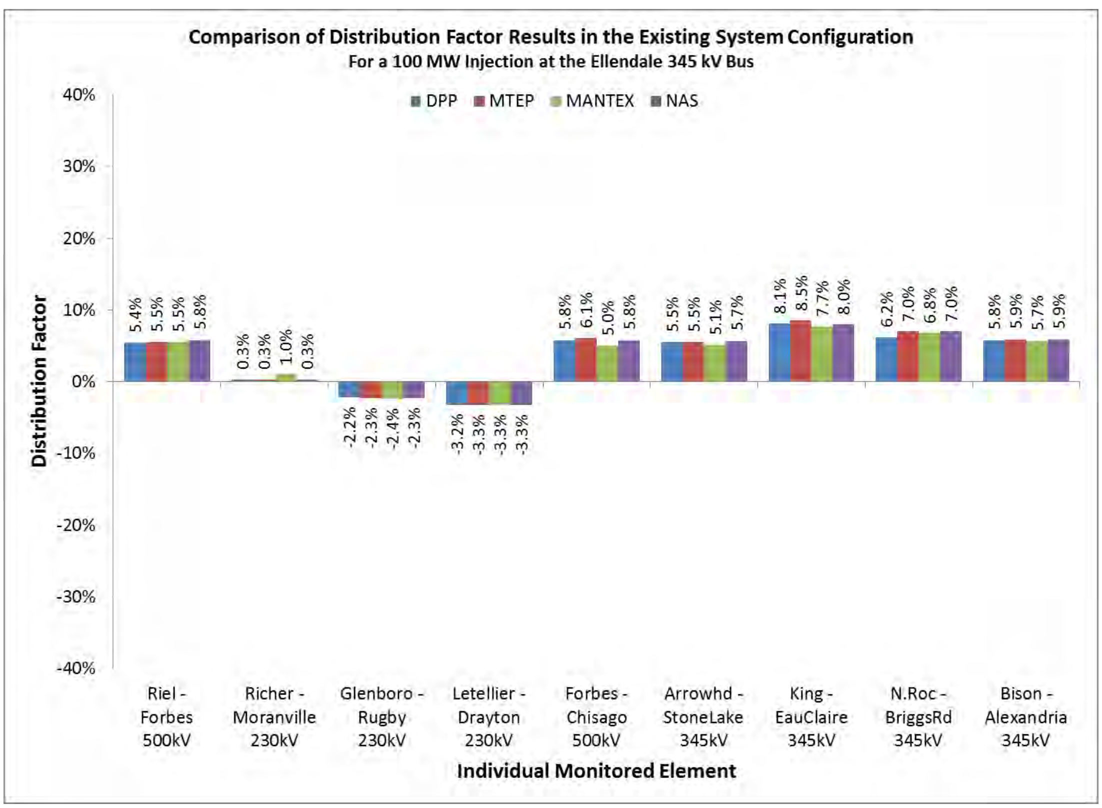


Figure 28: Comparison of Distribution Factor Results for the Ellendale Injection (XS)

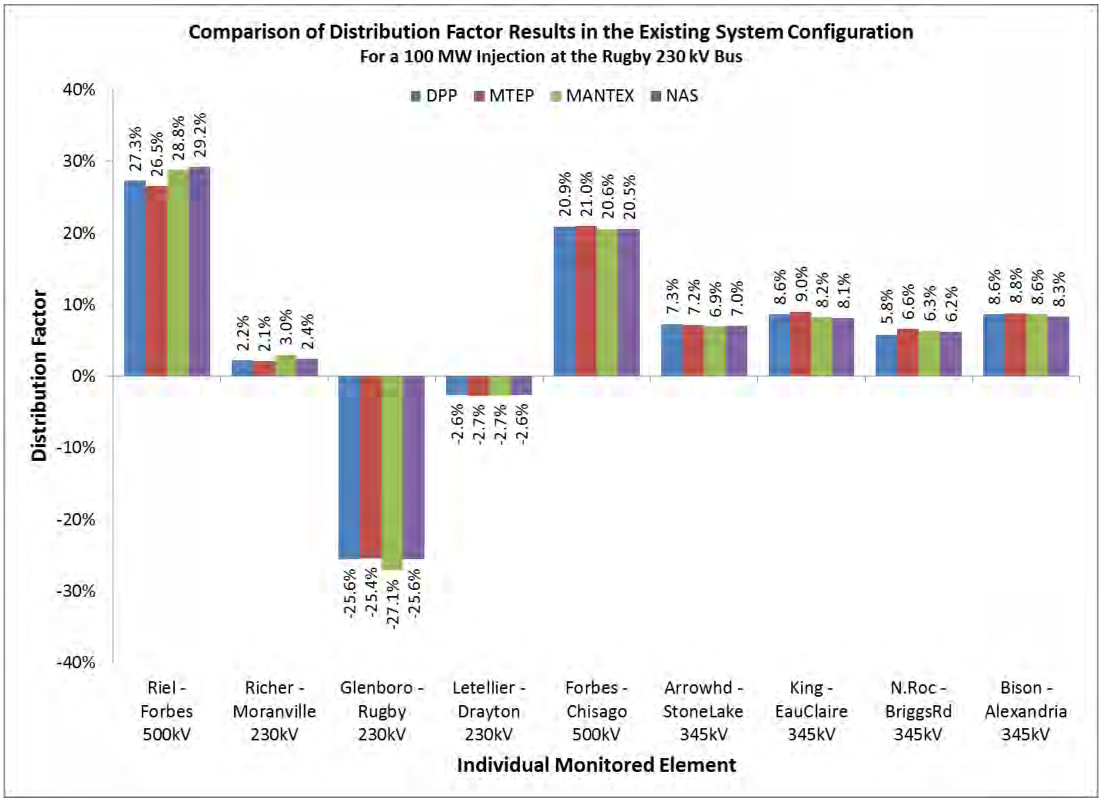


Figure 29: Comparison of Distribution Factor Results for the Rugby Injection (XS)

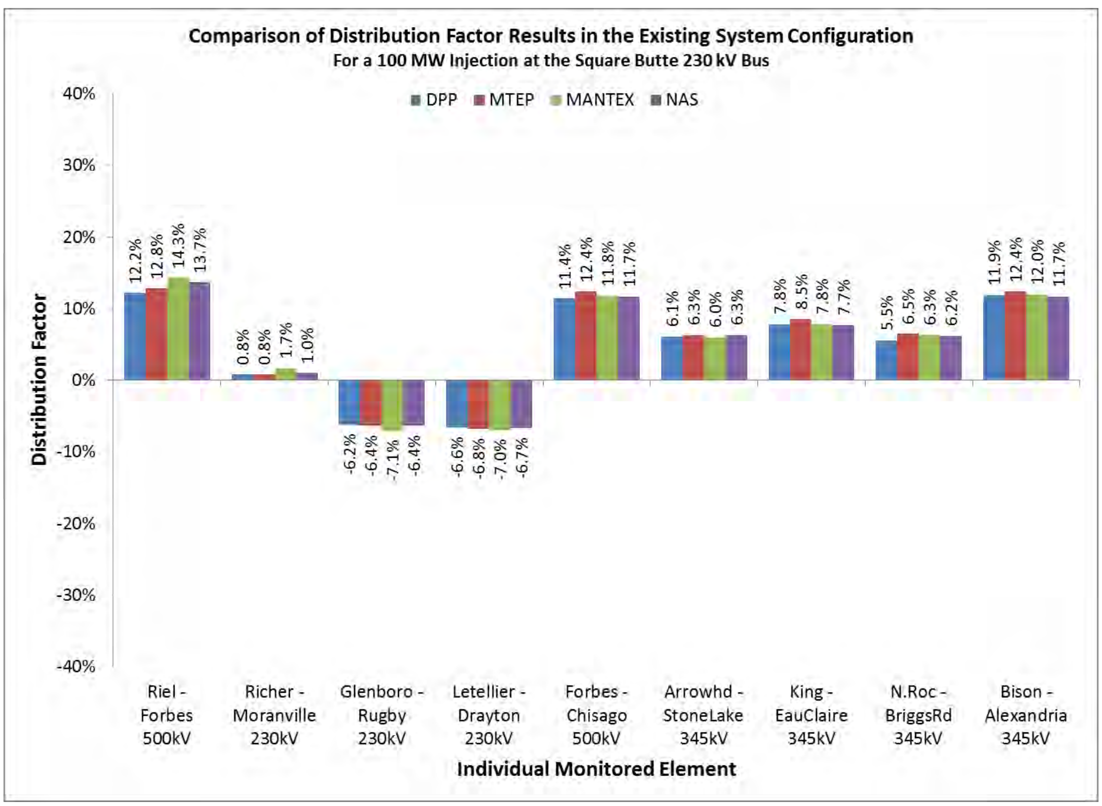


Figure 30: Comparison of Distribution Factor Results for the Square Butte Injection (XS)

Total Loop Flow Impact

The total North Dakota – Manitoba loop flow associated with each transmission configuration can be measured by calculating the sum of the average North Dakota generation distribution factors on all Manitoba – North Dakota tie lines present in the transmission configuration. Manitoba – North Dakota tie lines include the Glenboro – Rugby 230 kV Line (G82R), the Letellier – Drayton 230 kV Line (L20D), and the Dorsey – Barnesville 500 kV Line, if present. Since these lines are normally defined directionally from Manitoba to the United States, incremental generation inside the North Dakota export boundary – which wants to flow in the opposite direction – has a negative distribution factor on the lines. This is demonstrated in Figure 27 – Figure 30 above. Because the objective of this section is to observe and compare the percentage of the total output from a conceptual generator in North Dakota that will flow into Manitoba on these tie lines for each of the transmission configurations, the lines will be defined directionally from North Dakota to Manitoba, resulting in the positive distribution factors discussed throughout this section.

As discussed above, all four benchmark cases produce very similar distribution factor results. Therefore the Total Loop Flow Impact results discussed below are from the MTEP case only. The Total Loop Flow Impact results from the DPP, MANTEX, and NAS cases are provided in Appendix E: Additional Total Loop Flow Impact Results.

The total North Dakota – Manitoba loop flow associated with the various transmission configurations being studied is compared to the Existing System in Figure 31 below, from the MTEP case.

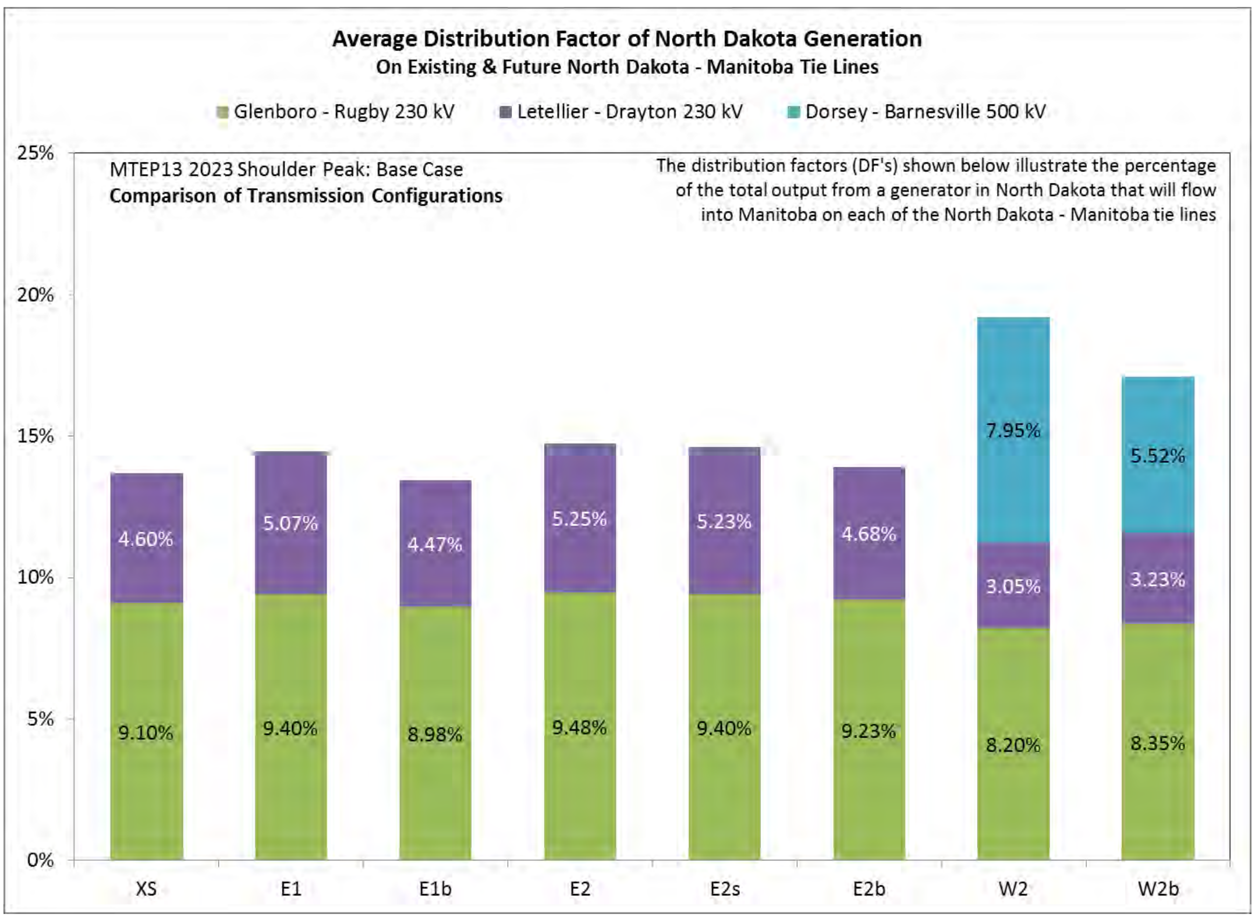


Figure 31: Comparison of Total Loop Flow Impact

In the Existing System (XS) configuration, prior to the addition of any new Manitoba – United States tie lines, the average North Dakota generation distribution factor on the two existing 230 kV North Dakota – Manitoba tie lines is 13.7 percent. This means that approximately 13.7 MW out of every 100 MW of incremental North Dakota generation can be expected to flow into Manitoba on the existing North Dakota – Manitoba tie lines (G82R & L20D), creating North Dakota – Manitoba loop flow. Most of the new transmission configurations cause an increase in the total North Dakota – Manitoba loop flow relative to the Existing System level.

In general, the Eastern Plan and associated transmission configurations cause a slight increase in the total North Dakota – Manitoba loop flow. This is due to the addition of the Dorsey – Iron Range 500 kV Line, which lowers the overall impedance of the loop flow "exit path" from Manitoba into Minnesota. The increase in total North Dakota – Manitoba loop flow is limited, however, by the higher impedance of the loop flow "entry path" from North Dakota into Manitoba on the two 230 kV tie lines. Configuration E1, the basic Eastern Plan configuration, increases total North Dakota – Manitoba loop flow by 0.77 percent over the Existing System, to 14.48 percent total. Configuration E2, the combination of the Eastern Plan and the double circuit Iron Range – Arrowhead 345 kV Line, causes the most significant North Dakota – Manitoba loop flow increase of all Eastern Plan configurations, resulting in 1.03 percent more North Dakota – Manitoba loop flow than the Existing System case. The addition of the second circuit on the Bison – Monticello 345 kV Line has a positive impact for the Eastern Plan, actually reducing total North Dakota – Manitoba loop flow in configuration E1b by 0.25 percent compared to the Existing System, down to 13.45 percent total.

The Western Plan and associated transmission configurations cause a more significant increase in the total North Dakota – Manitoba loop flow than the Eastern Plan. This is due to the fact that the Western Plan's Dorsey – Barnesville 500 kV Line actually lowers the overall impedance of the North Dakota – Manitoba loop flow "entry path," connecting the North Dakota transmission system (and the generation that is interconnected to it) more tightly to the Manitoba transmission system. As seen in Figure 31, approximately 5.52 – 7.95 MW out of every 100 MW of incremental North Dakota generation can be expected to flow into Manitoba on the new Dorsey – Barnesville 500 kV Line. When the average North Dakota generation distribution factors on the two existing North Dakota – Manitoba tie lines are added to the distribution factor on the Dorsey – Barnesville 500 kV Line, Configuration W2, the basic Western Plan, increases total North Dakota – Manitoba loop flow by 5.5 percent over the Existing System level, to 19.20 percent total. Similar to the Eastern Plan configurations, the addition of the second circuit on the Barnesville – Monticello 345 kV Line has a positive impact for the Western Plan, reducing total North Dakota – Manitoba loop flow to 17.1 percent, which represents a more modest increase of 3.4 percent compared to the Existing System.

Comparing the Eastern Plan and the Western Plan, it is evident that the Eastern Plan has a more favorable overall impact on total North Dakota – Manitoba loop flow than the Western Plan because it does not provide an additional path for North Dakota generation to flow into Manitoba[6]. Therefore, in a consideration of the total loop flow impact, the Eastern Plan is to be preferred over the Western Plan.

[6] The conceptual impact of the electrical configuration of the two plans on total North Dakota – Manitoba loop flow is discussed in further detail in Appendix L: Conceptual Loop Flow Impact of the Western Plan

Riel – Forbes 500 kV Line Impact

The impact of North Dakota – Manitoba loop flow on the Riel – Forbes 500 kV Line can be determined simply by comparing the average North Dakota generation distribution factor on the Riel – Forbes 500 kV Line (M602F) obtained for each of the transmission configurations. The total North Dakota – Manitoba loop flow described in the previous section enters Manitoba on the North Dakota – Manitoba tie lines and leaves Manitoba on the Manitoba – Minnesota tie lines, including M602F, the Richer – Moranville 230 kV Line (R50M), and the Dorsey – Iron Range 500 kV Line, if present. Since M602F is much larger and lower impedance than R50M, North Dakota – Manitoba loop flow affects M602F almost exclusively prior to the addition of the Dorsey – Iron Range 500 kV Line.

As discussed above, all four benchmark cases produce very similar distribution factor results. Therefore the Riel – Forbes 500 kV Line Impact results discussed below are from the MTEP case only. Results from the DPP, MANTEX, and NAS cases are provided in Appendix F: Additional Riel – Forbes 500 kV Line Impact Results.

The impact of North Dakota – Manitoba loop flow on the Manitoba – Minnesota tie lines associated with the various transmission configurations being studied is compared to the Existing System in Figure 32 below, from the MTEP case.

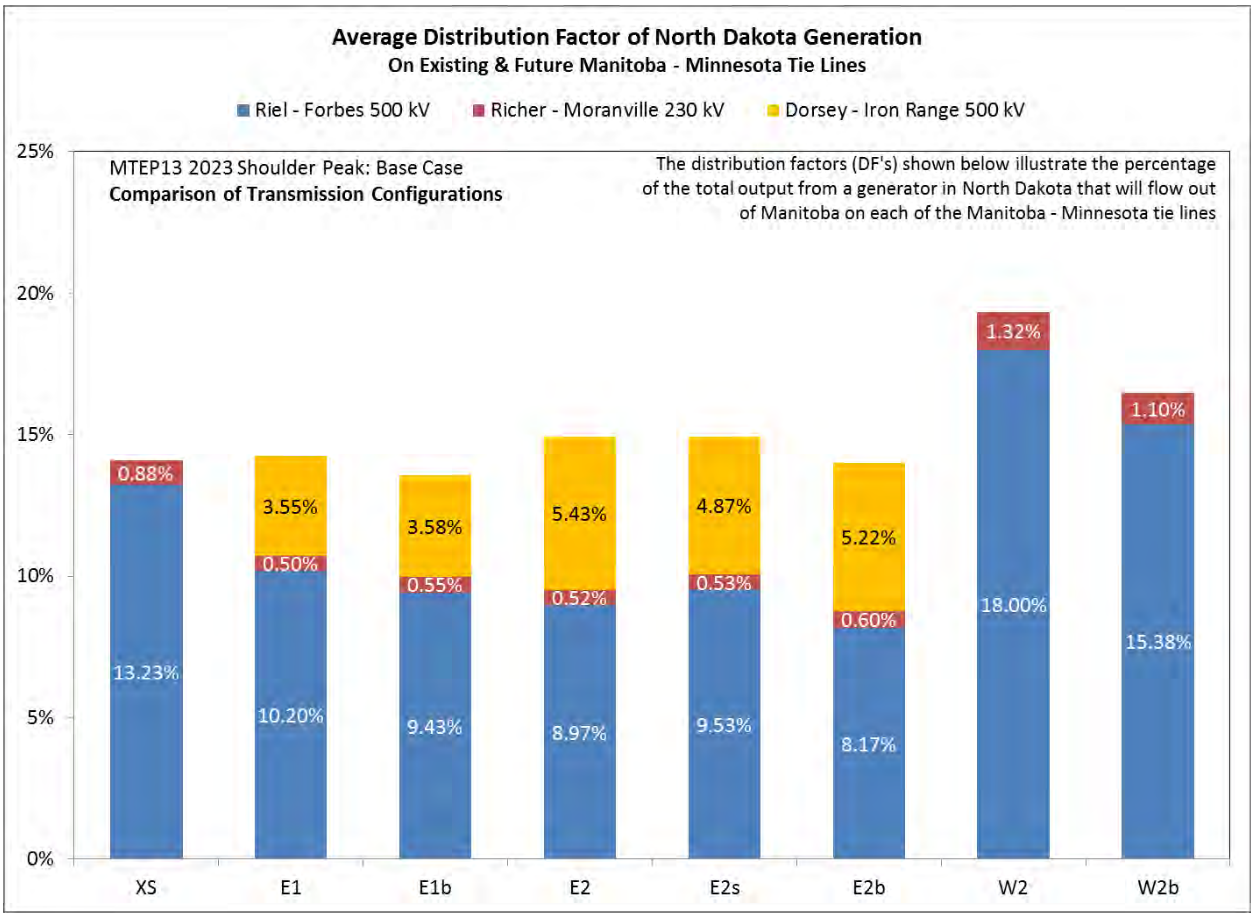


Figure 32: Comparison of Riel - Forbes 500 kV Line Impact

In the Existing System (XS) configuration, prior to the addition of any new Manitoba – United States tie lines, the average North Dakota generation distribution factor on M602F is 13.23 percent. This means that approximately 13.23 MW out of every 100 MW of incremental North Dakota generation will flow through Manitoba and into Minnesota on M602F. As mentioned above and demonstrated in Figure 32, the average North Dakota generation distribution factor on R50M is comparatively small.

The Eastern Plan and the associated transmission configurations notably reduce the impact of North Dakota – Manitoba loop flow on the Manitoba – Minnesota tie lines, and particularly M602F. This is due to the addition of the Dorsey – Iron Range 500 kV Line, which carries some of the North Dakota – Manitoba loop flow that would normally flow on the two existing tie lines. Configuration E1, the basic Eastern Plan configuration, reduces the amount of North Dakota – Manitoba loop flow on M602F by 3.03 percent compared to the Existing System, down to a total of 10.20 percent. Configuration E2, the combination of the Eastern Plan and the double circuit Iron Range – Arrowhead 345 kV Line, decreases the amount of North Dakota – Manitoba loop flow on M602F by 4.25 percent compared to the Existing System, down to a total of 8.97 percent. The addition of the second circuit on the Bison – Monticello 345 kV Line also has a positive impact, decreasing the amount of North Dakota – Manitoba loop flow on M602F to totals of 9.43 percent for configuration E1b and 8.17 percent for configuration E2b (reductions of 3.80 and 5.05 percent, respectively).

The Western Plan and associated transmission configurations have the opposite impact on the amount of North Dakota – Manitoba loop flow present on M602F. As seen in Figure 32, approximately 18 MW out of every 100 MW of incremental North Dakota generation can be expected to flow through Manitoba and into Minnesota on M602F for configuration W2, the basic Western Plan configuration. This is due to an increase of 4.77 percent in the average North Dakota generation distribution factor on M602F compared to the Existing System. Similar to Eastern Plan configurations, the addition of the second circuit on the Barnesville – Monticello 345 kV Line has a positive impact for the Western Plan, reducing the amount of North Dakota – Manitoba loop flow on M602F compared to configuration W2. However, even with the addition of this 345 kV line, the average North Dakota generation distribution factor on M602F for configuration W2b is still 15.38 percent, which is 2.15 percent higher than the Existing System.

Table 7 below shows how the total amount of North Dakota – Manitoba loop flow present on all Manitoba – Minnesota tie lines is distributed among the individual tie lines, by percentage. Prior to addition of the Dorsey – Iron Range 500 kV Line, and in the Western Plan configurations, M602F carries 93 to 94 percent of the total North Dakota – Manitoba loop flow present on the two existing Manitoba – Minnesota tie lines. When incorporated into the system, the Dorsey – Iron Range 500 kV Line carries 25 to 37 percent of the total loop flow present on the three Manitoba – Minnesota tie lines. As a result, the share of loop flow on M602F is reduced to 58 to 72 percent of the total. Therefore, if the total loop flow present on the Manitoba – Minnesota tie lines is 100 MW, M602F can be expected to carry 93 to 94 of the 100 MW in the Existing System and Western Plan configurations, but only 58 to 72 of the 100 MW in the Eastern Plan configurations.

Manitoba – Minnesota Tie Line	XS	E1	E1b	E2	E2s	E2b	W2	W2b
Riel – Forbes 500 kV Line	94%	72%	70%	60%	64%	58%	93%	93%
Richer – Moranville 230 kV Line	6%	4%	4%	4%	4%	4%	7%	7%
Dorsey – Iron Range 500 kV Line	n/a	25%	26%	36%	33%	37%	n/a	n/a

Table 7: Comparison of Loop Flow Distribution on Manitoba – Minnesota Tie Lines

Comparing the Eastern Plan and the Western Plan, it is evident that the Eastern Plan improves the performance of the Riel – Forbes 500 kV Line (M602F) because the Eastern Plan Dorsey – Iron Range 500 kV Line actually carries some of the North Dakota – Manitoba loop flow that would normally flow on M602F and R50M, reducing the overall impact of North Dakota – Manitoba loop flow on M602F. In contrast, the Western Plan actually causes more North Dakota – Manitoba loop flow on M602F, arguably degrading the performance of the line. This is because the Western Plan Dorsey – Barnesville 500 kV Line actually increases the total amount of North Dakota – Manitoba loop flow notably by providing an additional loop flow "entry path" (as discussed in the previous section) without providing an additional transmission line "exit path" adjacent to the existing Manitoba – Minnesota tie lines[7]. The consequence is that nearly all of the resulting additional North Dakota – Manitoba loop flow associated with the Western Plan must flow on M602F. The end result of the Western Plan, therefore, is a significant increase in the impact of North Dakota – Manitoba loop flow on M602F. Therefore, in a consideration of the impact of North Dakota – Manitoba loop flow on the Riel – Forbes 500 kV Line, the Eastern Plan is to be preferred over the Western Plan.

Simultaneous North Dakota & Manitoba Outlet Capability

The level of North Dakota outlet capability that can be achieved at the expected level of Manitoba export before overloading the Roseau series capacitors on the Riel – Forbes 500 kV Line ("simultaneous North Dakota and Manitoba outlet capability") is a practical application of the metrics described in the previous two sections. This is because the simultaneous North Dakota and Manitoba outlet capability is a direct result of the total North Dakota – Manitoba loop flow and the specific impact of loop flow on the loading of the Riel – Forbes 500 kV Line (M602F). Using this metric provides a good indication of the relative impact of the various transmission configurations being studied on regional generation outlet capability and overall system efficiency.

The thermal limit of M602F was selected as the basis for determining simultaneous North Dakota and Manitoba outlet capability for this study because it is the primary common path for Manitoba Hydro exports and North Dakota – Manitoba loop flow. Since M602F is the largest, lowest-impedance tie line between Manitoba and the United States, incremental transfers from Manitoba have a much more significant impact on M602F than they do on the other three tie lines. This is demonstrated by the distribution factor results provided in the "Comparison of Benchmark Case Results" section above. Figure 26 shows that the Dorsey injection distribution factor on M602F is approximately 70 percent, compared to only 5 to 15 percent distribution factors on the other three tie lines. The same is true for North Dakota – Manitoba loop flow, as demonstrated in Table 7 in the "Riel – Forbes 500 kV Line Impact" section above, in which it is shown that at least 93 percent of the total North Dakota – Manitoba loop flow ends up on M602F as it flows from Manitoba back into the United States. Historical studies for both the Manitoba Hydro Export (MHEX) and North Dakota Export (NDEX) interfaces have also demonstrated that M602F is the primary thermal constraint associated with North Dakota – Manitoba loop flow. A more recent example of such a study is the CapX2020 study report "Impact of CapX Facilities on North Dakota Export for the Year 2016" (see "Background").

Simultaneous North Dakota and Manitoba outlet capability was determined using the nomogram calculation methodology described in the "Study Methodology" section above, which produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F. In some cases other constraints besides M602F may exist that would limit simultaneous North Dakota and Manitoba outlet capability to something less than what is anticipated by the nomogram. Based on historical transmission planning practice for the MHEX and NDEX interfaces, however, it can be assumed that there should not be any thermal constraints on North Dakota outlet capability when NDEX is in the range of 1900 to 2200 MW simultaneous with an MHEX level of 1850 to 2175 MW. The approximate North Dakota outlet capability was calculated based on the historical NDEX definition plus planned or recently built transmission lines

[7] The conceptual impact of the electrical configuration of the two plans on total North Dakota – Manitoba loop flow is discussed in further detail in Appendix L: Conceptual Loop Flow Impact of the Western Plan

that cross the historical NDEX boundary. Manitoba outlet capability was calculated based on the historical MHEX definition plus the additional 500 kV tie line (either Dorsey – Iron Range or Dorsey – Barnesville). A list of the transmission lines included in the calculation of North Dakota outlet capability/NDEX and Manitoba outlet capability/MHEX for this study is given in the "Study Methodology" section above.

As discussed above, all four benchmark cases produce very similar distribution factor results. Consequentially, the nomogram plots associated with each of the four benchmark cases, which are based on the distribution factor results, are also generally similar. Therefore the Simultaneous North Dakota and Manitoba Outlet Capability results discussed below are from the MTEP case only. Results from the DPP, MANTEX, and NAS cases are provided in Appendix G: Additional Simultaneous Outlet Capability Results.

Figure 33 below provides an overview of the anticipated simultaneous North Dakota and Manitoba outlet capability associated with each of the transmission configurations, as compared to the Existing System and current North Dakota and Manitoba export limits[8].

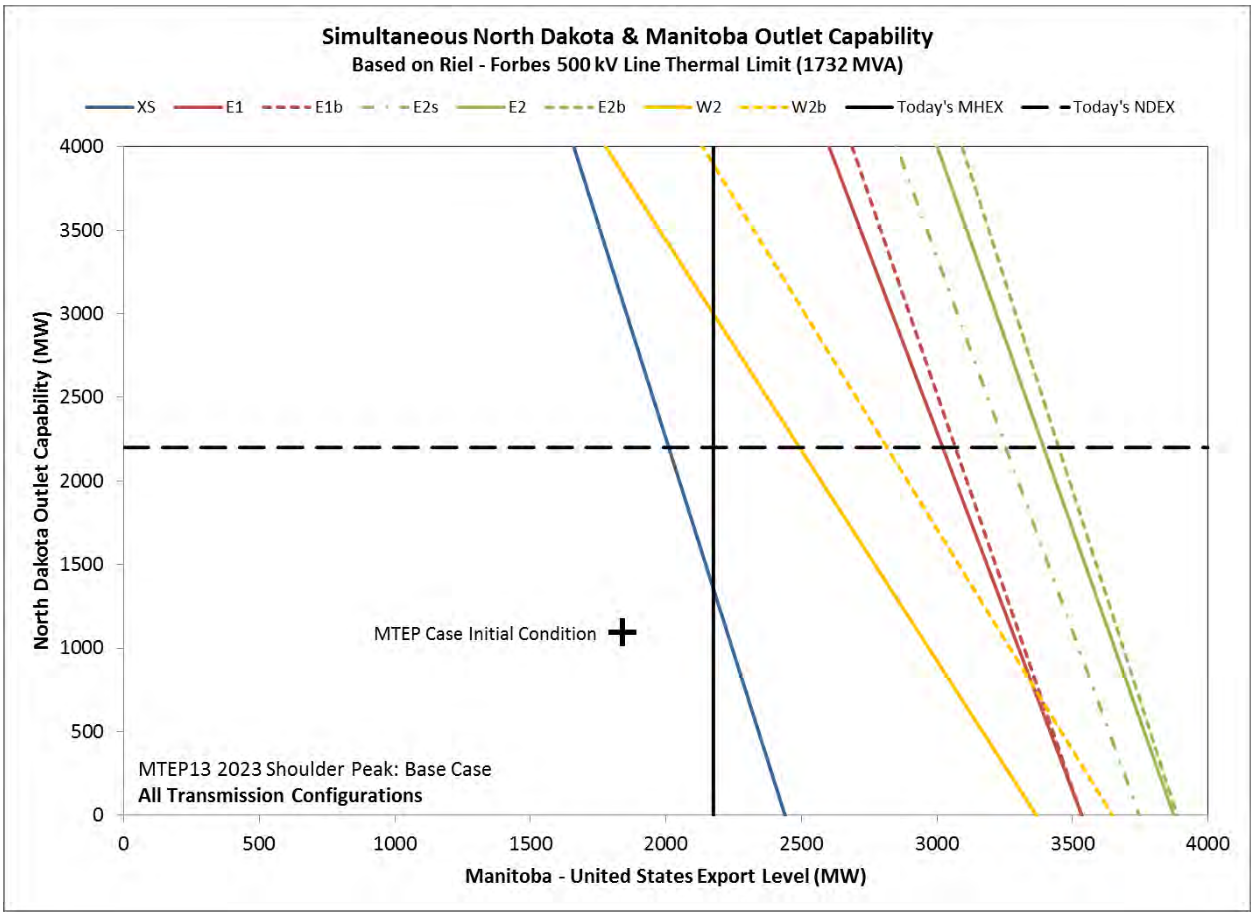


Figure 33: Simultaneous North Dakota & Manitoba Outlet Capability - All Configurations

As shown on the chart, the initial condition of the MTEP case is moderately stressed, with MHEX at approximately 1850 MW and NDEX at approximately 1100 MW. This is well within the capability of the

[8] Current North Dakota outlet capability was assumed to be 2200 MW based on the NDEX stability limit identified in "Impact of CapX Facilities on North Dakota Export for the Year 2016 Report"

Existing System (XS) configuration. The Existing System configuration is actually more limiting than the current simultaneous North Dakota and Manitoba export limit; however, this may potentially be explained by the fact that the 2175 MHEX limit includes a reliability margin over the actual 1850 MW firm transfer level recognized by MISO. At the 1850 MW firm transfer level, North Dakota outlet capability meets and exceeds the current expected level. Determination of the exact cause of the Existing System configuration limitation is outside the scope of this study. The models are sufficient to accomplish the purpose of the study, which is to compare the relative performance of several different transmission configurations.

Comparing the results for the various transmission configurations, four general observations can be made from Figure 33:

1. Both the Eastern and Western plans provide increased simultaneous North Dakota and Manitoba outlet capability compared to the Existing System
2. The Eastern Plan configurations generally provide more potential simultaneous North Dakota and Manitoba outlet capability than the Western Plan configurations
3. The addition of a double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) is a more effective solution than a single circuit Iron Range – Arrowhead 345 kV Line (configuration E2s) for further increasing the potential simultaneous North Dakota and Manitoba outlet capability available from the Eastern Plan (configuration E1)
4. The addition of a second circuit on the Fargo – Monticello 345 kV Line (configuration W2b, E1b, or E2b) also further increases potential simultaneous North Dakota and Manitoba outlet capability, though the impact is more pronounced for the Western Plan

The first two observations, which provide very useful insight into the general loop flow impact of the Eastern Plan and the Western Plan, will be discussed in further detail below. The last two observations, which provide more secondary insight into the loop flow impact of the Iron Range – Arrowhead and Fargo – Monticello 345 kV lines, are discussed further in Appendix H: Additional Nomogram Observations.

East and West versus Existing System

Both the Eastern Plan and the Western Plan provide increased simultaneous North Dakota and Manitoba outlet capability compared to the Existing System.

Figure 34 below shows the potential additional capability afforded by the basic Eastern Plan (configuration E1) compared to the Existing System (configuration XS). Configuration E1 results in a relationship between North Dakota outlet capability and Manitoba outlet capability that is very similar to the existing system, as shown by the almost perfectly parallel slopes of the two nomogram lines in Figure 34. The result is that both North Dakota outlet capability and Manitoba outlet capability are increased proportionally by configuration E1 relative to the Existing System. Therefore, it can be said that the Eastern Plan provides increased Manitoba to United States transfer capability without inherently limiting potential outlet capability from North Dakota relative to the Existing System.

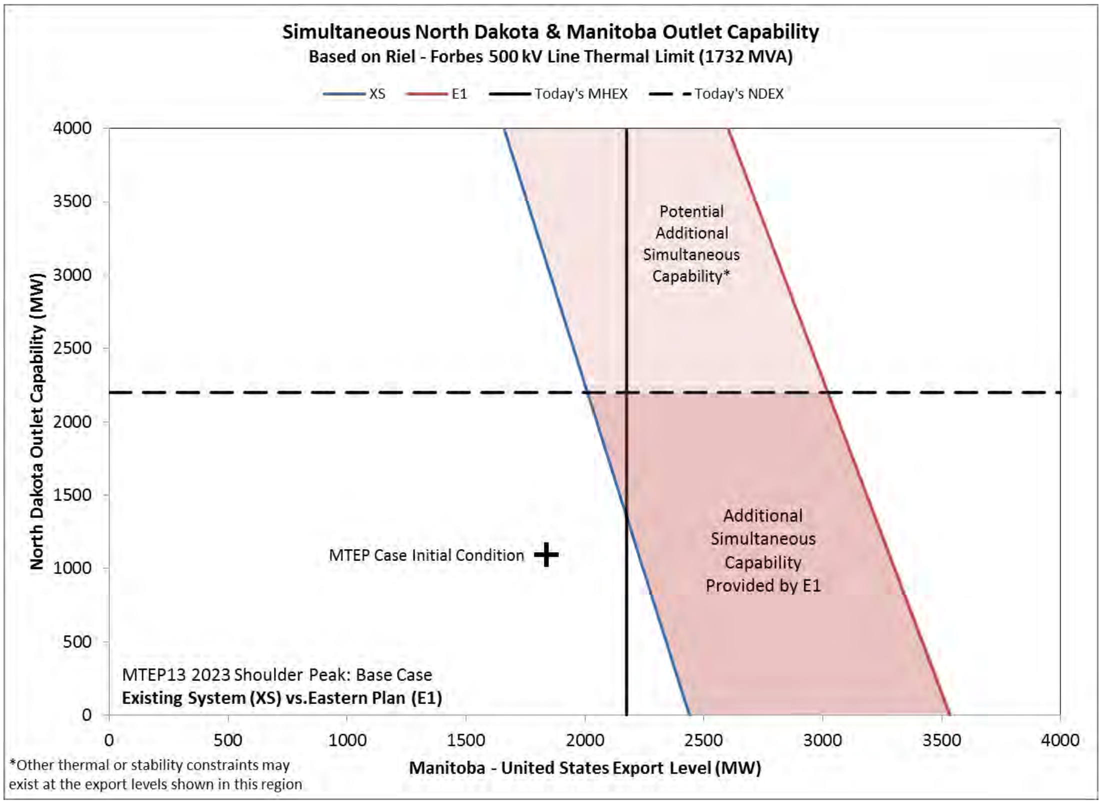


Figure 34: Simultaneous North Dakota & Manitoba Outlet Capability – XS vs. E1

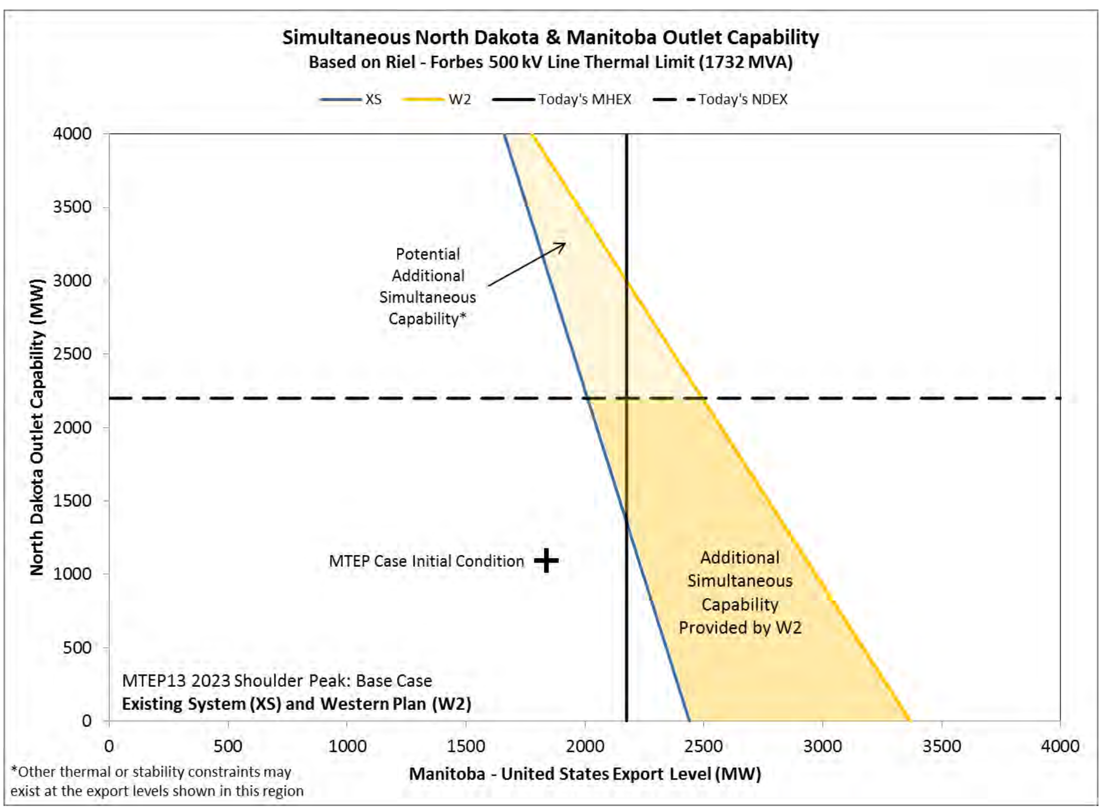


Figure 35: Simultaneous North Dakota & Manitoba Outlet Capability – XS vs. W2

Figure 35 above shows the potential additional capability afforded by the basic Western Plan (configuration W2) compared to the Existing System (configuration XS). With configuration W2, the slope of the nomogram line becomes more gradual than the slope of the line associated with the Existing System, causing the two lines to approach each other as North Dakota outlet capability increases. This demonstrates that North Dakota outlet capability and Manitoba outlet capability increase disproportionately due to the loop flow impact of the Western Plan. As a result, the greater the desired incremental Manitoba outlet capability is, the more limited the associated North Dakota outlet capability becomes due to overloads on the Riel – Forbes 500 kV Line. In other words, the higher the desired North Dakota outlet capability is, the less the incremental Manitoba outlet capability is that can be achieved with configuration W2 before M602F is overloaded. Conversely, at lower levels of North Dakota outlet capability, configuration W2 is capable of facilitating more substantial increases in Manitoba outlet capability compared to the Existing System. Therefore, it can be said that the Western Plan provides increased Manitoba to United States transfer capability, but it does so while inherently limiting the potential simultaneous outlet capability from North Dakota.

East versus West

The Eastern Plan configurations generally provide more potential simultaneous North Dakota and Manitoba outlet capability than the Western Plan configurations.

The Eastern Plan has been designed and is being permitted to facilitate a near-term need for at least 750 MW of incremental transfer capability from Manitoba to the United States (MHEX = 2925 MW). In the longer term, there is a potential need for a total of 1100 MW of incremental transfer capability from Manitoba to the United States (MHEX = 3275 MW). The Eastern Plan has been designed such that it could be staged with a double circuit Iron Range – Arrowhead 345 kV Line to achieve the full 1100 MW of potential incremental Manitoba to United States transfer capability, if the need arises. The Western Plan has been described conceptually as a single 500 kV build that can facilitate 1100 MW of incremental Manitoba to United States transfers. If desired, it has been asserted that additional transfer capability could be achieved with the Western Plan by installing a second circuit on the Barnesville – Alexandria – Quarry – Monticello 345 kV Line. While the Western Plan thus described does not have an associated configuration that is directly comparable the Eastern Plan for facilitating 750 MW of incremental transfers from Manitoba, the basic Western Plan (configuration W2) will be compared with the corresponding Eastern Plan configuration at both the 750 MW (configuration E1) and the 1100 MW (configuration E2) incremental transfer levels.

The capability of the Eastern Plan (configuration E1) and the Western Plan (configuration W2) to facilitate the near-term need for 750 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is compared in Figure 36 below.

Configuration E1 is capable of facilitating at least 2200 MW of North Dakota outlet capability (today's level[9]) simultaneously with 2925 MW of Manitoba Hydro export without overloading M602F. In fact, it appears that configuration E1 could potentially facilitate up to 2613 MW of North Dakota outlet capability at this level of MHEX without overloading M602F, though other stability or thermal constraints besides M602F may exist at this level of simultaneous export. On the other hand, if North Dakota outlet capability is maintained at today's 2200 MW level, configuration E1 could potentially facilitate a total Manitoba Hydro export of over to 3020 MW prior to an overload on M602F. Therefore, the Eastern Plan could facilitate at least 750 MW, and possibly over 840 MW, of incremental Manitoba

[9] Current North Dakota outlet capability was assumed to be 2200 MW based on the NDEX stability limit identified in "Impact of CapX Facilities on North Dakota Export for the Year 2016 Report"

to United States transfer capability before limiting North Dakota outlet capability below today's level based on the M602F constraint.

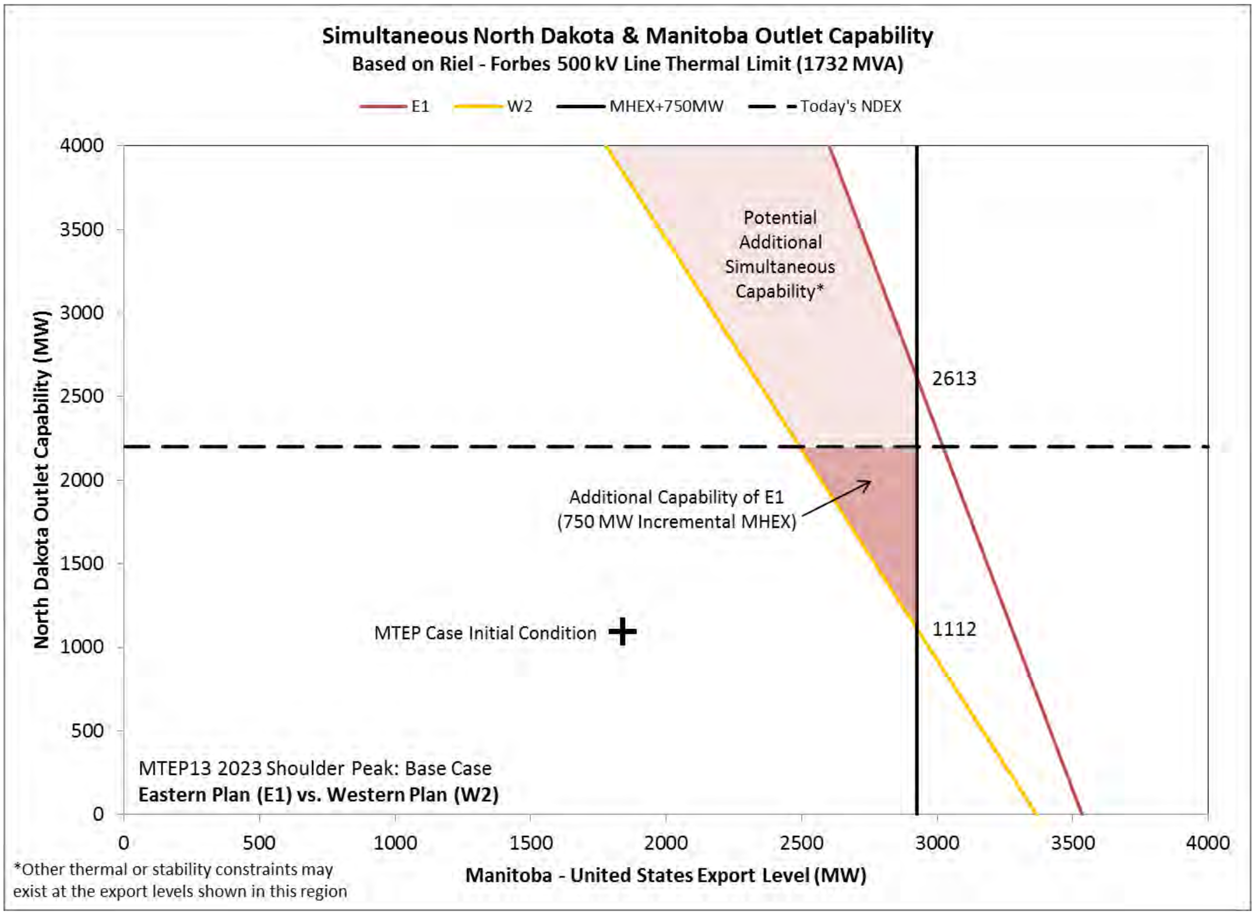


Figure 36: Simultaneous North Dakota & Manitoba Outlet Capability – E1 vs. W2

In contrast, configuration W2 would limit North Dakota outlet capability to no more than 1112 MW simultaneously with 2925 MW of Manitoba Hydro export. This is a reduction of nearly 1090 MW in North Dakota outlet capability compared to today's level. In order for configuration W2 to maintain North Dakota outlet capability at today's 2200 MW level without overloading M602F, Manitoba Hydro export would have to be reduced to approximately 2500 MW. Therefore, the Western Plan could facilitate no more than 325 MW of incremental Manitoba to United States transfer capability before limiting North Dakota outlet capability below today's level based on the M602F constraint.

Comparing the potential simultaneous North Dakota and Manitoba outlet capability afforded by the two transmission configurations at the 750 MW incremental Manitoba to United States transfer level, it is obvious that the Eastern Plan provides significant additional simultaneous outlet capability compared to the Western Plan. While the Eastern Plan would at least maintain (and possibly increase) simultaneous transfer capability out of North Dakota after adding an incremental 750 MW of Manitoba to United States transfers, the Western Plan would actually put considerable limitations on North Dakota outlet capability because of the impact of North Dakota – Manitoba loop flow in overloading the Riel – Forbes 500 kV Line. Therefore, in a consideration of simultaneous North Dakota and Manitoba outlet capability at the 750 MW incremental Manitoba to United States transfer level, the Eastern Plan is to be preferred over the Western Plan.

The capability of the combined Eastern Plan and double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) and the Western Plan (configuration W2) to facilitate the longer-term need for 1100 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is shown in Figure 37 below.

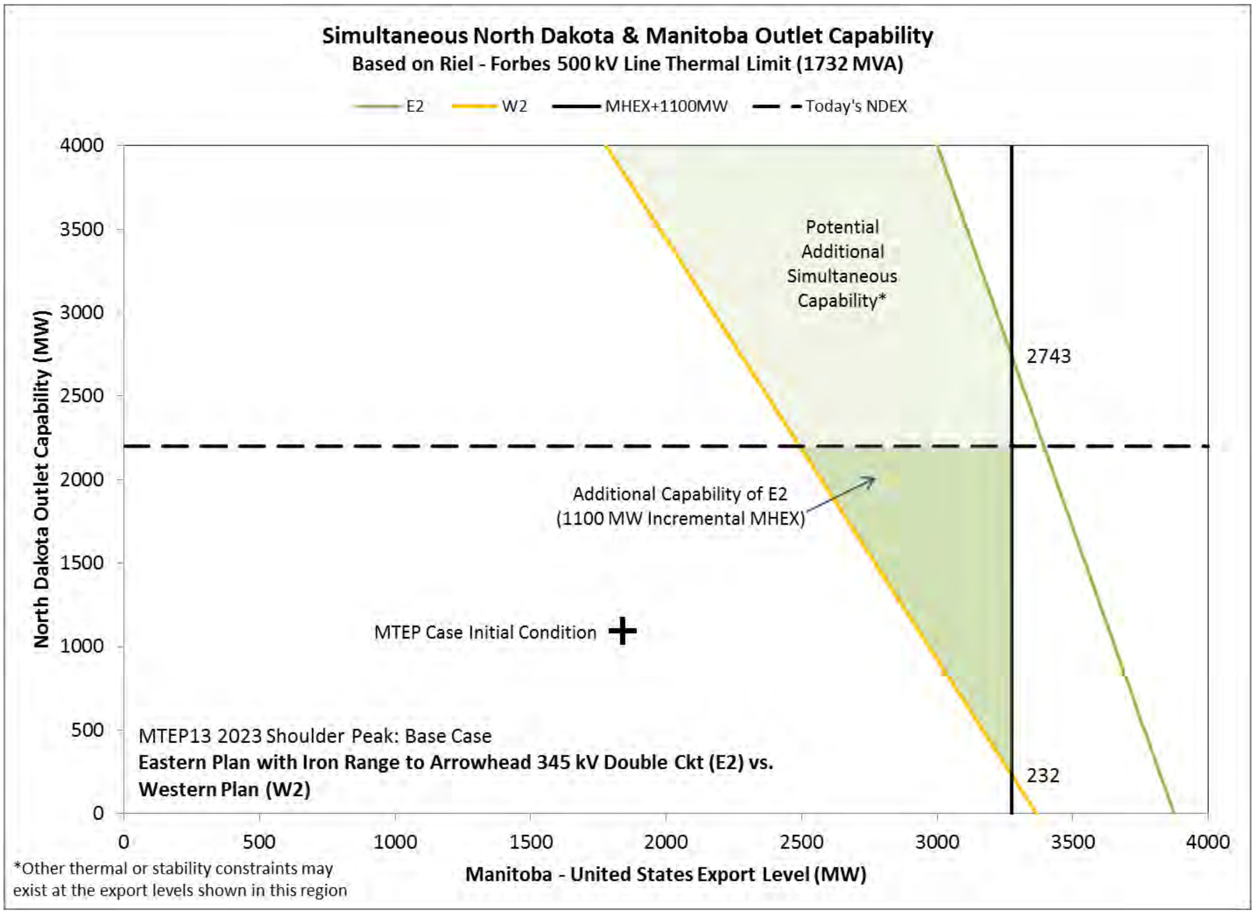


Figure 37: Simultaneous North Dakota & Manitoba Outlet Capability – E2 vs. W2

The results for configuration E2 at the 1100 MW incremental transfer level are very similar to the results for configuration E1 at the 750 MW incremental transfer level. Configuration E2 is capable of facilitating at least 2200 MW of North Dakota outlet capability (today's level) simultaneously with 3275 MW of Manitoba Hydro export without overloading M602F. In fact, it appears that configuration E2 could potentially facilitate up to 2743 MW of North Dakota outlet capability at this level of MHEX without overloading M602F, though other stability or thermal constraints besides M602F may exist at this level of simultaneous export. On the other hand, if North Dakota outlet capability is maintained at today's 2200 MW level, configuration E2 could potentially facilitate a total Manitoba Hydro export of nearly 3400 MW prior to an overload on M602F. Therefore, the combination of the Eastern Plan and the double circuit Iron Range – Arrowhead 345 kV Line could facilitate at least 1100 MW, and possibly up to 1225 MW, of incremental Manitoba to United States transfer capability before limiting North Dakota outlet capability below today's level based on the M602F constraint.

In contrast, configuration W2 would limit North Dakota outlet capability to no more than 232 MW simultaneously with 3275 MW of Manitoba Hydro export. This is a reduction of 1968 MW in North

Dakota outlet capability compared to today's level. As stated above, in order for configuration W2 to maintain North Dakota outlet capability at today's 2200 MW level without overloading M602F, Manitoba Hydro export would have to be reduced to approximately 2500 MW. Therefore, the Western Plan could facilitate no more than 325 MW of incremental Manitoba to United States transfer capability before limiting North Dakota outlet capability below today's level based on the M602F constraint.

In view of the North Dakota outlet capability limitations caused by the basic Western Plan, a more appropriate comparison case is probably the Western Plan with the second circuit on the Barnesville – Monticello 345 kV Line. Therefore, the capability of the Eastern Plan with the double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) and the Western Plan with the second circuit on the Barnesville – Monticello 345 kV Line (configuration W2b) to facilitate the longer-term need for 1100 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is shown in Figure 38 below.

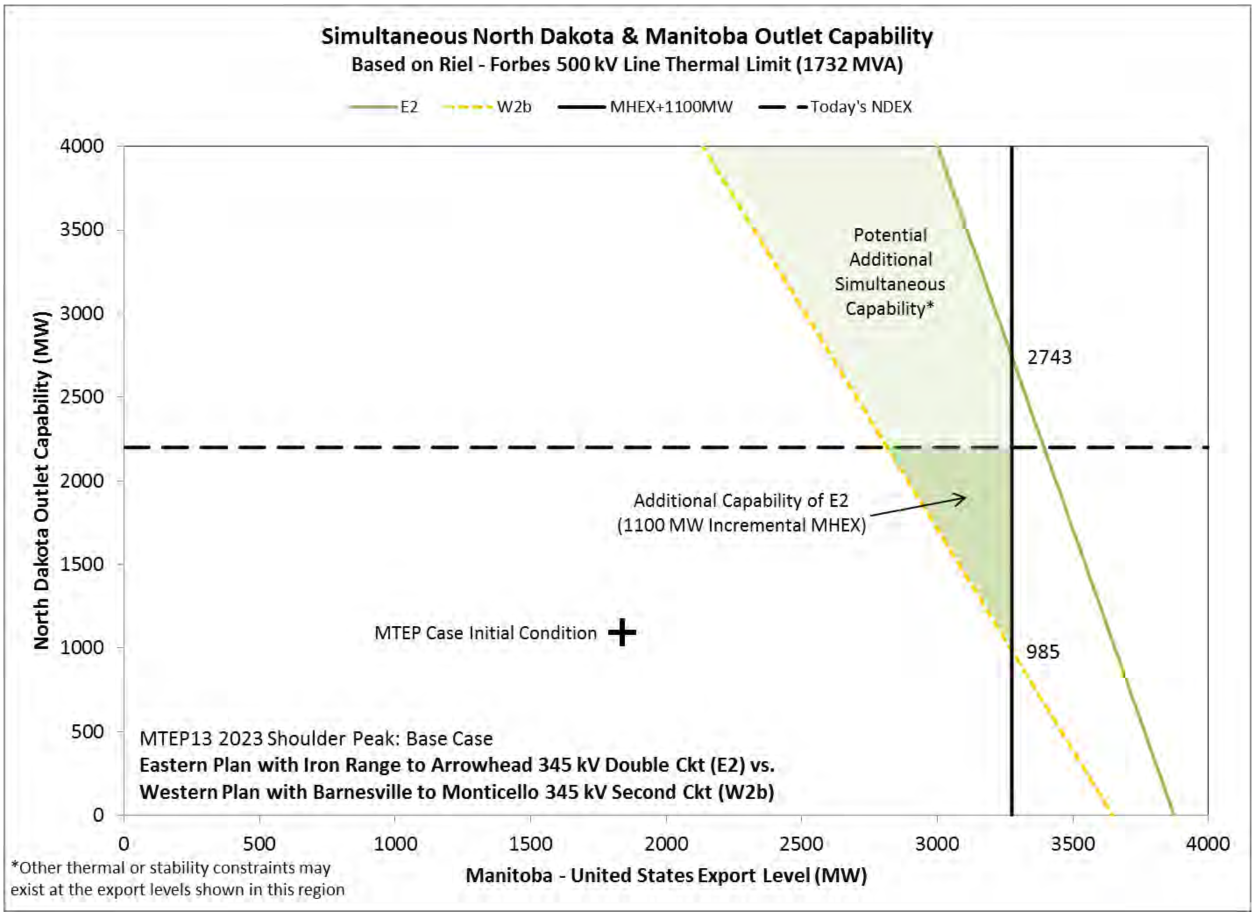


Figure 38: Simultaneous North Dakota & Manitoba Outlet Capability – E2 vs. W2b

Configuration W2b would limit North Dakota outlet capability to no more than 985 MW simultaneously with 3275 MW of Manitoba Hydro export. This is a reduction of 1215 MW in North Dakota outlet capability compared to today's level. In order for configuration W2b to maintain North Dakota outlet capability at today's 2200 MW level without overloading M602F, Manitoba Hydro export would have to be reduced to approximately 2815 MW. Therefore, even combined with the second circuit on the Barnesville – Alexandria – Quarry – Monticello 345 kV Line, the Western Plan could facilitate no more than 640 MW of incremental Manitoba to United States transfers before limiting North Dakota outlet capability below today's level based on the M602F constraint.

Comparing the simultaneous North Dakota and Manitoba outlet capability afforded by the two transmission configurations at the 1100 MW incremental Manitoba to United States transfer level, it is obvious that the Eastern Plan, combined with the Iron Range – Arrowhead 345 kV Line, provides significant additional simultaneous outlet capability compared to the Western Plan, even if the Western Plan is combined with the second circuit on the Barnesville – Monticello 345 kV Line. The Eastern Plan, combined with the Iron Range – Arrowhead 345 kV Line, would at least maintain (and possibly increase) simultaneous transfer capability out of North Dakota after adding an incremental 1100 MW of Manitoba to United States transfers. In contrast, the Western Plan, combined with the second circuit on the Barnesville – Monticello 345 kV Line, would actually put considerable limitations on North Dakota outlet capability because of the impact of North Dakota – Manitoba loop flow in overloading the Riel – Forbes 500 kV Line. Therefore, in a consideration of simultaneous North Dakota and Manitoba outlet capability at the 1100 MW incremental Manitoba to United States transfer level, the corresponding Eastern Plan configuration is to be preferred over both of the Western Plan configurations.

Section 6: Sensitivity Results

Several sensitivities were applied to the various benchmark models used for the Loop Flow Impact Study. These sensitivities are meant to capture the impact that various conceptual or planned changes to the transmission system in the upper Midwest have on the results of the Loop Flow Impact Study for the transmission configurations being studied. The results from the various sensitivities are discussed in detail in the sections below.

Roseau Series Capacitor Upgrade

The series capacitors located at the Roseau County Station limit the maximum continuous rating of the Riel – Forbes 500 kV Line (M602F) to 2000 Amps (1732 MVA). The basic premise of the Loop Flow Impact Study is that the limit associated with the Roseau series capacitor banks as a component of M602F constrains simultaneous North Dakota and Manitoba outlet capability. While it is technically feasible to increase the rating of M602F from 2000 Amps to 2500 Amps (2165 MVA) by upgrading the Roseau series capacitor banks, this upgrade would be highly complex and raise a number of potential issues relating to the operation of the line and terminal equipment as well as the reliability of the regional transmission system. The specific concerns are discussed in more detail in Appendix M: Concerns with the Roseau Series Capacitor Upgrade.

The Roseau Series Capacitor Upgrade sensitivity was applied to all four benchmark cases and all transmission configurations except E1b, E2s, and E2b. It consisted of increasing the thermal limit of the Riel – Forbes 500 kV line from 1732 MVA to 2165 MVA. Since distribution factors are related to impedance and unaffected by transmission line ratings, the only area of interest of this sensitivity is in the impact it has on the simultaneous North Dakota and Manitoba outlet capability associated with the various transmission configurations. As in the base case, simultaneous North Dakota and Manitoba outlet capability was determined using the nomogram calculation methodology described in the "Study Methodology" section above, which produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F. The only difference from the base case to the sensitivity is that M602F was allowed to load up to 2165 MW before it was considered to be overloaded.

As discussed previously, all four benchmark cases produce very similar distribution factor results. Therefore the Roseau Series Capacitor Upgrade sensitivity results discussed below are from the MTEP case only. Results from the DPP, MANTEX, and NAS cases are provided in Appendix I: Additional Series Capacitor Upgrade Sensitivity Results.

Figure 39 below provides an overview of the anticipated simultaneous North Dakota and Manitoba outlet capability associated with each of the transmission configurations after upgrade of the Roseau series capacitors, as compared to the base case results, current North Dakota outlet capability, and three potential increased Manitoba export levels.

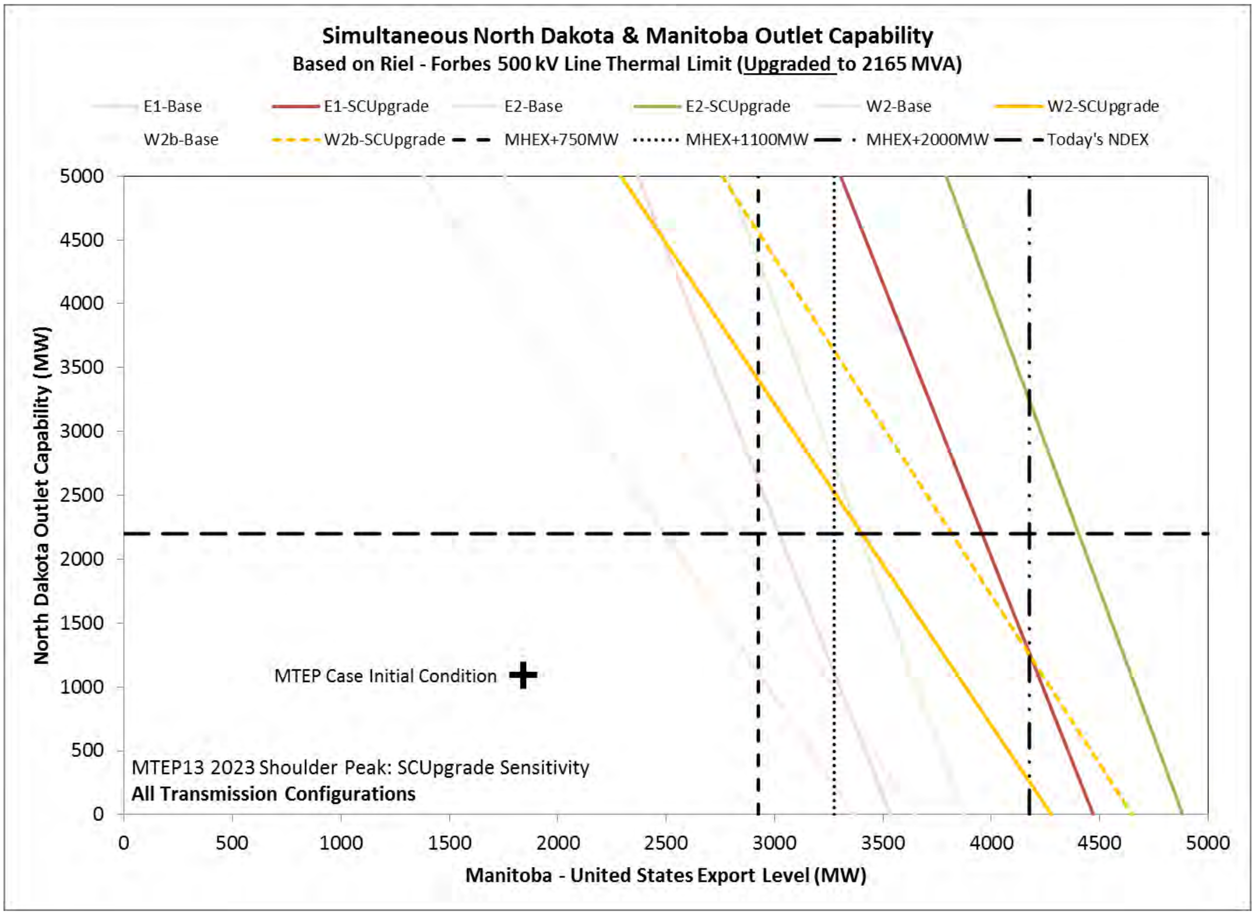


Figure 39: Simultaneous North Dakota & Manitoba Outlet Capability – All Configurations (SCUpgrade Sensitivity)

The sensitivity results are very similar to the base case results but are shifted to the right on the plot, indicating a similar amount of increased simultaneous outlet capability for all transmission configurations. With the Roseau series capacitors upgraded to 2500 Amps, both the Eastern Plan (E1) and Western Plan (W2), and the associated configurations (E2 & W2b) are capable of facilitating incremental Manitoba – United States exports of at least 1100 MW without limiting North Dakota outlet capability below today's level based on the M602F constraint. With the series capacitor upgrade, there is an elevated likelihood that other thermal or stability constraints will become more limiting than the M602F constraint at high simultaneous transfer levels, but identification of those constraints is outside the scope of this study. The results are indicative of the potential value of the series capacitor upgrade for each of the transmission configurations.

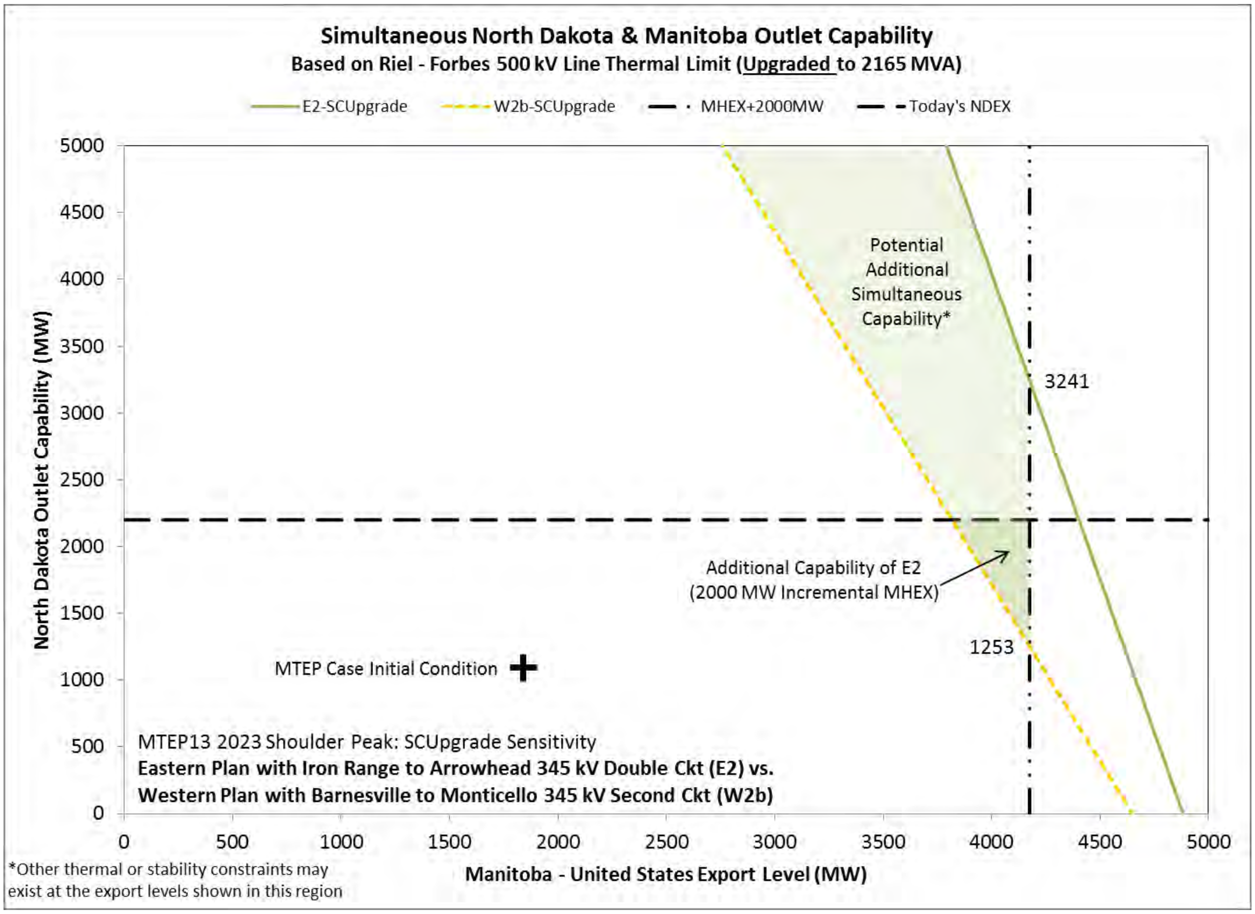


Figure 40: Simultaneous North Dakota & Manitoba Outlet Capability – E2 v. W2b (SCUpgrade Sensitivity)

The capability of the Eastern Plan with the double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) and the Western Plan with the second circuit on the Barnesville – Monticello 345 kV Line (configuration W2b) to facilitate 2000 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is shown in Figure 40 above. An incremental Manitoba to United States transfer capability of 2000 MW (MHEX = 4175 MW) was chosen as a conceptual ultimate transfer capability level to gauge the long-term viability of the two transmission configurations.

The series capacitor upgrade sensitivity results for configuration E2 at the 2000 MW incremental transfer level are similar to the base case results for configuration E2 at the 1100 MW incremental transfer level. If the Roseau series capacitors are upgraded to 2500 Amps, configuration E2 is capable of facilitating at least 2200 MW of North Dakota outlet capability (today's level) simultaneously with 4175 MW of Manitoba Hydro export without overloading M602F. In fact, it appears that configuration E2 could potentially facilitate up to 3241 MW of North Dakota outlet capability at this level of MHEX without causing power flow on M602F to exceed the increased rating associated with the series capacitor upgrade, though other stability or thermal constraints besides M602F may exist at this level of simultaneous export. On the other hand, if North Dakota outlet capability is maintained at today's 2200 MW level, configuration E2 with series capacitors upgraded could potentially facilitate a total Manitoba Hydro export of over 4400 MW prior to an overload on M602F. In the base case results, configuration E2 was found to be capable of facilitating up to 3400 MW of incremental Manitoba to United States transfer capability without limiting North Dakota outlet capability below today's level based on the

M602F (1732 MVA) constraint. Based on the sensitivity results, an upgrade of the Roseau series capacitors could potentially realize an additional 1000 MW of incremental Manitoba to United States transfer capability for configuration E2 without limiting North Dakota outlet capability below today's level based on the M602F (2165 MVA) constraint.

Configuration W2b, with Roseau series capacitors upgraded, would limit North Dakota outlet capability to no more than 1253 MW simultaneously with 4175 MW of Manitoba Hydro export based on the M602F constraint. This is a reduction of 947 MW in North Dakota outlet capability compared to today's level. On the other hand, if North Dakota outlet capability is maintained at today's 2200 MW level, configuration W2b with series capacitors upgraded could potentially facilitate a total Manitoba Hydro export of just over 3815 MW prior to an overload of M602F. In the base case results, W2b was found to be capable of facilitating up to 2815 MW of incremental Manitoba to United States transfer capability without limiting North Dakota outlet capability below today's level based on the M602F (1732 MVA) constraint. Based on the sensitivity results, an upgrade of the Roseau series capacitors could potentially realize an additional 1000 MW of incremental Manitoba to United States transfer capability for configuration W2b without limiting North Dakota outlet capability below today's level based on the M602F (2165 MVA) constraint.

Upgrading the Roseau series capacitors from 2000 Amps to 2500 Amps would provide significant incremental Manitoba, North Dakota, or simultaneous outlet capability for all transmission configurations. In fact, the sensitivity results indicate that the Western Plan (configuration W2), which in the base case limited North Dakota outlet capability to 232 MW simultaneously with 1100 MW of incremental Manitoba to United States transfers, would actually be capable of maintaining today's 2200 MW outlet capability from North Dakota when combined with the Roseau series capacitor upgrade. However, the series capacitor upgrade appears to have similar relative benefits for all transmission configurations. In fact, with North Dakota outlet capability maintained at today's 2200 MW level, the incremental Manitoba Hydro export capability afforded by the Roseau series capacitor upgrade is practically the same – 1000 MW – for the Eastern Plan with double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) and the Western Plan with the second circuit on the Barnesville – Monticello 345 kV Line (configuration W2b). Since the Eastern Plan configurations by themselves facilitate significantly more simultaneous outlet capability than the Western Plan configurations, as demonstrated in the base case results, and the Roseau series capacitor upgrade provides more or less the same incremental outlet capability for both plans, the Roseau Series Capacitor Upgrade sensitivity results confirm that the Eastern Plan configurations are to be preferred over the Western Plan configurations.

Glenboro Phase Shifter

In connection with the development of a new 500 kV tie line from Manitoba to the United States, Manitoba Hydro has proposed to install a new phase shifting transformer (PST) on the Glenboro – Rugby 230 kV Line (G82R). The new PST will be located at the Glenboro Substation in Manitoba, and its main purpose is to limit loop flow on G82R, which is the main path for North Dakota – Manitoba loop flow (as demonstrated by Figure 31 in the "Total Loop Flow Impact" section above). Manitoba Hydro has preliminarily proposed to operate the Glenboro phase shifter so that it limits power flow on G82R to 0 MW under normal system conditions. The phase shifter would then be used during prior outages or certain system conditions to optimize the Manitoba – United States interface by scheduling increased Manitoba to United States or United States to Manitoba power flows on G82R as appropriate.

The Glenboro Phase Shifter sensitivities were applied to the DPP case only, to all transmission configurations except E1b, E2s, and E2b. Five control points were studied:

1. **PST_80deg+:** Maintaining +80 degrees phase shift (maximum south flow)
2. **PST_0MW:** Maintaining power flow on G82R at 0 MW
3. **PST_0deg:** Maintaining 0 degrees phase shift
4. **PST_250i:** Maintaining power flow on G82R at 250 MW north
5. **PST_80deg-:** Maintaining -80 degrees phase shift (maximum north flow)

As in the base case, simultaneous North Dakota and Manitoba outlet capability was determined using the nomogram calculation methodology described in the "Study Methodology" section above, which produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F. A key difference from the base case is that the addition of the Glenboro phase shifter in either of the fixed power flow control modes above (PST_0MW or PST_250i) introduces a nonlinear element into the system. When the phase shifter is in fixed power flow control mode, the transformer taps must adjust as the angle across the phase shifter changes in order to maintain its power flow set point. If the angle across the phase shifter becomes larger than the phase shifter's angle limits (+/- 80 degrees in this case), the phase shifter will no longer be able to maintain its power flow set point. So at larger angles, the power flow set point will no longer be valid and the phase shifter will simply be maintaining the maximum angle. While incorporating this nonlinear functionality into the nomogram calculation methodology is beyond the scope of this study, it can be approximated by developing a nomogram with the phase shifter at maximum angle (PST_80deg+ or PST_80deg-) and identifying where the two nomogram curves cross. Within the range of interest of the Loop Flow Impact Study (MHEX 0 – 4000 MW, NDEX 0 – 4000 MW), phase shifter operation for the PST_250i scenario reached the -80 degree limit for lower levels of North Dakota export in every transmission configuration. The PST_0MW scenario did not enter the nonlinear region. This is clearly depicted in the nomogram plots created for the Glenboro Phase Shifter sensitivities, which are provided in Appendix J: Additional Glenboro Phase Shifter Sensitivity Results.

Another difference from the base case nomogram calculation is that there is an increased level of error in the nomogram calculation for the Glenboro Phase Shifter sensitivities. While the distribution factor of any incremental injection on G82R should theoretically be zero when the phase shifter is maintaining a certain megawatt set point, the simulated results are actually slightly non-zero. Therefore, when the calculated distribution factors are used to anticipate the impact of much larger levels of Manitoba or North Dakota exports, this slight error will be magnified to the point that the megawatt set point for G82R may no longer be respected. For the PST_250i scenario, the largest error observed at the incremental NDEX level where the thermal limit of M602F was exceeded was 13.32 percent in configuration W2b. For the PST_0MW scenario, the largest error observed at the incremental NDEX level where the thermal limit of M602F was exceeded was 75 MW in configuration E2.

The calculated North Dakota outlet capability that can be achieved simultaneously with a Manitoba Hydro export level of 2925 MW (750 MW incremental transfers over today's MHEX level) without overloading M602F is provided for the Eastern Plan (E1), the Western Plan (W2), and the Western Plan with the second circuit on the Barnesville – Monticello 345 kV Line (W2b) in Figure 41 below.

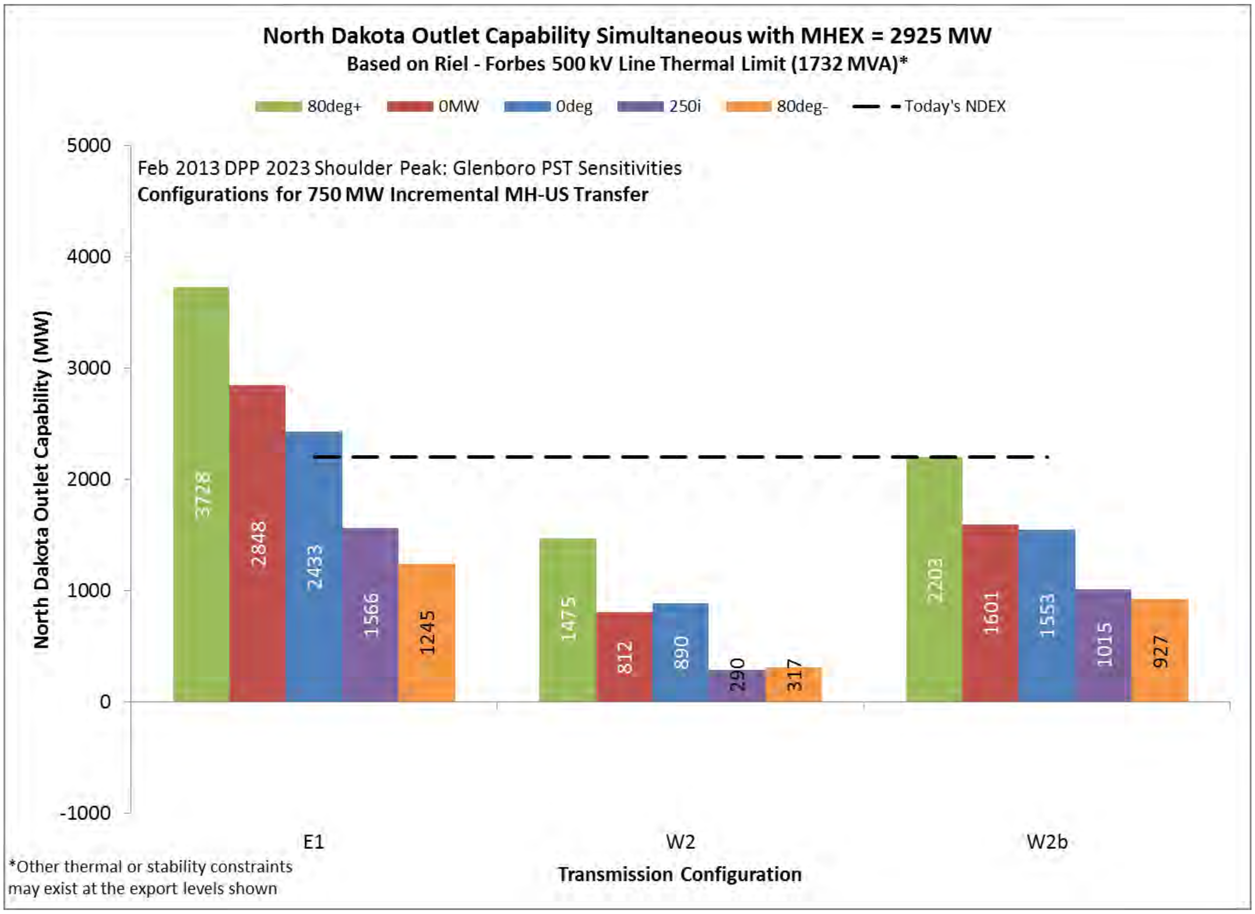


Figure 41: North Dakota Outlet Capability Simultaneous with MHEX = 2925 MW (Glenboro PST Sensitivities)

The PST_0deg scenario is the most similar to the base case, with a little added impedance on G82R due to the addition of the Glenboro phase shifter, which causes slightly less power to flow on the line. In general, the PST_250i and PST_80deg- scenarios limit North Dakota outlet capability by forcing power to flow north on G82R into Manitoba. This forced North Dakota – Manitoba loop flow overloads M602F sooner than it would otherwise be overloaded. This demonstrates that using the Glenboro phase shifter to schedule north flows on G82R is probably only a feasible operating condition when Manitoba Hydro is importing power from the United States rather than exporting. On the other hand, the PST_0MW and PST_80deg+ scenarios both generally increase North Dakota outlet capability by blocking North Dakota – Manitoba loop flow and (in the case of the PST_80deg+ scenario) forcing power to flow south on G82R into North Dakota. At its maximum angle (+80 degrees), the Glenboro phase shifter increases the potential North Dakota outlet capability associated with configuration E1, which already exceeds today's 2200 MW level in the PST_0deg scenario, by nearly 1300 MW in the PST_80deg+ scenario, though other thermal or stability constraints besides M602F likely exist at such a high simultaneous export level. Configurations W2 and W2b benefit slightly less, as the Glenboro phase shifter increases the potential North Dakota outlet capability by 585 MW and 650 MW, respectively, for the two Western Plan configurations.

Of note for the 750 MW incremental transfer configurations is that the Western Plan, with a second circuit on the Barnesville – Monticello 345 kV Line and the Glenboro phase shifter operating at maximum angle to force power south into North Dakota, would just barely be capable of maintaining today's North Dakota outlet capability (2200 MW) simultaneously with 750 MW of incremental Manitoba to United States transfers without overloading M602F. However, the Glenboro phase shifter shows substantially more benefit for the Eastern Plan than it does for either of the Western Plan configurations.

Since Manitoba Hydro is installing the Glenboro phase shifter to optimize the capability of the MHEX interface, another consideration for the Glenboro Phase Shifter sensitivities is the level of Manitoba Hydro export capability available at various levels of North Dakota export. The same formula used to determine the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F can also be modified to calculate the level of Manitoba Hydro export capability that can be achieved at any expected level of North Dakota export before overloading M602F. The calculated Manitoba Hydro export capability that can be achieved simultaneously with a North Dakota export level of 1100 MW (half of today's 2200 MW limit) without overloading M602F is provided for all four transmission configurations in Figure 42 below.

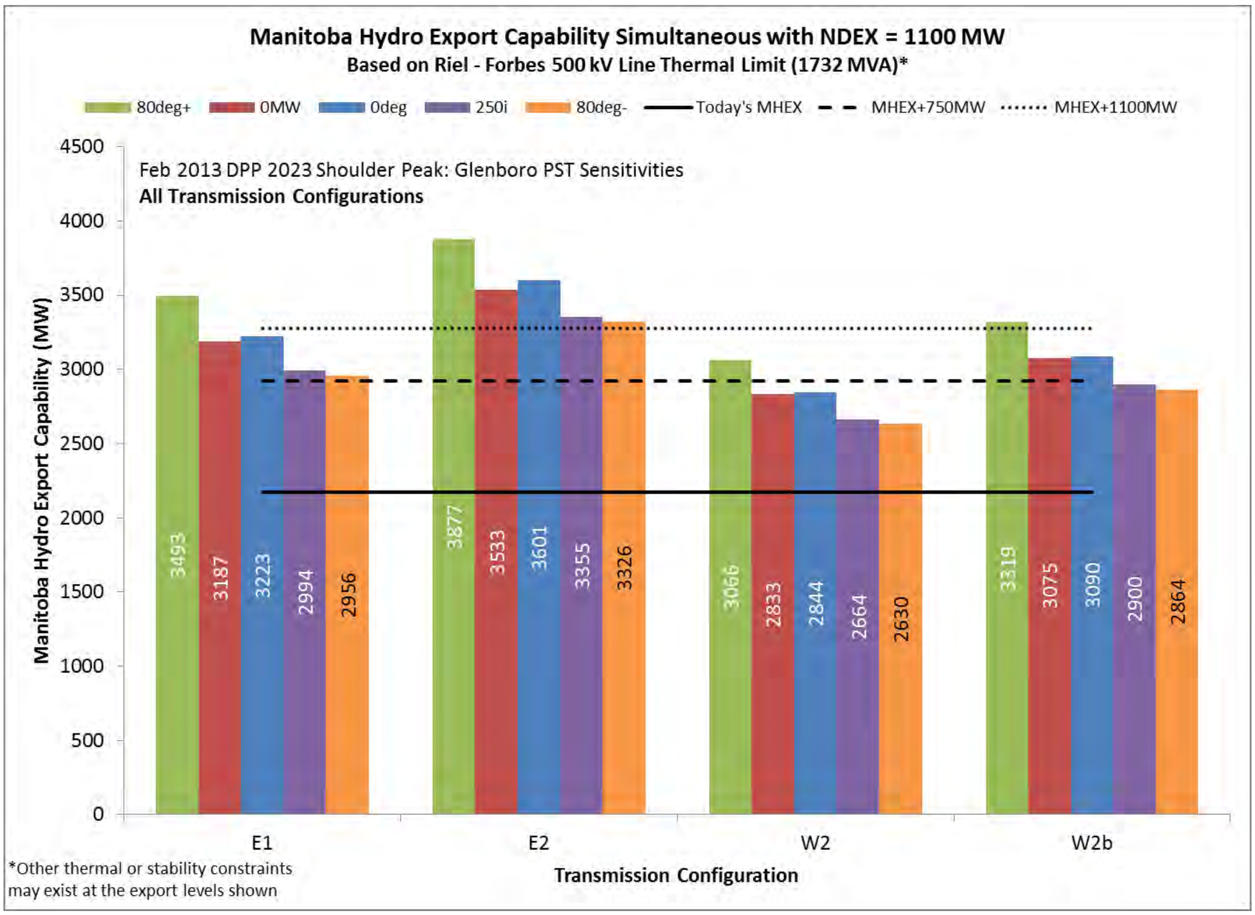


Figure 42: Manitoba Hydro Export Capability Simultaneous with NDEX = 1100 MW (Glenboro PST Sensitivities)

Of interest is how the PST_80deg+ and PST_0MW scenarios compare to the PST_0deg scenario. In general, operating the Glenboro phase shifter with a set point of 0 MW (PST_0MW) will slightly reduce Manitoba Hydro export capability when North Dakota export is 1100 MW. This means that, with NDEX at 1100 MW, the Glenboro phase shifter is limiting power flow on G82R to 0 MW in a condition when power would normally be flowing south on the line. Utilizing the full capability of the Glenboro phase shifter to schedule power flow south on G82R in the PST_80deg+ scenario, Manitoba Hydro export capability is increased by approximately 270 MW for configurations E1 and E2, and by approximately 225 MW for configurations W2 and W2b. With the exception of configuration W2, this additional capability would enable the other three transmission configurations to facilitate in excess of 1100 MW of incremental Manitoba to United States transfers simultaneous with 1100 MW of North Dakota export without overloading M602F. At that level of MHEX, other constraints besides M602F may exist, the identification of which is outside the scope of this study.

The calculated Manitoba Hydro export capability that can be achieved simultaneously with a North Dakota export level of 2200 MW (today's limit) without overloading M602F is provided for all four transmission configurations in Figure 43 below.

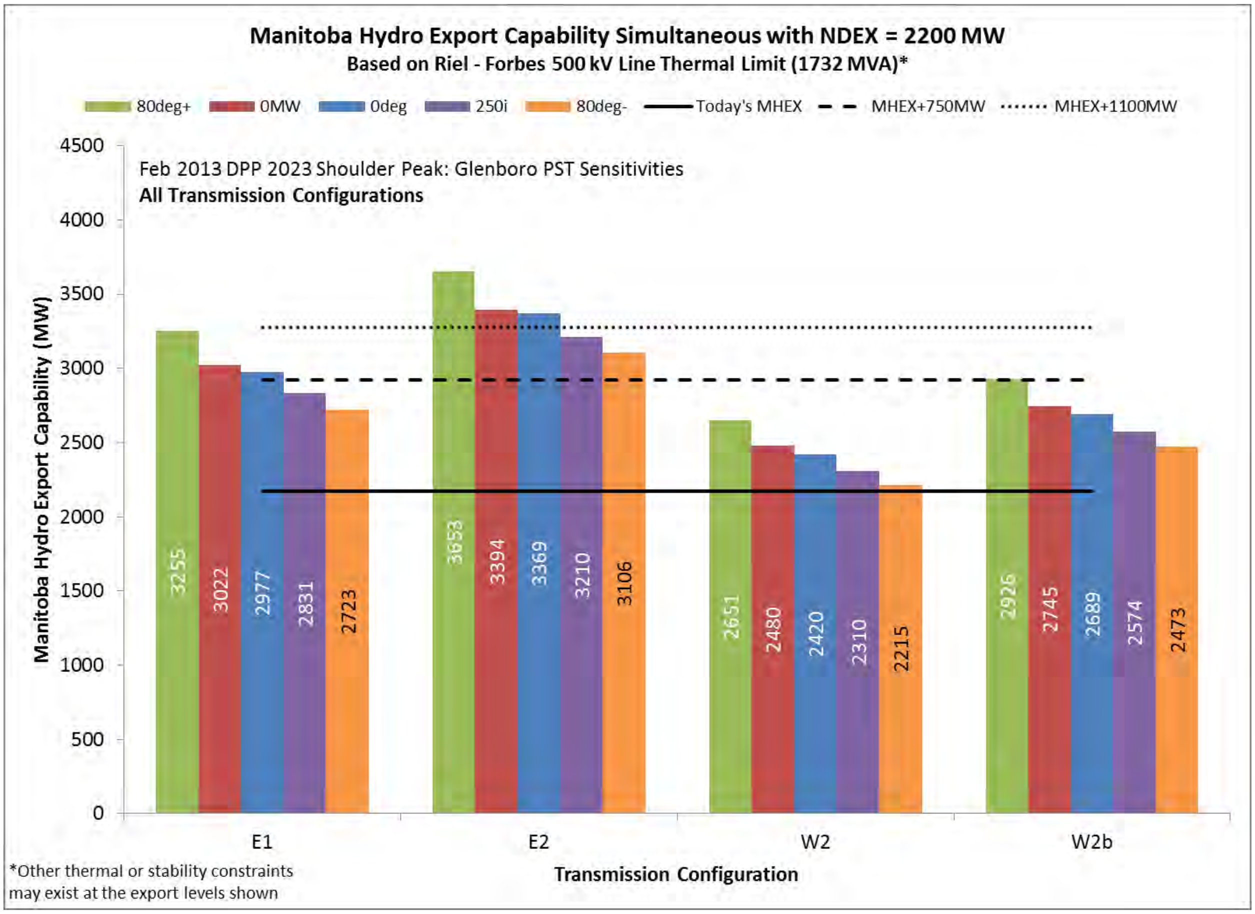


Figure 43: Manitoba Hydro Export Capability Simultaneous with NDEX = 2200 (Glenboro PST Sensitivities)

With North Dakota export increased to 2200 MW, operating the Glenboro phase shifter with a set point of 0 MW (PST_0MW) will slightly increase Manitoba Hydro export capability when North Dakota export is 2200 MW. This means that, with NDEX at 2200 MW, the Glenboro phase shifter is accomplishing its intended purpose of limiting North Dakota – Manitoba loop flow when it is set to maintain 0 MW on G82R. Utilizing the full capability of the Glenboro phase shifter to schedule power flow south on G82R in the PST_80deg+ scenario, Manitoba Hydro export capability is increased by approximately 280 MW for configurations E1 and E2, and by approximately 235 MW for configurations W2 and W2b. For configurations E1 and E2, which are capable of facilitating more than the desired Manitoba Hydro export levels of 2925 MW and 3275 MW, respectively, simultaneous with North Dakota export of 2200 MW, the additional export capability provides another layer of flexibility and optimization for the MHEX interface. For configurations W2 and W2b, the additional export capability afforded by the Glenboro phase shifter is not enough to enable the two transmission configurations to facilitate the desired Manitoba Hydro export level of 3275 MW.

In summary, the Glenboro phase shifter shows benefit for all transmission configurations when used to limit North Dakota – Manitoba loop flow or force power flow south on G82R, but the greatest benefits from this facility are realized by the Eastern Plan configurations.

MVP & CapX2020 Lines

The MISO Multi-Value Project (MVP) portfolio and the CapX2020 Brookings County – Hampton (part of the MVP portfolio) and Hampton – Rochester – Lacrosse (not part of the MVP portfolio) 345 kV lines represent a significant transmission expansion in the upper Midwest. Because of their electrical configuration, several of these projects have the potential to alter the bias of power flow out of North Dakota in such a way that there is more power flowing south and east out of North Dakota and less loop flow through Manitoba. Since all of these lines were included in the benchmark cases, the best way to understand the impact they have on the results of the Loop Flow Impact Study is to remove them from the models to obtain a comparison of North Dakota – Manitoba loop flow before and after the development of the MVP and CapX2020 lines.

The MVP & CapX2020 Lines sensitivities were applied to the DPP case only, to all transmission configurations except E1b, E2s, and E2b. Three levels of cumulative transmission line removal were studied:

1. **MVP_W:** Remove two MISO MVP 345 kV lines in North and South Dakota
2. **MVP_S:** In addition to MVP_W, remove several MISO MVP 345 kV lines in northern Iowa and southern Wisconsin
3. **CapX:** In addition to MVP_S, remove CapX2020 Brookings County – Hampton Corners and Hampton Corners – Briggs Road 345 kV lines

As in the base case, simultaneous North Dakota and Manitoba outlet capability was determined using the nomogram calculation methodology described in the “Study Methodology” section above, which produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F.

The calculated North Dakota outlet capability that can be achieved simultaneously with Manitoba Hydro export levels of 2925 MW (750 MW incremental transfers over today’s MHEX level) and 3275 MW (1100 MW incremental transfers) without overloading M602F is provided for the corresponding transmission configurations in Figure 44 and Figure 45 below. The results are generally similar for all configurations. The cumulative addition of CapX2020 and MISO MVP 345 kV lines decreases the impact of North Dakota – Manitoba loop flow on M602F and therefore increases the North Dakota outlet capability that can potentially be realized at the given Manitoba Hydro export level. For the Western Plan configurations, the inclusion of the CapX2020 and MISO MVP 345 kV lines provides approximately 210 – 380 MW of additional North Dakota outlet capability in the Base Case as compared to the CapX case in which all lines are removed. Interestingly, it is configuration W2b, which includes the second circuit on the Barnesville to Monticello 345 kV line, that is most impacted. For the Eastern Plan configurations, the inclusion of the CapX2020 and MISO MVP 345 kV lines provides approximately 310 – 370 MW of additional North Dakota outlet capability in the Base Case as compared to the CapX case, with configuration E1 being more impacted than configuration E2.

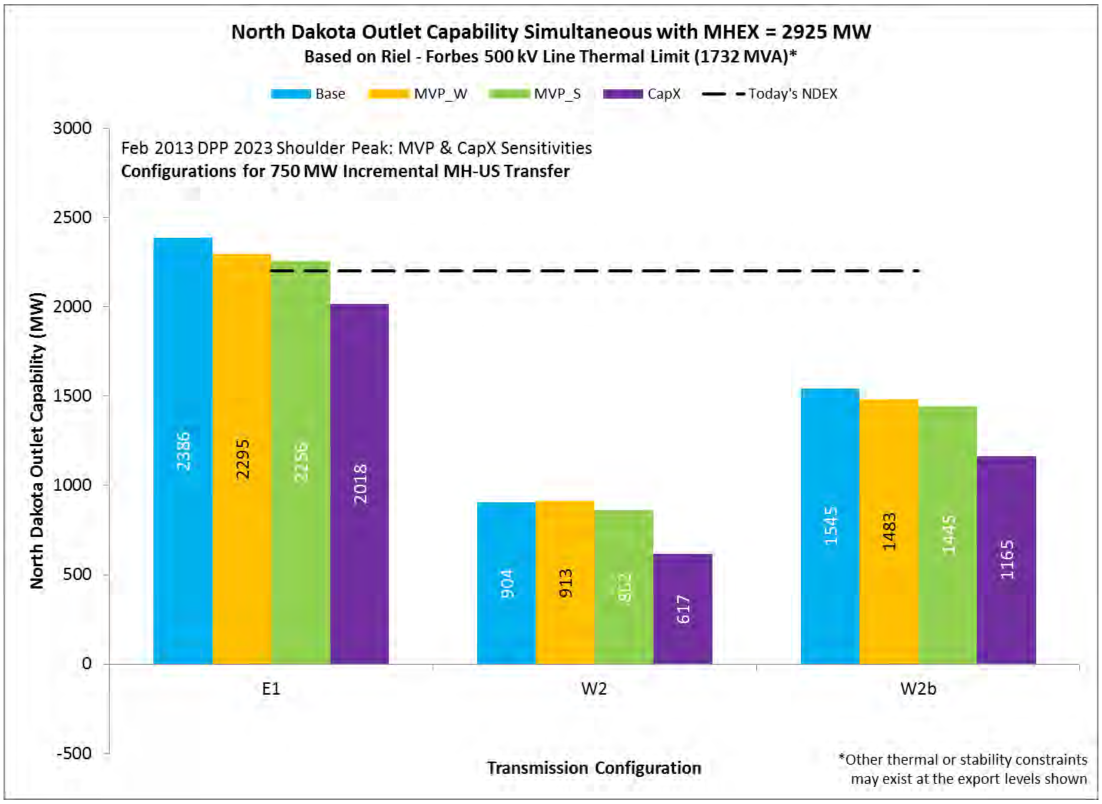


Figure 44: North Dakota Outlet Capability Simultaneous with MHEX = 2925 MW (MVP & CapX Sensitivities)

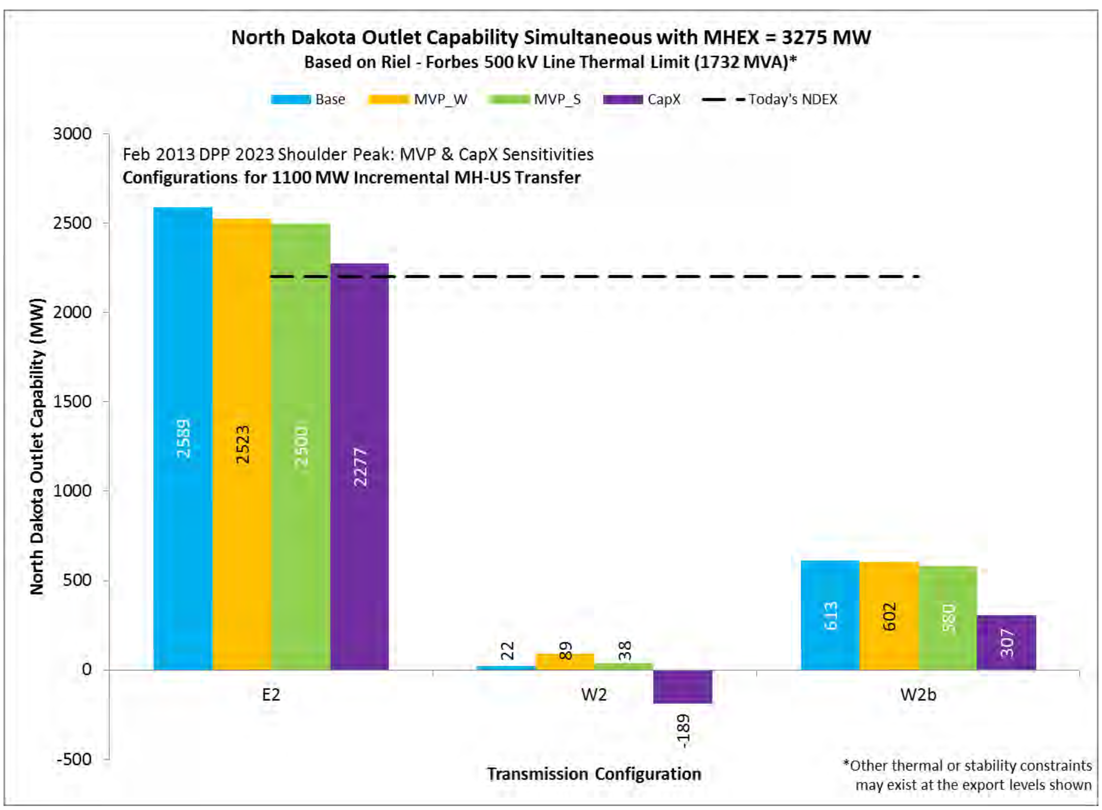


Figure 45: North Dakota Outlet Capability Simultaneous with MHEX = 3275 MW (MVP & CapX Sensitivities)

In summary, the MISO MVP and CapX2020 345 kV lines in North and South Dakota, southern Minnesota, northern Iowa, and southern Wisconsin cumulatively reduce the total North Dakota – Manitoba loop flow by drawing more power south and east out of North Dakota. The impact of these lines appears to be similar for both the Eastern Plan and the Western Plan.

Western Plan Alternative Endpoints

As described above in the Background section and in Appendix L: Conceptual Loop Flow Impact of the Western Plan, the endpoint for the Western Plan lies within the traditional North Dakota export boundary, creating a new path for North Dakota – Manitoba loop flow. To capture the impact that moving the endpoint of the Western Plan away from North Dakota to the south and/or east has on the amount and impact of North Dakota – Manitoba loop flow associated with the Western Plan, several alternative Western Plan endpoints were studied.

The Western Plan Alternative Endpoints sensitivities were applied to the MTEP13 case, configuration W2b only. Six alternative endpoints for the Western Plan, including two that involve the development of a second 500 kV line from the Fargo area to the south, were studied:

- **W2alx:** Move 500 kV endpoint southeast to the Alexandria Substation near Alexandria, MN
- **W2qry:** Move 500 kV endpoint southeast to the Quarry Substation near St. Cloud, MN
- **W2mnt:** Move 500 kV endpoint southeast to the Monticello Substation near Monticello, MN
- **W2bis:** Move 500 kV endpoint northwest to the Bison Substation near Fargo, ND
- **W2hln:** Move 500 kV endpoint northwest to the Bison Substation near Fargo, ND, and add a second 500 kV line from Bison southeast to the Helena Substation near New Prague, MN
- **W2brk:** Move 500 kV endpoint northwest to the Bison Substation near Fargo, ND, and add a second 500 kV line from Bison directly south to the Brookings Co. Substation near Brookings, SD

As in the base case, simultaneous North Dakota and Manitoba outlet capability was determined using the nomogram calculation methodology described in the “Study Methodology” section above, which produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F.

The calculated North Dakota outlet capability that can be achieved simultaneously with Manitoba Hydro export levels of 2925 MW (750 MW incremental transfers over today’s MHEX level) and 3275 MW (1100 MW incremental transfers) without overloading M602F is provided for each of the alternative Western Plan endpoints listed above, the Western Plan with second circuit on the Barnesville – Monticello 345 kV Line (configuration W2b), and the Eastern Plan with double circuit Iron Range – Arrowhead 345 kV Line (configuration E2), in Figure 46 below.

As shown in Figure 46, the Bison (W2bis), Barnesville (W2b), Alexandria (W2alx), and Brookings (W2brk) endpoints all produce considerably lower simultaneous North Dakota and Manitoba outlet capability than configuration E2, which has endpoints on the Iron Range and in Duluth. Therefore it must be concluded that each of those alternative Western Plan endpoints still provides an effective low-impedance path for North Dakota generation to flow into Manitoba, leading to an increased impact of North Dakota – Manitoba loop flow on M602F loading. Only after extending the 500 kV line all the way to the St. Cloud area (W2qry) does the Western Plan produce simultaneous outlet capability similar to or better than configuration E2. Endpoints that extend even further south and east (W2mnt and W2hln) show even greater potential for simultaneous North Dakota and Manitoba outlet capability. It must be noted, however, that Figure 46 does not reflect the additional constraints besides the overload of M602F that will arise at the given simultaneous export levels.

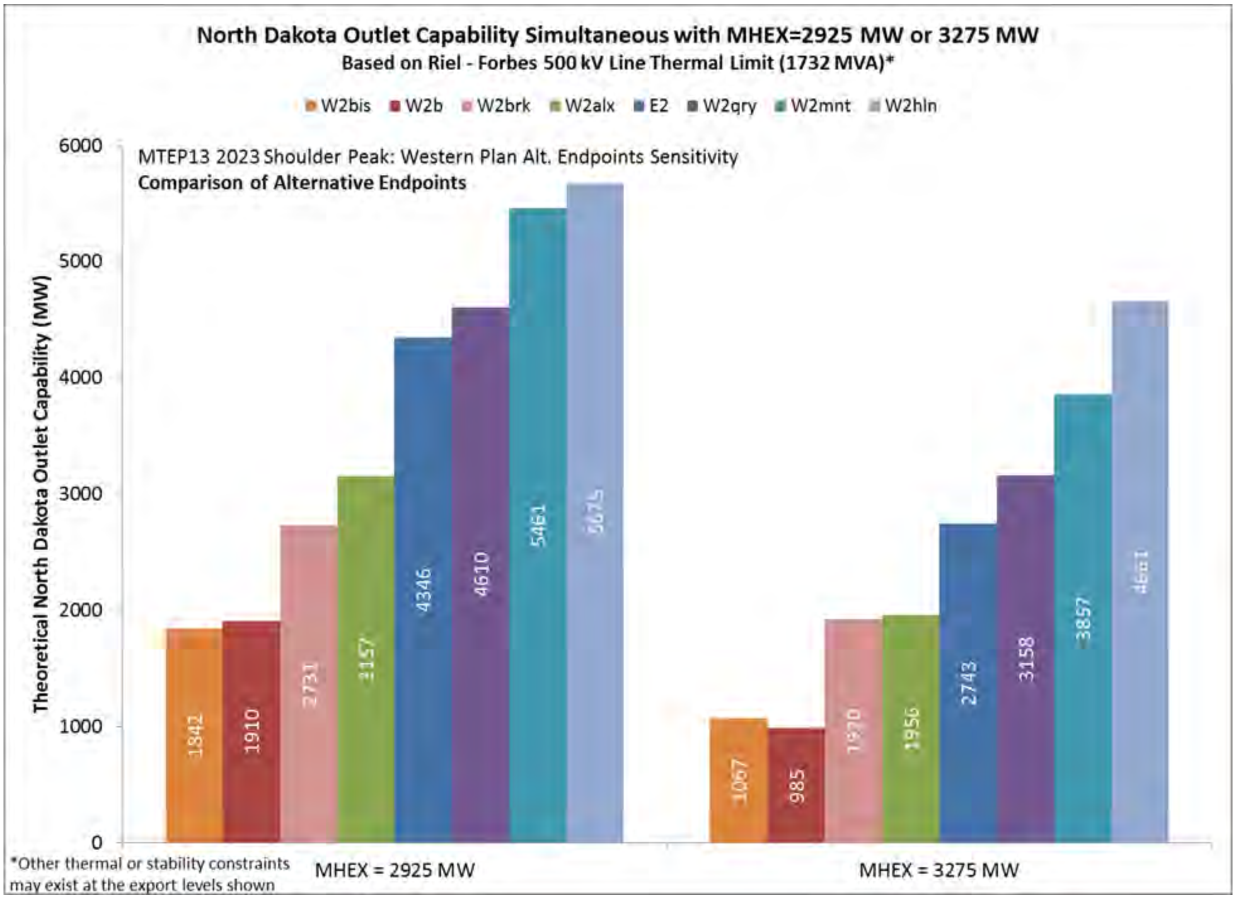


Figure 46: North Dakota Outlet Capability Simultaneous with MHEX (Alt. Endpoints Sensitivity)

In order for the Western Plan configurations to produce simultaneous North Dakota and Manitoba outlet capability that is comparable to or better than the Eastern Plan configurations, the endpoint of the Western Plan must be moved far to the southeast, away from North Dakota generation and toward large load centers in the Twin Cities. At a minimum, it appears that a comparable Western Plan project must extend at least from Winnipeg to the St. Cloud area (W2qry).

Northeastern Minnesota Generation

The Northeastern Minnesota Generation sensitivity was applied to the MANTEX case only, to all configurations except E1b, E2s, and E2b. It involved maintaining the Excelsior "Mesaba" generation facility online at 556.8 MW and keeping the associated Boswell – Riverton 230 kV line in service. While the Excelsior generation project has since been removed from the MISO generator interconnection queue, it was included in the benchmark MANTEX case and is a reasonable proxy for considering the impact that large new generation development in northeastern Minnesota has on the results of the Loop Flow Impact Study. As in the base case, simultaneous North Dakota and Manitoba outlet capability was determined using the nomogram calculation methodology described in the "Study Methodology" section above, which produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F.

The calculated North Dakota outlet capability that can be achieved simultaneously with Manitoba Hydro export levels of 2925 MW (750 MW incremental transfers over today's MHEX level) and 3275 MW (1100 MW incremental transfers) without overloading M602F is provided for the corresponding transmission configurations in Figure 47 and Figure 48 below.

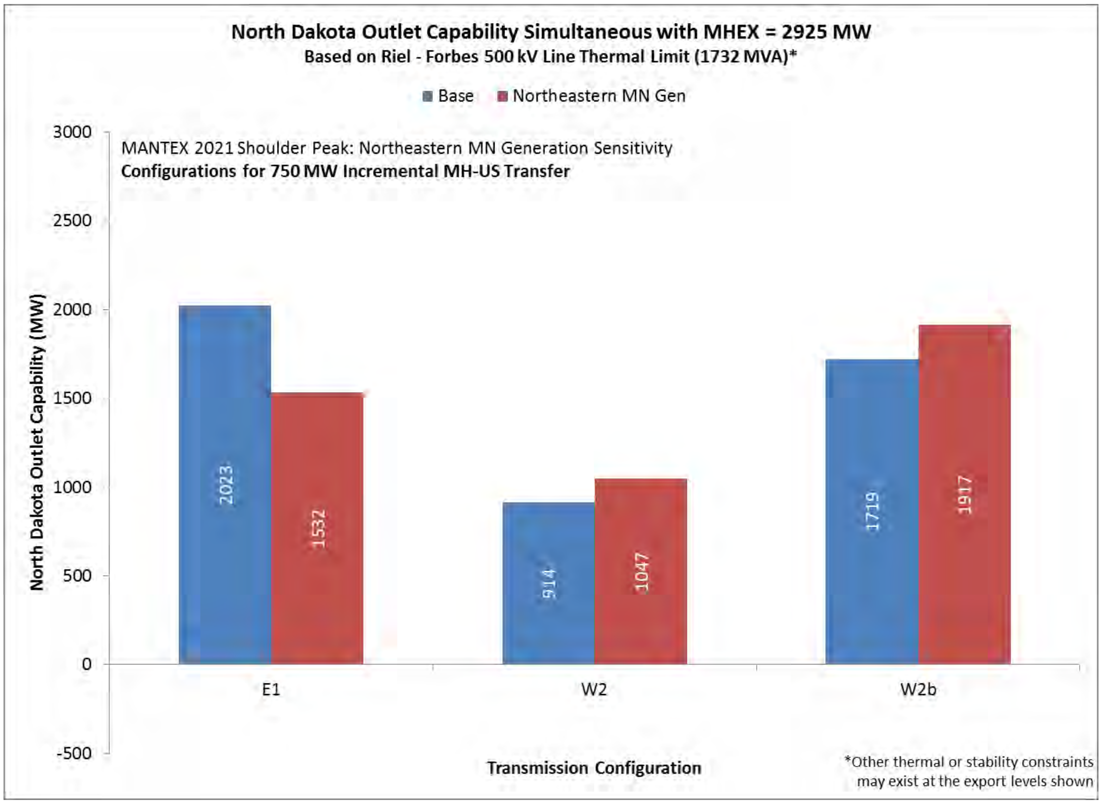


Figure 47: North Dakota Outlet Capability Simultaneous with MHEX = 2925 MW (Northeastern MN Generation Sensitivity)

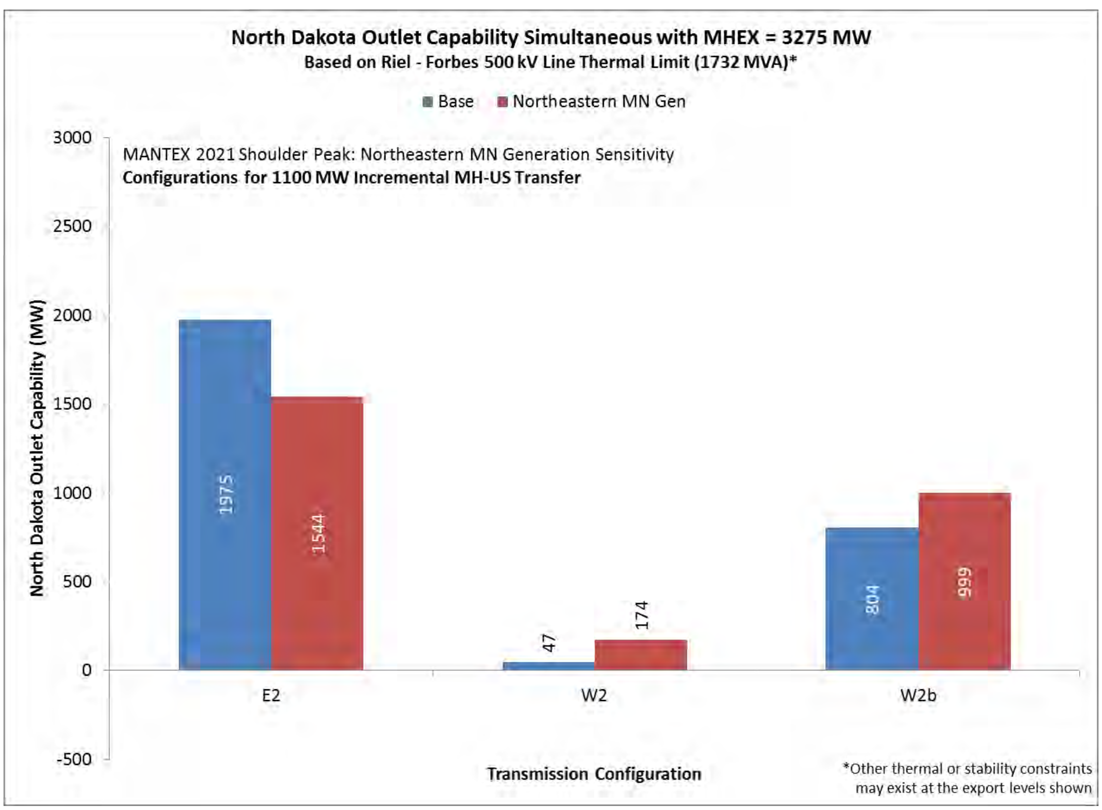


Figure 48: North Dakota Outlet Capability Simultaneous with MHEX = 3275 MW (Northeastern MN Generation Sensitivity)

There is a marked disparity in the impact of large new generation development in northeastern Minnesota on the Eastern Plan compared to the Western Plan. Similar to the way that loop flow from North Dakota changes the bias of the Manitoba – United States interface, generally reducing loading on the Manitoba – North Dakota tie lines (G82R & L20D) and increasing loading on the Manitoba – Minnesota tie lines (R50M & M602F), new generation in northeastern Minnesota changes the bias of the interface in the opposite direction, generally reducing loading on M602F and R50M. Therefore, the Western Plan tends to benefit from generation development in northeastern Minnesota because the new generation has the effect of reducing loading on M602F and increasing utilization of the Western Plan Dorsey – Barnesville 500 kV Line. For configurations W2 and W2b, the result was that North Dakota outlet capability simultaneous with MHEX = 2925 MW was increased by 133 MW and 198 MW, respectively, and North Dakota outlet capability simultaneous with MHEX = 3275 MW was increased by 126 MW and 195 MW, respectively.

The Eastern Plan, on the other hand, appears to be more sensitive to the electrical location of the generation on the northeastern Minnesota transmission system. For the Northeastern Minnesota Generation sensitivity, the chosen generator is directly interconnected to the Blackberry 230 kV Substation, which is practically the same electrical location as the Iron Range Substation, the endpoint of the Eastern Plan 500 kV line. New generation at this location changes the bias of the Manitoba – United States interface so that less power flows on the Eastern Plan Dorsey – Iron Range 500 kV Line and more power flows on M602F. In that way, its impact on the Eastern Plan is analogous to the impact of the Bison 345 kV bus injection point on the Western Plan in the main part of the Loop Flow Impact Study. Increased loading on M602F overloads the Roseau series capacitor banks sooner, limiting simultaneous Manitoba and North Dakota outlet capability. For configuration E1, the result was that North Dakota outlet capability simultaneous with MHEX = 2925 MW was reduced by 490 MW from the base case. For configuration E2, North Dakota outlet capability simultaneous with MHEX = 3275 MW was reduced by 430 MW from the base case.

If the new generator were interconnected to the Forbes 230 kV bus (approximately 30 miles away from the Blackberry Substation), it is likely that the opposite effect would be observed: reduced loading on the Dorsey – Forbes 500 kV Line (M602F) and increased utilization of the Dorsey – Iron Range 500 kV Line leading to higher simultaneous North Dakota and Manitoba outlet capability. In general, it could be said that any time large new generation is interconnected to the endpoint of one of the Manitoba – United States tie lines, it will have a similar impact.

In summary, new generation in northeastern Minnesota generally reduces the impact of North Dakota – Manitoba loop flow on M602F for the Western Plan, increasing the potential simultaneous North Dakota and Manitoba outlet capability. For the Eastern Plan, the impact of new generation in northeastern Minnesota is highly dependent on the location of the generator. In the worst case, with a new generator interconnected directly to the Blackberry Substation, simultaneous North Dakota and Manitoba outlet capability could be limited significantly. However, if a new generator were interconnected just 30 miles away at the Forbes Substation, it could have the opposite impact, actually improving simultaneous North Dakota and Manitoba outlet capability by reducing loading on M602F.

Northeastern Minnesota Loads

The Northeastern Minnesota Load sensitivities were applied to the NAS case only, to all configurations except E1b, E2s, and E2b. The Minnesota Power Load Pocket sensitivity (MP Load) involved retaining a 450 MW conceptual load pocket in northeastern Minnesota, with 225 MW located at the Forbes 230 kV bus and another 225 MW located at the Minntac 230 kV bus. Adding the northeastern Minnesota load pocket back in to the Northern Area Study model is a reasonable way to capture the impact that significant load additions in northeastern Minnesota have on the results of the Loop Flow Impact Study.

The Essar Phase 2 Delayed (Essar) sensitivity involved reducing the total Essar plant load to 120 MW (about a 150 MW reduction) and removing the associated Blackberry – McCarthy Lake 230 kV Line. Reducing the total load at Essar and removing the transmission associated with the steel mill expansion is a reasonable way to capture the impact of delayed or reduced load growth in northeastern Minnesota on the results of the Loop Flow Impact Study

As in the base case, simultaneous North Dakota and Manitoba outlet capability was determined using the nomogram calculation methodology described in the "Study Methodology" section above, which produces a formula for anticipating the level of North Dakota outlet capability that can be achieved at any expected level of Manitoba Hydro export before overloading M602F.

The calculated North Dakota outlet capability that can be achieved simultaneously with Manitoba Hydro export levels of 2925 MW (750 MW incremental transfers over today's MHEX level) and 3275 MW (1100 MW incremental transfers) without overloading M602F is provided for the corresponding transmission configurations in Figure 49 and Figure 50 below.

The MP Load sensitivity resulted in reduced simultaneous transfer capability for both the Eastern Plan and the Western Plan due to the electrical location of the proxy loads, which are both very near to the endpoint of the Dorsey – Forbes 500 kV Line (M602F). The additional load draws more power down M602F for both the Eastern Plan and the Western Plan, overloading the line sooner than it would otherwise be overloaded. For configuration E1, the result was that North Dakota outlet capability simultaneous with MHEX = 2925 MW was reduced by 115 MW from the base case. For configuration E2, North Dakota outlet capability simultaneous with MHEX = 3275 MW was reduced by 225 MW from the base case. The Western Plan configurations were more significantly impacted. For configurations W2 and W2b, North Dakota outlet capability simultaneous with MHEX = 2925 MW was reduced from the base case by 316 MW and 390 MW, respectively, and North Dakota outlet capability simultaneous with MHEX = 3275 MW was reduced by 322 MW and 380 MW, respectively.

The Essar sensitivity had a more disparate impact on the Eastern Plan and the Western Plan. For the Western Plan configurations, the removal of load in northeastern Minnesota shifted the bias of power flow away from M602F and toward the other Manitoba – United States tie lines, including the Dorsey – Barnesville 500 kV Line. For configurations W2 and W2b, the result was that North Dakota outlet capability simultaneous with MHEX = 2925 MW was increased over the base case by 47 MW and 69 MW, respectively, and North Dakota outlet capability simultaneous with MHEX = 3275 MW was increased by 41 MW and 71 MW, respectively. This result is consistent with the results of the Northeastern Minnesota Generation sensitivity, and demonstrates that increased generation or decreased load in northeastern Minnesota tend to improve the simultaneous outlet capability available with the Western Plan configurations.

For configuration E1, the removal of approximately 150 MW of load and the Blackberry – McCarthy Lake 230 kV Line shifted the bias of power flow away from the Dorsey – Iron Range 500 kV Line and onto M602F, reducing North Dakota outlet capability simultaneous with MHEX = 2925 MW by 243 MW from the base case. The impact was similar for configuration E2, with North Dakota outlet capability simultaneous with MHEX = 3275 reduced by 216 MW from the base case. Combined with the MP Load sensitivity results, this result is also consistent with the conclusions from the Northeastern Minnesota Generation sensitivity. In general, it could be said that significant load growth that is electrically near to the endpoint of one of the Manitoba – United States tie lines will draw more power down the line. If that line is M602F, the resulting increase in loading will limit simultaneous North Dakota and Manitoba outlet capability. If it is a different tie line, simultaneous outlet capability may be increased.

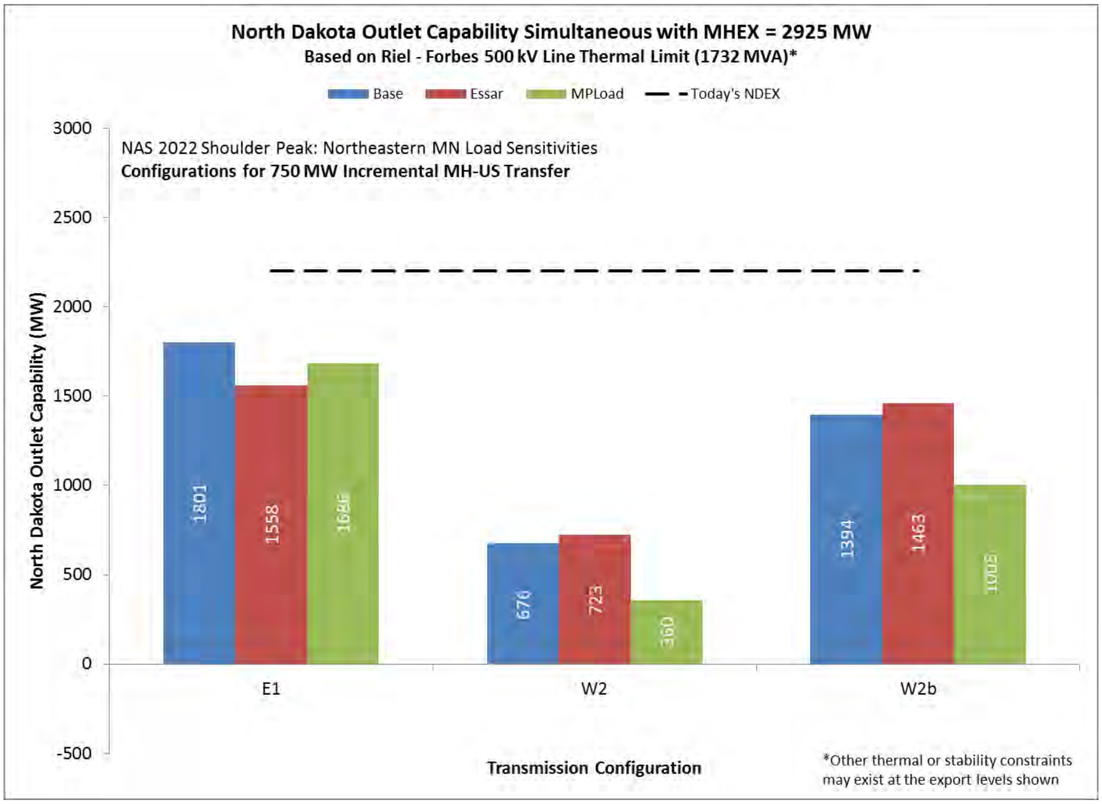


Figure 49: North Dakota Outlet Capability Simultaneous with MHEX = 2925 MW (Northeastern MN Load Sensitivities)

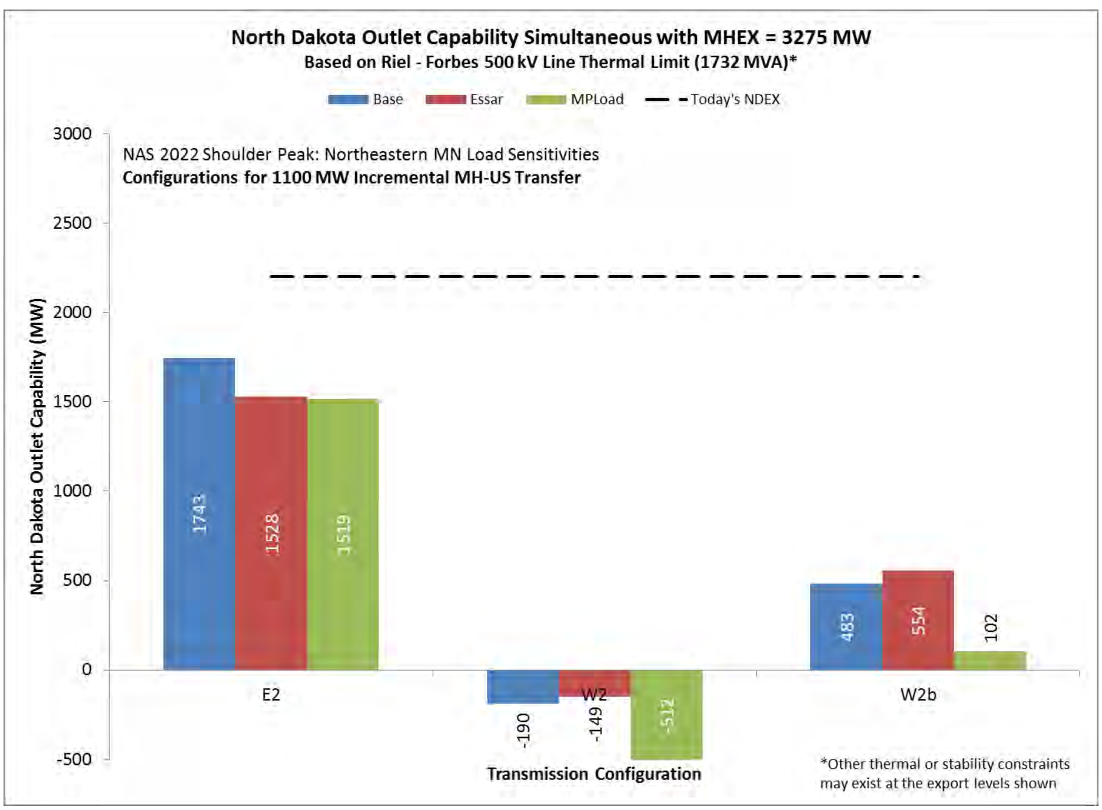


Figure 50: North Dakota Outlet Capability Simultaneous with MHEX = 3275 MW (Northeastern MN Load Sensitivities)

Section 7: Conclusions

The purpose of the New Tie Line Loop Flow Impact Study is to capture and compare the impact of a new 500 kV Manitoba – United States tie line on the North Dakota – Manitoba loop flow phenomenon. Specifically, the study is meant to compare the loop flow impact of an Eastern (Grand Rapids area) 500 kV tie line configuration and a Western (Fargo area) 500 kV tie line configuration. The results of the study and the various sensitivities also provide insight into the nature of North Dakota – Manitoba loop flow as well as the various factors that influence the level and impact of the loop flow.

The results of the study illustrate the fact that North Dakota – Manitoba loop flow is fundamentally a result of the system topology that facilitates the unwanted flow of North Dakota generation through Manitoba at higher levels of North Dakota generation export. Even if interface flows, load levels, and generation dispatch are such that only very low levels of North Dakota – Manitoba loop flow are observed, the same potential for loop flow at higher North Dakota export levels will exist as long as the system topology remains unchanged.

The results of the study support the assertion that the Eastern Plan has a more favorable overall impact on North Dakota – Manitoba loop flow than the Western Plan. The Western Plan introduces a new, very low impedance path for North Dakota generation to flow from North Dakota into Manitoba (the Dorsey – Barnesville 500 kV Line) and then back into the United States, primarily on the Riel – Forbes 500 kV Line. This has the impact of significantly increasing the total amount of North Dakota – Manitoba loop flow as well as the amount of loop flow that ends up on the Riel – Forbes 500 kV Line. In practice, the result would be that, the higher the North Dakota export is, the less power a new Dorsey – Barnesville 500 kV Line would carry from Manitoba to the United States. This would cause more power to flow on the existing Riel – Forbes 500 kV Line, overloading the line at much lower levels of simultaneous Manitoba and North Dakota export levels than would otherwise be possible if the new tie line did not connect North Dakota and Manitoba. While it can be demonstrated that the Western Plan provides additional outlet capability from Manitoba Hydro, this additional outlet capability would come at the expense of placing considerable limitations on North Dakota outlet capability absent any additional upgrades or new transmission developments.

The Eastern Plan, on the other hand, does not directly connect North Dakota generation to Manitoba. Instead, the Eastern Plan provides an additional transmission path parallel to the Riel – Forbes 500 kV Line, alleviating the main thermal constraint associated with North Dakota – Manitoba loop flow and thereby facilitating less interaction between North Dakota generation and Manitoba Hydro exports. While it is true that the Eastern Plan facilitates slightly more total North Dakota – Manitoba loop flow than the existing system, it also reduces the overall impact of loop flow on the Riel – Forbes 500 kV Line by carrying some of the North Dakota – Manitoba loop flow that would normally flow on the line. The result is that the Eastern Plan provides the desired additional outlet capability from Manitoba Hydro without inherently limiting potential transmission outlet capability for current and future North Dakota generation resources. In fact, the Eastern Plan is not only capable of maintaining North Dakota outlet capability at existing levels or better simultaneous with increased exports from Manitoba, it actually offers significant potential for increased North Dakota outlet capability without restrictions due to North Dakota – Manitoba loop flow.

In conclusion, the results of the New Tie Line Loop Flow Impact study indicate that the Eastern Plan is the superior long-term plan for developing a new 500 kV tie line between Manitoba and the United States when compared to the Western Plan based on the impact of the two transmission configurations on North Dakota – Manitoba loop flow.

Appendix A: Detailed Comparison of Benchmark Cases

In this Appendix, the initial conditions of the four benchmark model series used for the Loop Flow Impact Study, as modified to create the "Existing System" configuration described above, will be compared and contrasted.

Initial Conditions

One of the fundamental objectives of the Loop Flow Impact Study was to perform the analysis using a variety of existing models developed for different purposes, all of which had been thoroughly reviewed and benchmarked within the industry. Therefore, Shoulder Peak models from the 2021-2023 timeframe were selected from the February 2013 MISO Definitive Planning Phase (DPP) generator interconnection study, the MISO Midwest Transmission Expansion Planning (MTEP) 2013 reliability analysis performed for NERC TPL Standard compliance, the Manitoba Transmission Expansion (MANTEX) ad hoc study group, and the MISO Northern Area Study (NAS). To ensure consistency on key assumptions that could impact study results, a minimal number of modifications were made to the benchmark cases, which are described in the "Model Development" section of the main report. As shown in the tables below, these four model series have widely varying initial interface flow, load, and generation conditions.

Interface	DPP	MTEP	MANTEX	NAS
MHEX	1847.3	1843.5	3285.5	2708.0
NDEX	2752.0	1092.1	861.3	1486.4
MWEX	1708.3	1361.5	1431.4	1275.4

Table 8: Comparison of Interface Flows in the Existing System Configuration

Table 8 shows the interface flows for the Existing System configuration, for each model series. The DPP model generally shows the most stress, with high simultaneous levels of MHEX, NDEX, and MWEX. In fact, MWEX is loaded above its system operating limit (1665 MW), and North Dakota Export in the DPP model is well above the historical studied NDEX limit of 2080 MW. The MTEP model is the most modestly stressed case overall, with MHEX, NDEX, and MWEX all well within their studied limits. The MANTEX model includes an additional 1,100 MW of incremental Manitoba – United States transfers. Given the high MHEX, a higher MWEX would be expected, but the stress created by the incremental MHEX transfer is somewhat softened by the North Dakota Export level, which is the lowest of all benchmark cases by 230 MW. The load and generation levels of some Minnesota utilities (discussed below) also contribute to a lower-than-expected MWEX level for the MANTEX case. Finally, the NAS model also includes some incremental Manitoba – United States transfers and has a relatively high North Dakota Export as well, but it shows the lowest MWEX level of all three cases by nearly 100 MW, probably due to the load and generation levels in the model (discussed below).

Transmission Line	DPP	MTEP	MANTEX	NAS
Riel – Forbes 500 kV	1737.3	1448.4	2404.2	2233.1
Richer – Moranville 230 kV	195.0	175.9	219.7	267.5
Letellier – Drayton 230 kV	70.2	204.9	456.2	277.9
Glenboro – Rugby 230 kV	-155.2	14.3	178.4	-70.5

Table 9: Comparison of Manitoba - U.S. Flows in the Existing System Configuration

Table 9 shows the power flow on each of the four existing Manitoba – United States tie lines for the Existing System configuration, for each model series. The Riel – Forbes 500 kV line is heavily loaded in all four model series, and is actually overloaded in three out of the four cases. In the worst case, MANTEX, the existing 500 kV line is carrying 140 percent of its 1732 MVA rating. For the MANTEX and NAS benchmark cases, the overloads of the Riel – Forbes 500 kV Line are due to the addition of incremental

Manitoba – United States transfers in the Existing System case with no new transmission to facilitate the increased transfers. For the DPP benchmark case, the overload of the Riel – Forbes 500 kV Line is due to the large amounts of generation that are interconnected to the system causing North Dakota – Manitoba loop flow. Low power flows on the two North Dakota – Manitoba tie lines (Letellier – Drayton and Glenboro – Rugby) also indicate the effects of North Dakota – Manitoba loop flow in the DPP case and NAS case, both of which have relatively high North Dakota Export levels.

Transmission Line	DPP	MTEP	MANTEX	NAS
Leland Olds – Fort Thompson 345 kV	339.5	195.0	233.4	273.4
Leland Olds – Groton 345 kV	345.0	201.1	187.1	280.8
Antelope Valley – Broadland 345 kV	321.3	181.0	195.0	265.1
Bison – Alexandria 345 kV	412.2	247.5	300.1	306.3
Big Stone – Brookings 345 kV	254.1	84.0	-64.1	115.8
Cass Lake – Boswell 230 kV	48.0	-43.9	-74.8	-46.4

Table 10: Comparison of North Dakota Tie Line Flows in the Existing System Configuration

Table 10 shows the power flow on several of the tie lines that are used to define the North Dakota Export (NDEX) level, including recently developed or planned CapX2020 and MISO MVP lines, for the Existing System configuration, for each model series. Higher NDEX levels in the DPP and NAS cases correspond to generally higher power flows on the North Dakota 345 kV tie lines compared to the MTEP and MANTEX cases. The Bison – Alexandria 345 kV line, in particular, is much heavier loaded in the DPP case than in any of the other three cases.

Transmission Line	DPP	MTEP	MANTEX	NAS
Arrowhead – Stone Lake 345 kV	720.3	568.9	656.3	579.9
King – Eau Claire 345 kV	988.0	792.6	775.1	695.5
N.Rochester – Briggs Road 345 kV	748.4	603.2	586.0	553.4

Table 11: Comparison of Minnesota - Wisconsin Flows in the Existing System Configuration

Table 11 shows the power flow on three Minnesota - Wisconsin tie lines for the Existing System configuration, for each model series. Minnesota – Wisconsin 345 kV tie line flows vary consistent with the MWEX level in each of the model series. In every case, King – Eau Claire is the most heavily loaded of the three tie lines.

Area	Area #	DPP	MTEP	MANTEX	NAS
MH	667	3285.0	2369.6	2779.2	3285.0
MP	608	1844.0	1452.1	1221.1	1713.0
GRE	615	2160.3	2095.2	2377.9	2168.3
XEL	600	7948.6	7881.7	8315.3	7989.4
OTP	620	1195.8	1117.6	1175.2	1773.7
WAPA	652	4347.9	3948.7	3298.4	4365.1
MDU	661	428.4	484.8	459.7	437.7
WPS	696	2089.9	2045.7	2201.5	2089.9
DPC	680	706.7	755.3	821.0	706.0
WEC	295	5097.8	5150.0	5543.6	5358.5
ALTW	627	3282.3	3214.2	3178.6	3321.7
Total		**32,386.7**	**30,514.9**	**31,371.5**	**33,208.3**

Table 12: Comparison of Area Load Levels in the Existing System Configuration

Table 12 shows the load levels for several general areas of the transmission system by utility model area for the Existing System configuration, for each model series. The total load levels in the areas listed in the table are generally similar. The difference between the case with the lowest load level (MTEP – model year 2023) and the case with the highest load level (NAS – model year 2022) is approximately 2,700 MW. In the MANTEX model (model year 2022), Xcel (XEL) and Great River Energy (GRE) load levels are noticeably higher than they are in the other model series. This may provide some further insight into why the MWEX level in the MANTEX model is lower than expected given the high MHEX, which includes 1100 MW of incremental Manitoba – United States transfers.

Area	Area #	DPP	MTEP	MANTEX	NAS
MH	667	3285.0	2369.6	2779.2	3285.0
MP	608	1844.0	1452.1	1221.1	1713.0
GRE	615	2160.3	2095.2	2377.9	2168.3
XEL	600	7948.6	7881.7	8315.3	7989.4
OTP	620	1195.8	1117.6	1175.2	1773.7
WAPA	652	4347.9	3948.7	3298.4	4365.1
MDU	661	428.4	484.8	459.7	437.7
WPS	696	2089.9	2045.7	2201.5	2089.9
DPC	680	706.7	755.3	821.0	706.0
WEC	295	5097.8	5150.0	5543.6	5358.5
ALTW	627	3282.3	3214.2	3178.6	3321.7
Total		**41,218.1**	**35,990.5**	**38,157.6**	**40,604.8**

Table 13: Comparison of Area Generation Levels in the Existing System Configuration

Table 13 shows the generation levels for several general areas of the transmission system by utility model area for the Existing System configuration, for each model series. There is a substantial difference between the case with the lowest generation level (MTEP) and the case with the highest generation level (DPP). The difference in total area generation between these two cases is approximately 5,200 MW. This makes sense in light of the purposes of the two models: the DPP model is developed for the MISO generation interconnection process, and therefore must include a significant amount of non-firm future generation. The MTEP model, on the other hand, is developed for reliability analysis and generation is dispatched based on load levels and transmission constraints in the model. In the MANTEX case, the combined generation associated with the WAPA and MDU areas in North Dakota is 1,400 – 2,700 MW lower than in the other three model series. This difference may provide some insight into what is driving the lower North Dakota Export levels in the MANTEX models.

This comparison demonstrates that, while all four benchmark cases are set up to reflect a Shoulder Peak scenario with high transfer levels, there are considerable differences in the interface flows, load levels, and generation levels. These variations reflect the differing purposes for which the models were developed, and do not reflect on the validity of the models themselves.

Appendix B: Description of Study Methodology

Distribution Factor Analysis

The main study methodology used for the New Tie Line Loop Flow Impact Study involves the calculation of distribution factors describing the percentage of the total output of conceptual new generators in Manitoba and North Dakota that will flow on each of the existing and new Manitoba – United States tie lines. An average North Dakota generation distribution factor will be calculated for each tie line based on the distribution factors for individual injection points (proxy new generators) at several locations in North Dakota. The methodology for calculating these distribution factors is described below.

The power system analysis software package *PSSE* will be used to perform distribution factor (DF) analysis on each of the configurations described in the Report for an incremental 100 MW injection at various locations in Manitoba and North Dakota. The names and numbers of the modeled buses to be used for these injection points are provided in Table 14 below, and their geographical locations are shown in Figure 25 of the Report.

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
657756	SQBUTTE4	230 kV	620-OTP
620379	RUGBY 4	230 kV	620-OTP

Table 14: Injection Points for Distribution Factor Analysis

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:

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

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 section of the Report) 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

Appendix C: Validation of Study Methodology

The development of nomogram plots for the Loop Flow Impact Study is described in Appendix B: Description of Study Methodology. The methodology for developing the nomogram plots uses the calculated Manitoba and North Dakota distribution factors derived from the power flow models to develop a formula for the line that connects two points: ($NDEX_{ND}$, $MHEX_{ND}$) and ($NDEX_{MH}$, $MHEX_{MH}$). As discussed in Appendix B: Description of Study Methodology, these two points represent simultaneous NDEX and MHEX levels beyond which the Riel – Forbes 500 kV line (M602F) will be overloaded. The line that connects these two points represents the boundary condition for simultaneous NDEX and MHEX capability for the particular transmission configuration under consideration based on the M602F constraint. Using the formula for this line, the level of North Dakota Export possible at any given level of MHEX before overloading M602F can be calculated and compared with other transmission configurations.

This methodology is highly dependent on the assumption that the relationship between MHEX and NDEX and the loading on M602F is truly linear, and that the calculated distribution factors, which are based on 100 MW injections, can be used to anticipate the impact of much more significant North Dakota or Manitoba injections on M602F loading. To validate this methodology, the Existing System configuration from the MTEP model series was selected and actual injections in North Dakota and Manitoba were simulated to verify that M602F loading behaved as expected from the derived nomogram formula. The results of this study methodology validation exercise for the North Dakota injection and the Manitoba injection are shown in Table 15 and Table 16, and are discussed below.

Validation Based on North Dakota Injection		Power Flow (MW)		
Monitored Element	Pre-Injection	ND+2050 (Calculated)	ND+2050 (Simulated)	Percent Error
601001 FORBES 2 500.00 601017 CHIS-N 2 500.00 1	1011.7	1271.0	1256.7	-1.14%
601012 ROSEAUN2 500.00 667501 RIEL 2 500.00 1	-1461.7	-1732.8	-1722.2	-0.62%
601014 AS KING3 345.00 601028 EAU CL 3 345.00 1	793.9	979.4	969.6	-1.01%
601039 NROC 3 345.00 601044 BRIGGS RD 3 345.00 1	601.6	787.1	736.9	-6.82%
601067 BISON 3 345.00 658047 ALEX SS 3 345.00 1	251.6	542.2	539.4	-0.52%
602013 ROSEAU 4 230.00 667046 RICHER 4 230.00 1	-171.0	-188.9	-187.6	-0.71%
620379 RUGBY 4 230.00 667052 GLENBOR4 230.00 1	-10.5	176.1	172.8	-1.88%
657752 DRAYTON4 230.00 667048 LETELER4 230.00 1	-197.5	-103.2	-105.5	2.18%
667500 DORSEY 2 500.00 667501 RIEL 2 500.00 1	898.7	1054.5	1049.0	-0.52%
694078 STONE LK B4 345.00 699449 ARROWHD 345.00 1	-558.2	-693.5	-682.9	-1.55%
INTERFACE MHEX_INT	1840.7	1847.9	1842.5	-0.29%
INTERFACE MWEX_INT	1352.1	1673.4	1652.5	-1.27%
INTERFACE NDEX_INT	1092.1	3039.1	2979.0	-2.02%

Table 15: Validation of Study Methodology Based on North Dakota Injection

To validate the use of the composite North Dakota distribution factor, equal incremental injections were modeled at the four North Dakota buses used for the study (Bison, Ellendale, Rugby, and Square Butte). The total incremental North Dakota injection at these four buses was then increased to 2,050 MW, the level at which M602F was expected to be overloaded based on the calculated composite North Dakota distribution factor. As indicated in Table 15 above, the difference between the expected (calculated) loading of M602F and the actual (simulated) loading of M602F is less than 1 percent. Similar accuracy is observed for most other monitored elements.

Validation Based on Manitoba Injection		Power Flow (MW)		
Monitored Element	Pre-Injection	MH+390 (Calculated)	MH+390 (Simulated)	Percent Error
601001 FORBES 2 500.00 601017 CHIS-N 2 500.00 1	1011.7	1194.2	1191.7	-0.21%
601012 ROSEAUN2 500.00 667501 RIEL 2 500.00 1	-1461.7	-1732.8	-1733.6	0.05%
601014 AS KING3 345.00 601028 EAU CL 3 345.00 1	793.9	835.6	834.2	-0.17%
601039 NROC 3 345.00 601044 BRIGGS RD 3 345.00 1	601.6	643.3	628.1	-2.42%
601067 BISON 3 345.00 658047 ALEX SS 3 345.00 1	251.6	260.2	259.8	-0.15%
602013 ROSEAU 4 230.00 667046 RICHER 4 230.00 1	-171.0	-192.5	-192.8	0.18%
620379 RUGBY 4 230.00 667052 GLENBOR4 230.00 1	-10.5	-47.6	-48.0	0.94%
657752 DRAYTON4 230.00 667048 LETELER4 230.00 1	-197.5	-255.2	-255.0	-0.09%
667500 DORSEY 2 500.00 667501 RIEL 2 500.00 1	898.7	1149.9	1150.7	0.07%
694078 STONE LK B4 345.00 699449 ARROWHD 345.00 1	-558.2	-596.8	-593.8	-0.51%
INTERFACE MHEX_INT	1840.7	2228.0	2229.3	0.06%
INTERFACE MWEX_INT	1352.1	1432.4	1428.0	-0.31%
INTERFACE NDEX_INT	1092.1	1083.9	1081.3	-0.24%

Table 16: Validation of Study Methodology Based on Manitoba Injection

To validate the use of the Manitoba distribution factor, an incremental 390 MW injection was modeled at the Dorsey 500 kV bus. This 390 MW is the level at which M602F was expected to be overloaded based on the calculated Manitoba distribution factor. As indicated in Table 16 above, the difference between the expected (calculated) loading of M602F and the actual (simulated) loading of M602F is less than 0.1 percent. Similar accuracy is observed for most other monitored elements.

Based on this simple validation exercise, it was concluded that the study methodology for the Loop Flow Impact Study, used to develop nomogram plots and identify maximum simultaneous North Dakota and Manitoba transfer levels based on the M602F constraint, is valid and highly accurate.

Appendix D: Additional Distribution Factor Analysis Results

In this Appendix, the distribution factor analysis results for the Eastern Plan (E1) and Western Plan (W2) configurations are provided in order to compare the results of the four benchmark model series.

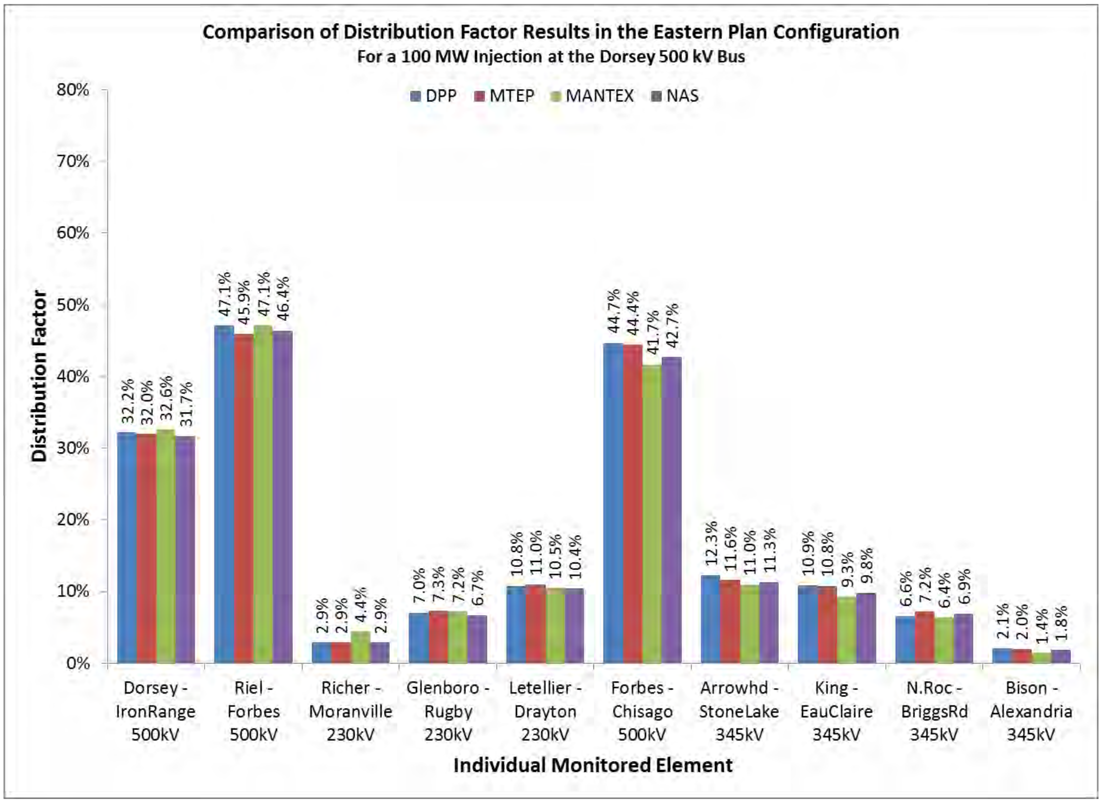


Figure 51: Comparison of Distribution Factor Results for the Dorsey Injection (E1)

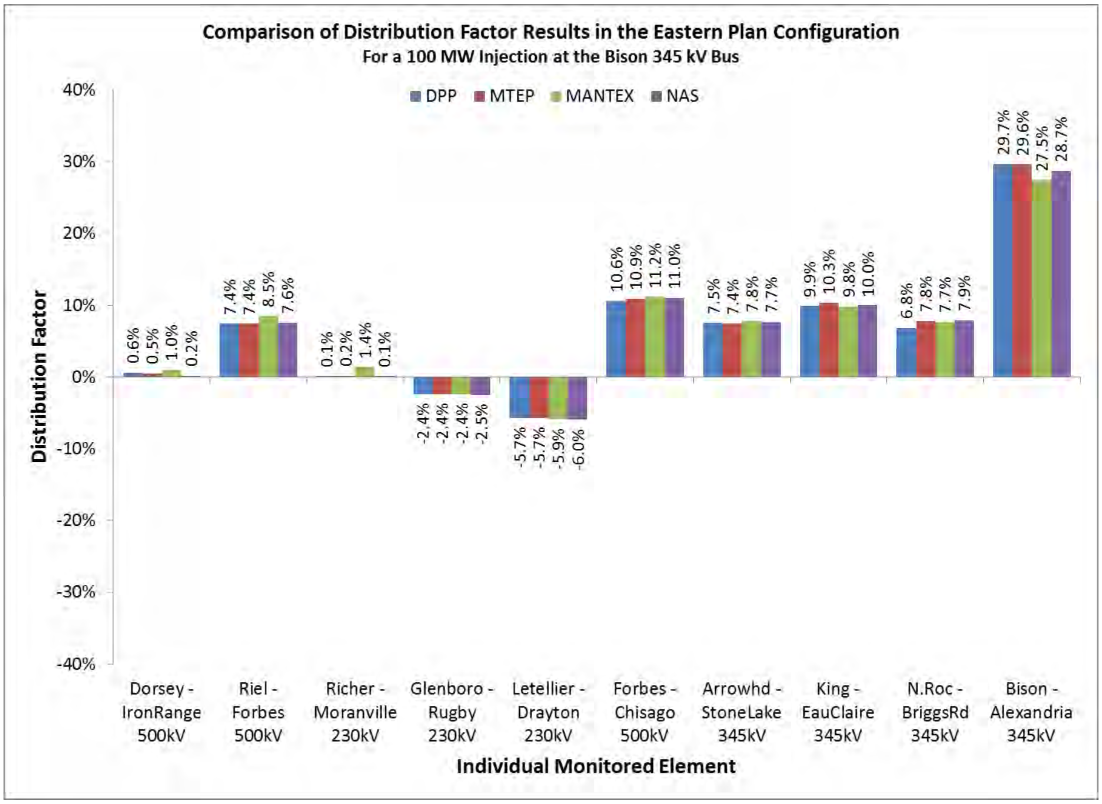


Figure 52: Comparison of Distribution Factor Analysis Results for the Bison Injection (E1)

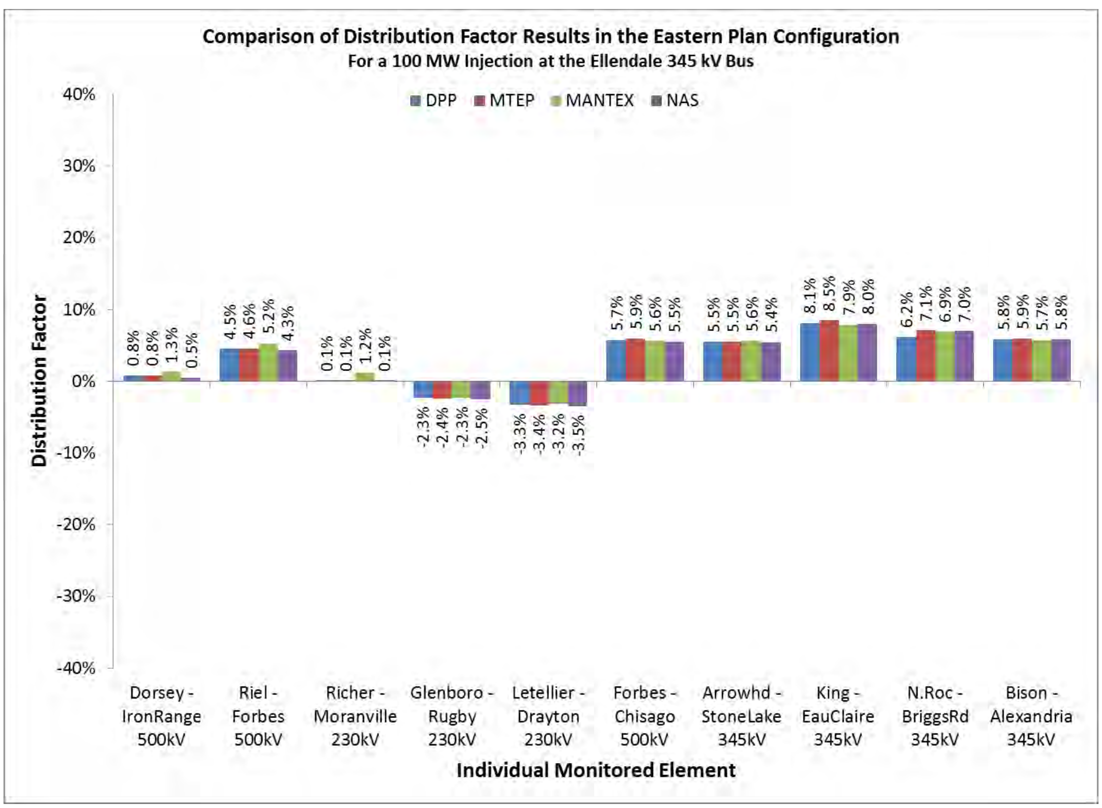


Figure 53: Comparison of Distribution Factor Analysis Results for the Ellendale Injection (E1)

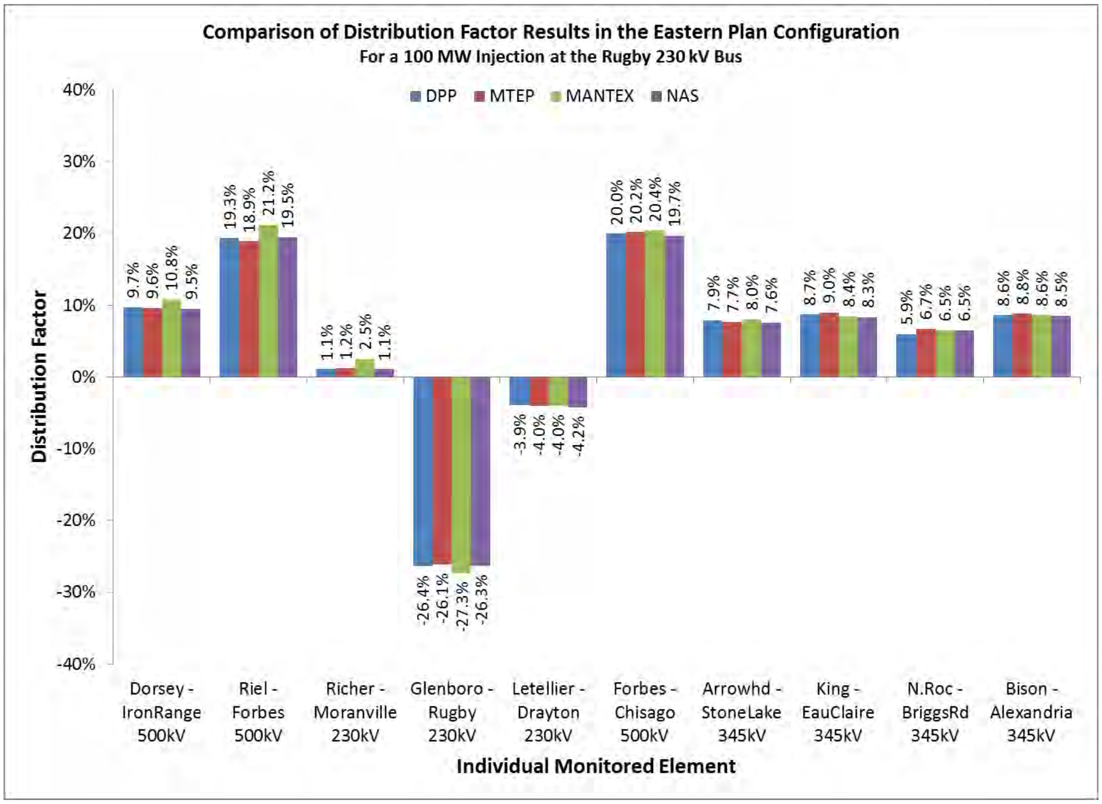


Figure 54: Comparison of Distribution Factor Analysis Results for the Rugby Injection (E1)

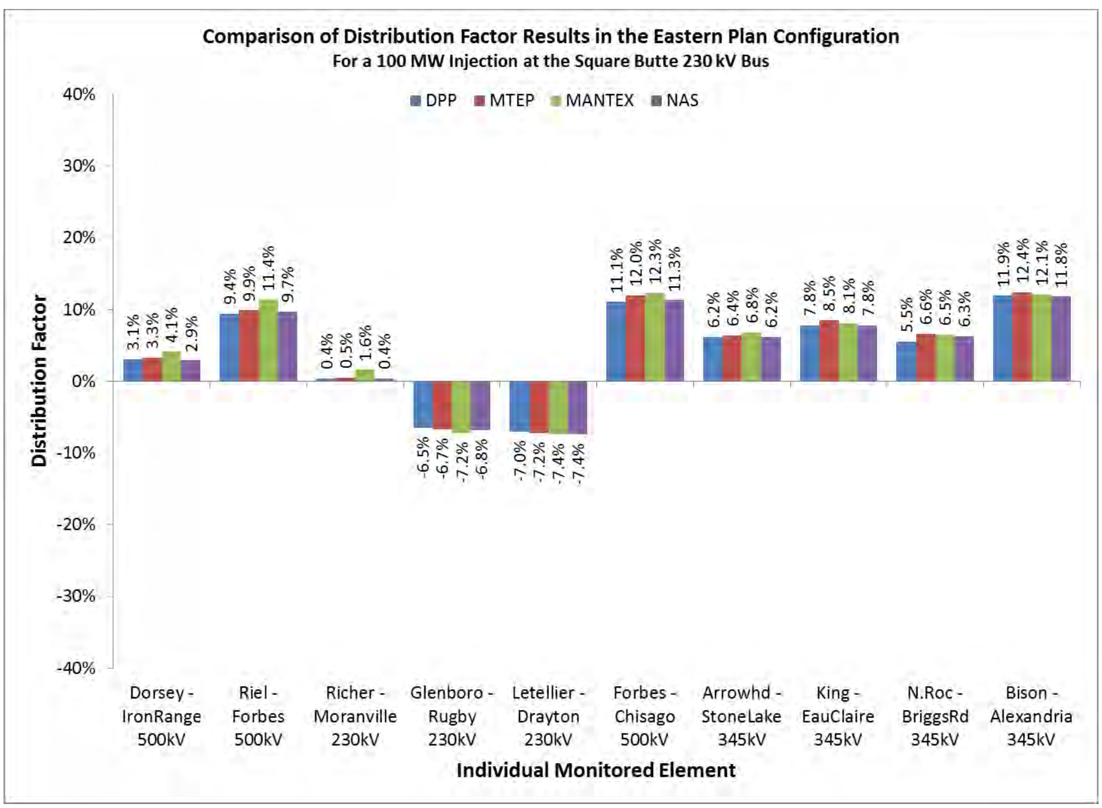


Figure 55: Comparison of Distribution Factor Analysis Results for the Square Butte Injection (E1)

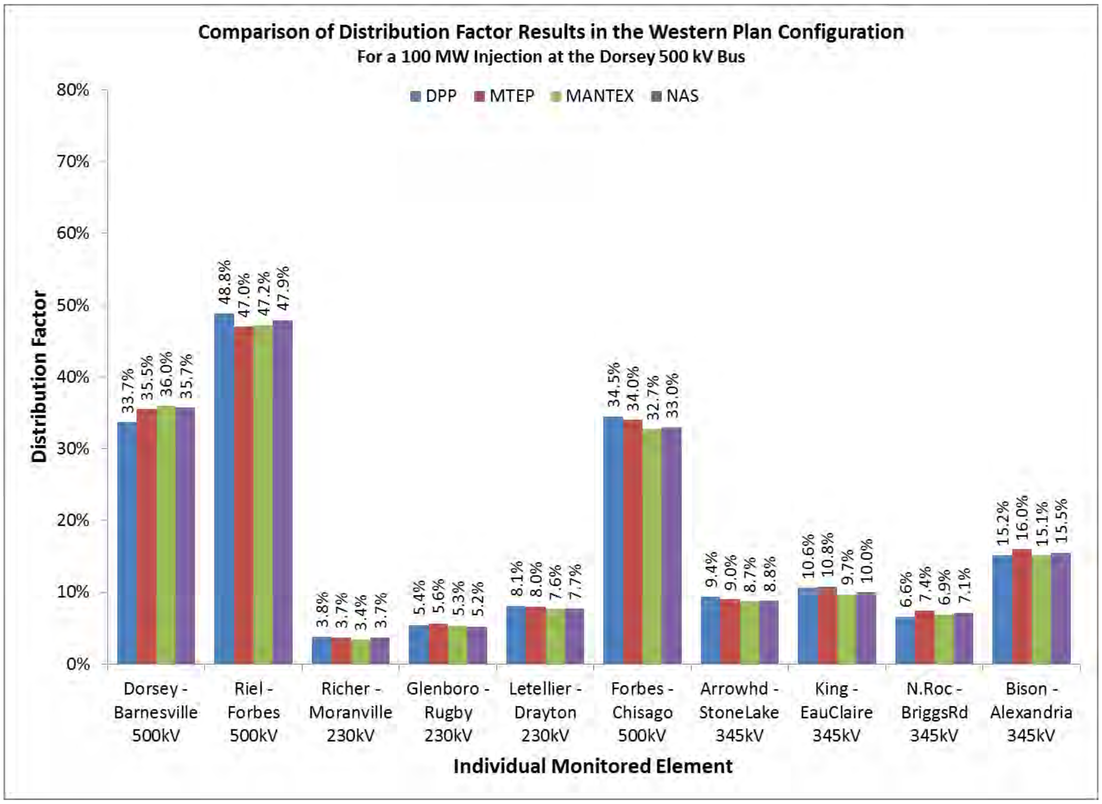


Figure 56: Comparison of Distribution Factor Analysis Results for the Dorsey Injection (W2)

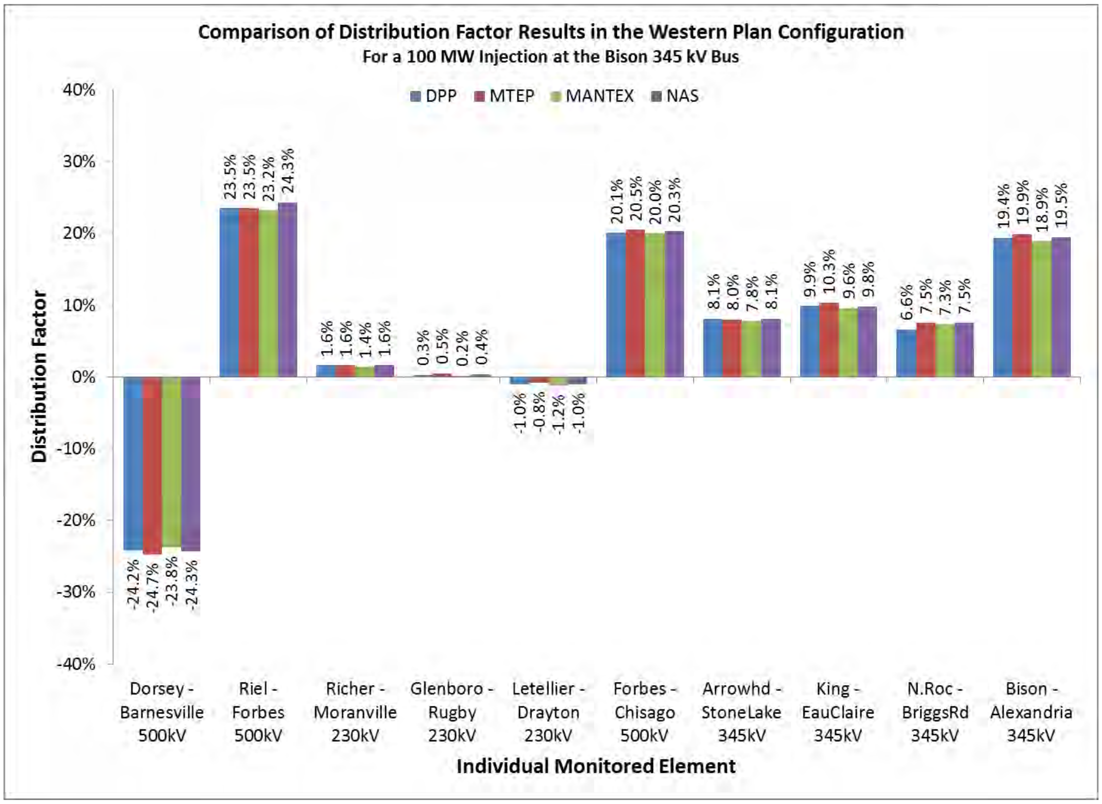


Figure 57: Comparison of Distribution Factor Analysis Results for the Bison Injection (W2)

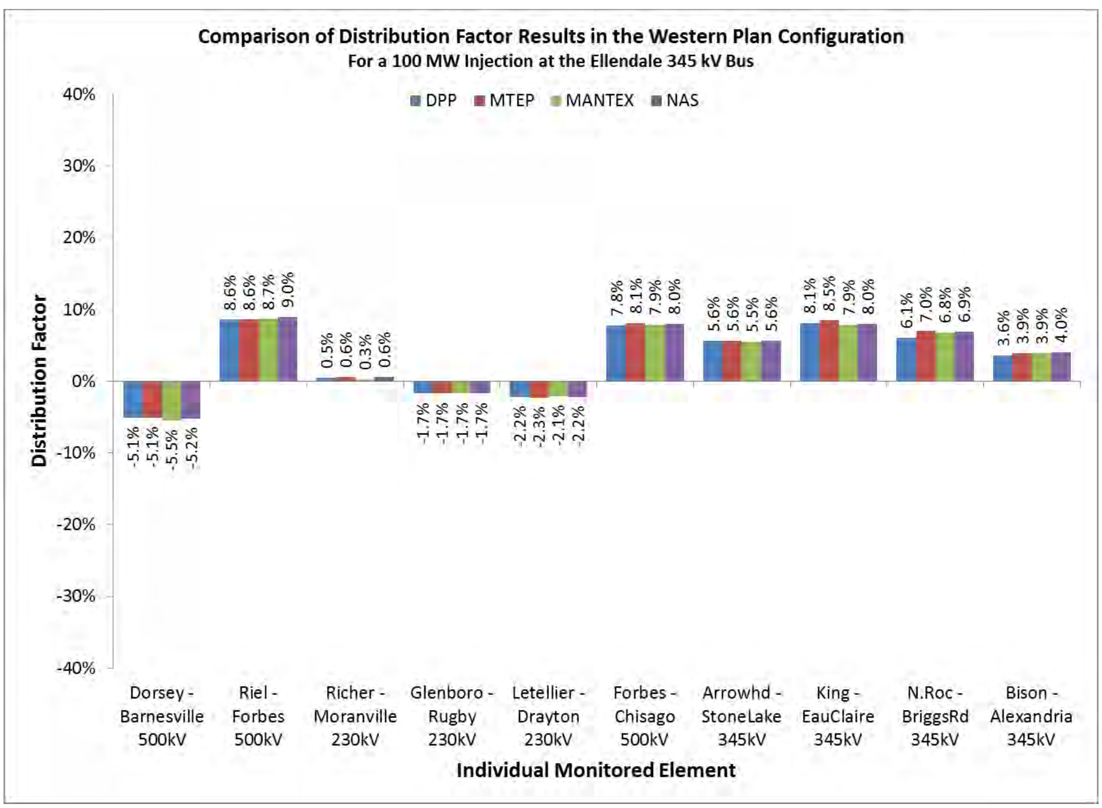


Figure 58: Comparison of Distribution Factor Analysis Results for the Ellendale Injection (W2)

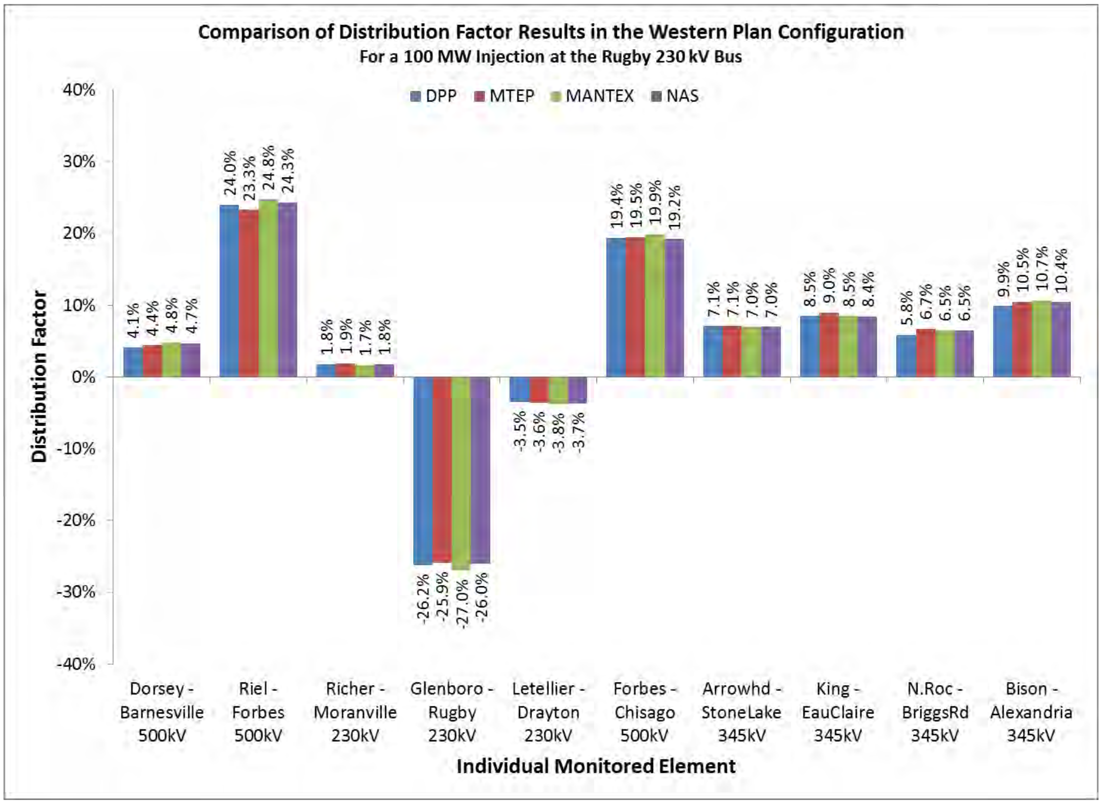


Figure 59: Comparison of Distribution Factor Analysis Results for the Rugby Injection (W2)

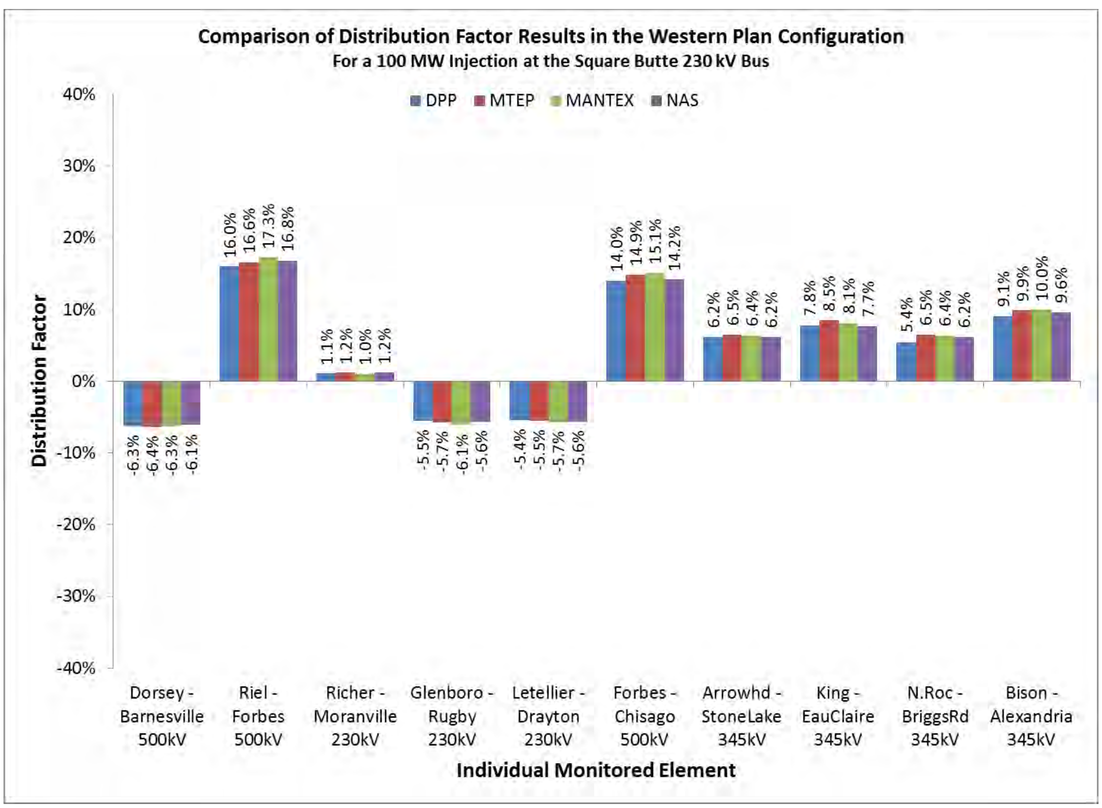


Figure 60: Comparison of Distribution Factor Analysis Results for the Square Butte Injection (W2)

Appendix E: Additional Total Loop Flow Impact Results

As discussed in the Total Loop Flow Impact section of the Report, all four benchmark cases used for the Loop Flow Impact Study produce very similar distribution factor results. Therefore the total loop flow results from the DPP, MANTEX, and NAS cases were omitted from the main text of the Report, which focused solely on the results from the MTEP case. Total loop flow impact results from the DPP, MANTEX, and NAS cases are provided below, alongside the MTEP results provided in the Report.

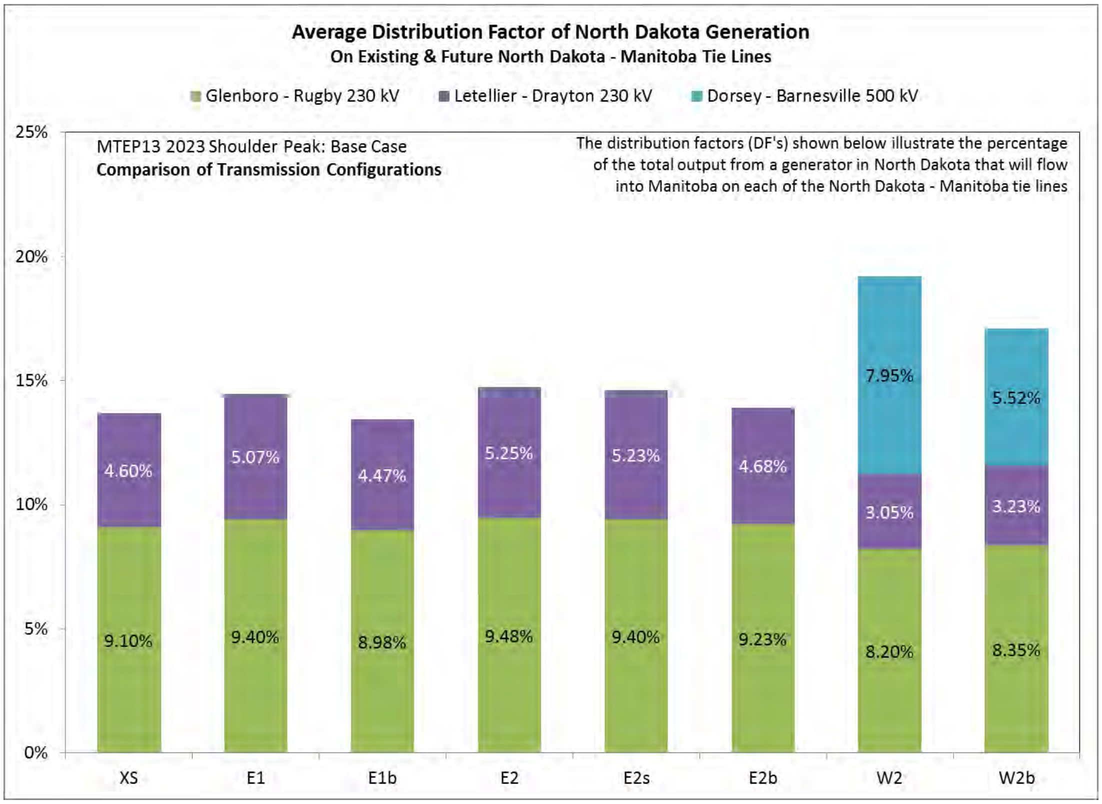


Figure 61: Comparison of Total Loop Flow Impact (MTEP Case)

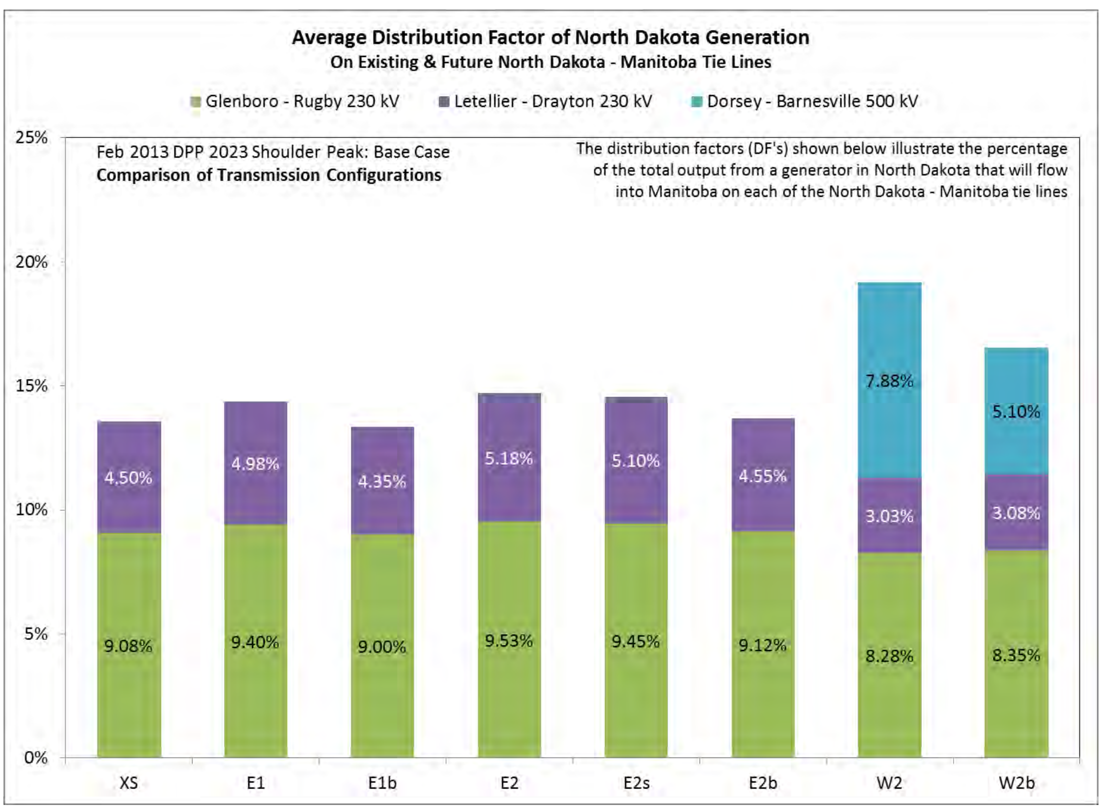


Figure 62: Comparison of Total Loop Flow Impact (DPP Case)

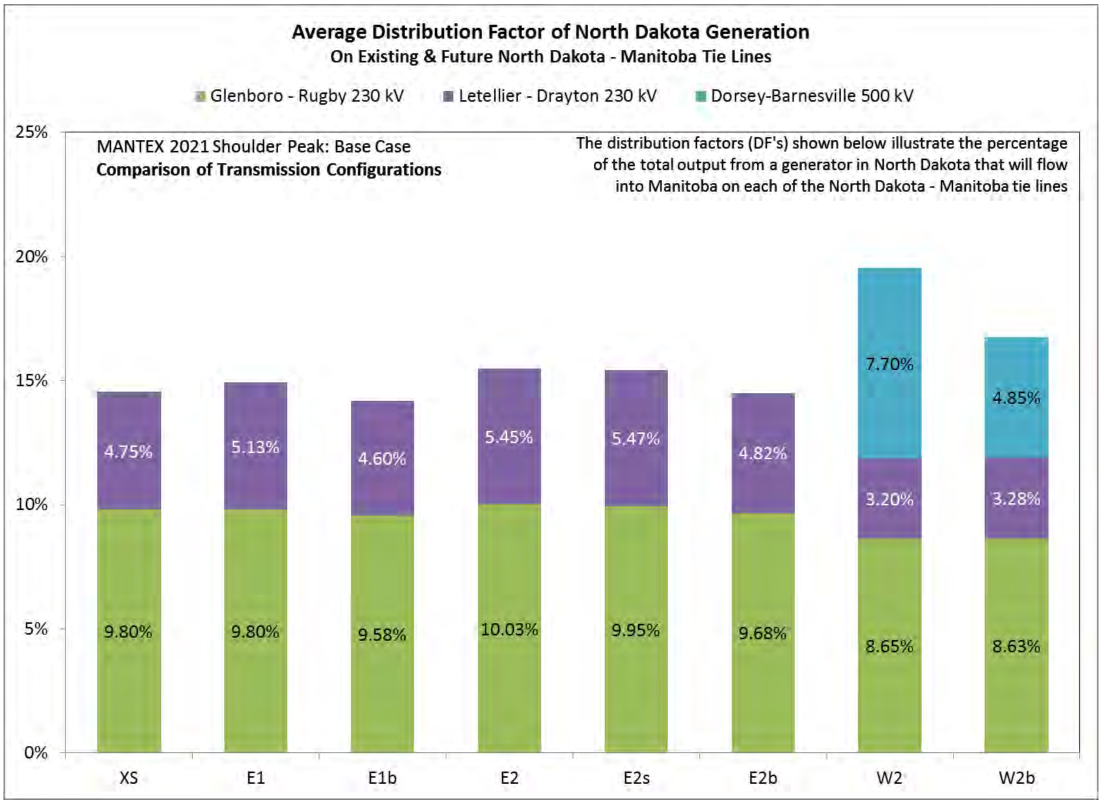


Figure 63: Comparison of Total Loop Flow Impact (MANTEX Case)

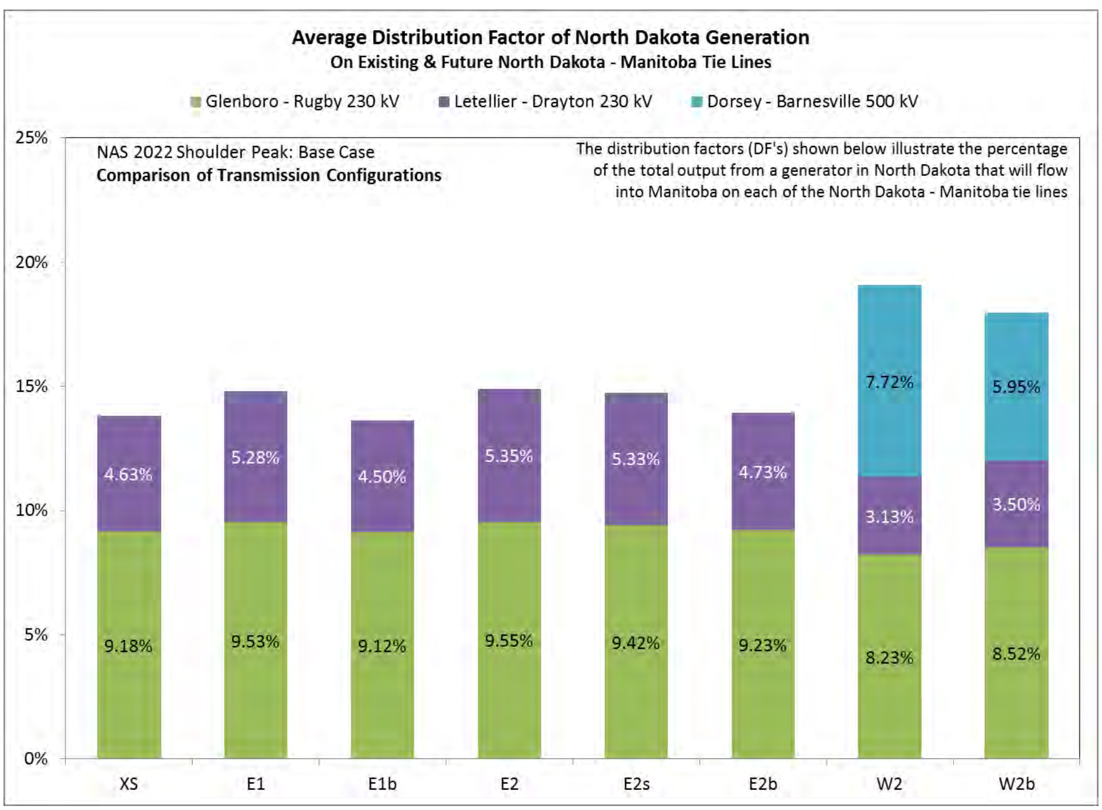


Figure 64: Comparison of Total Loop Flow Impact (NAS Case)

Appendix F: Additional Riel – Forbes 500 kV Line Impact Results

As discussed in the Riel – Forbes 500 kV Line Impact section of the Report, all four benchmark cases used for the Loop Flow Impact Study produce very similar distribution factor results. Therefore the Riel – Forbes 500 kV Line impact results from the DPP, MANTEX, and NAS cases were omitted from the main text of the Report, which focused solely on the results from the MTEP case. Riel – Forbes 500 kV Line impact results from the DPP, MANTEX, and NAS cases are provided below, alongside the MTEP results provided in the Report.

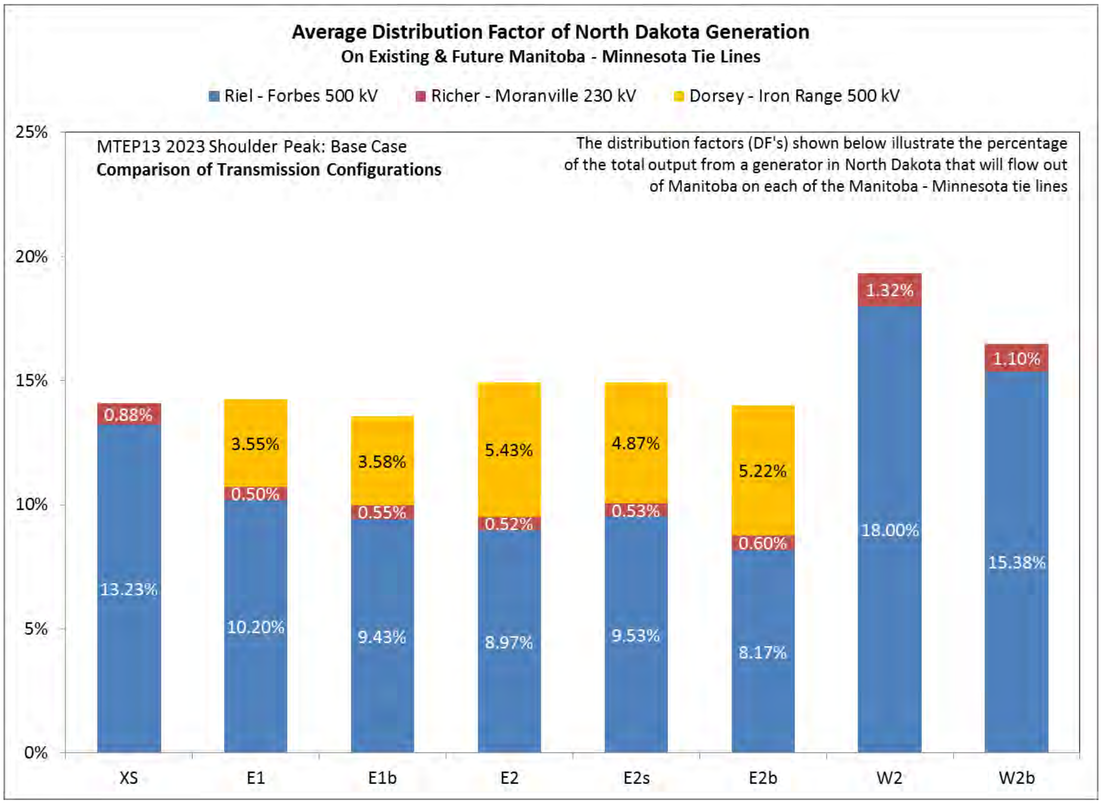


Figure 65: Comparison of Riel - Forbes 500 kV Line Impact (MTEP Case)

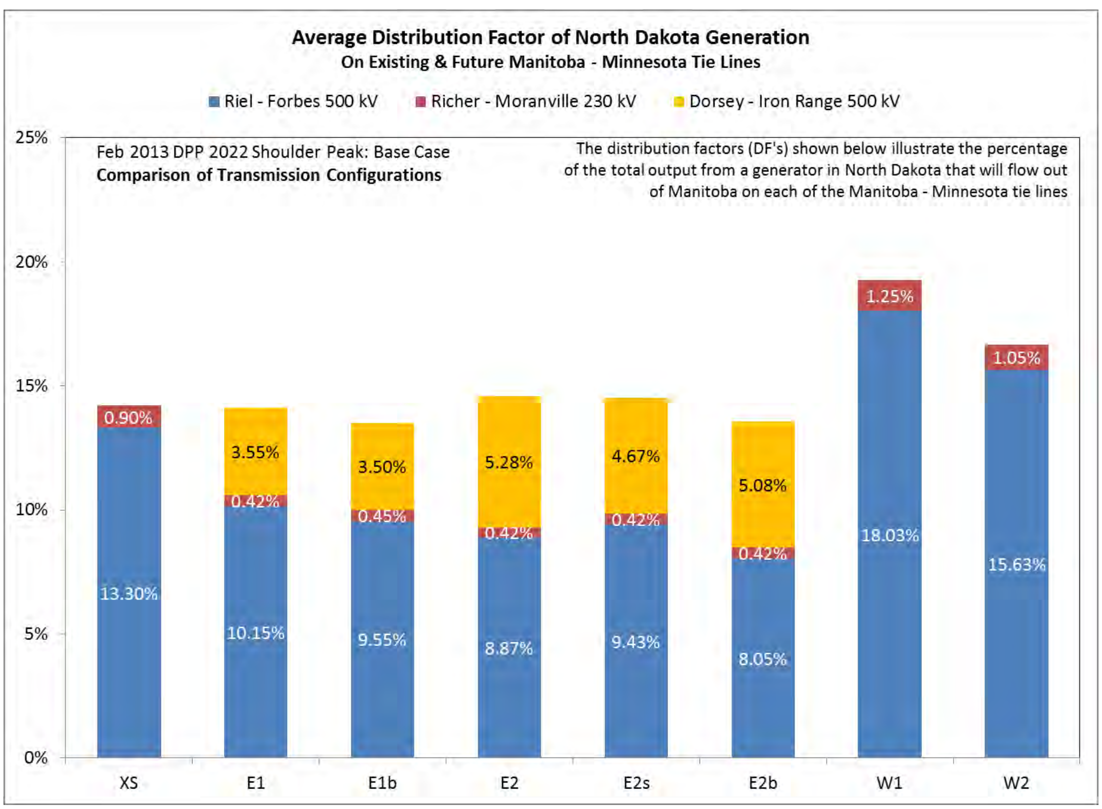


Figure 66: Comparison of Riel - Forbes 500 kV Line Impact (DPP Case)

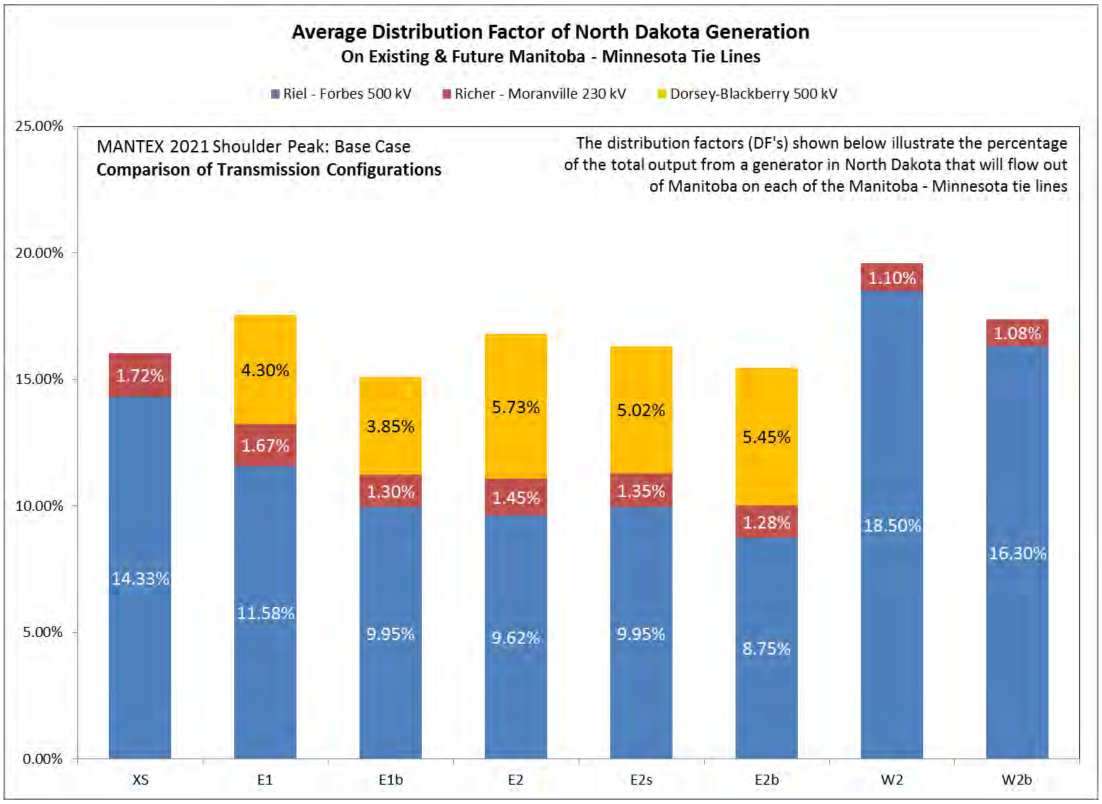


Figure 67: Comparison of Riel - Forbes 500 kV Line Impact (MANTEX Case)

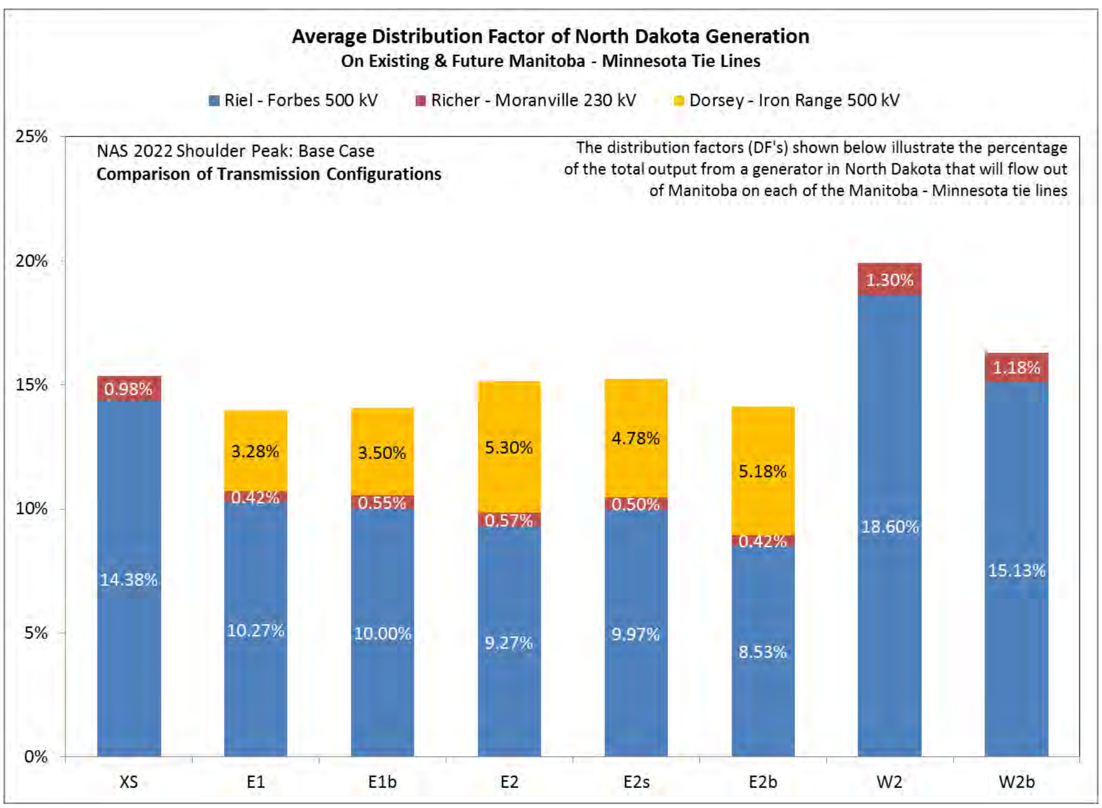


Figure 68: Comparison of Riel - Forbes 500 kV Line Impact (NAS Case)

Appendix G: Additional Simultaneous Outlet Capability Results

As discussed in the Simultaneous North Dakota & Manitoba Outlet Capability section of the Report, all four benchmark cases used for the Loop Flow Impact Study produce very similar distribution factor results. Therefore the simultaneous North Dakota & Manitoba outlet capability results from the DPP, MANTEX, and NAS cases were omitted from the main text of the Report, which focused solely on the results from the MTEP case. Simultaneous North Dakota & Manitoba outlet capability results from the DPP, MANTEX, and NAS cases are provided below, alongside the MTEP results provided in the Report.

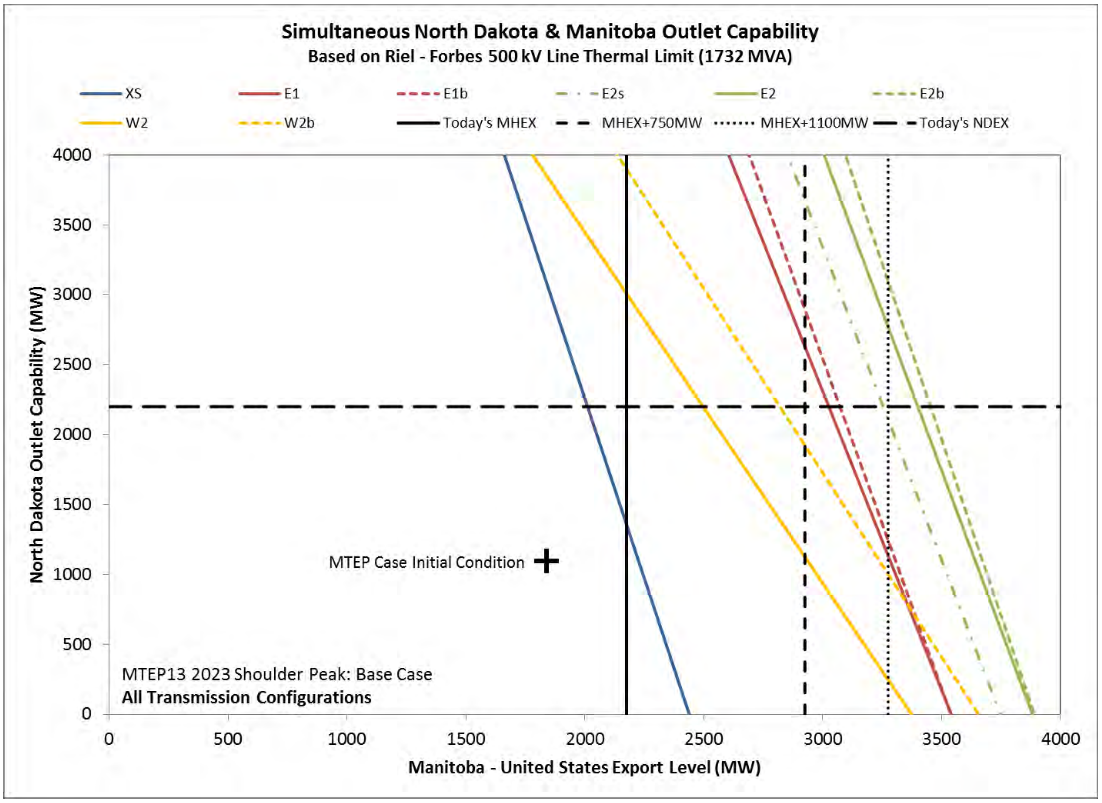


Figure 69: Simultaneous North Dakota & Manitoba Outlet Capability (MTEP Case)

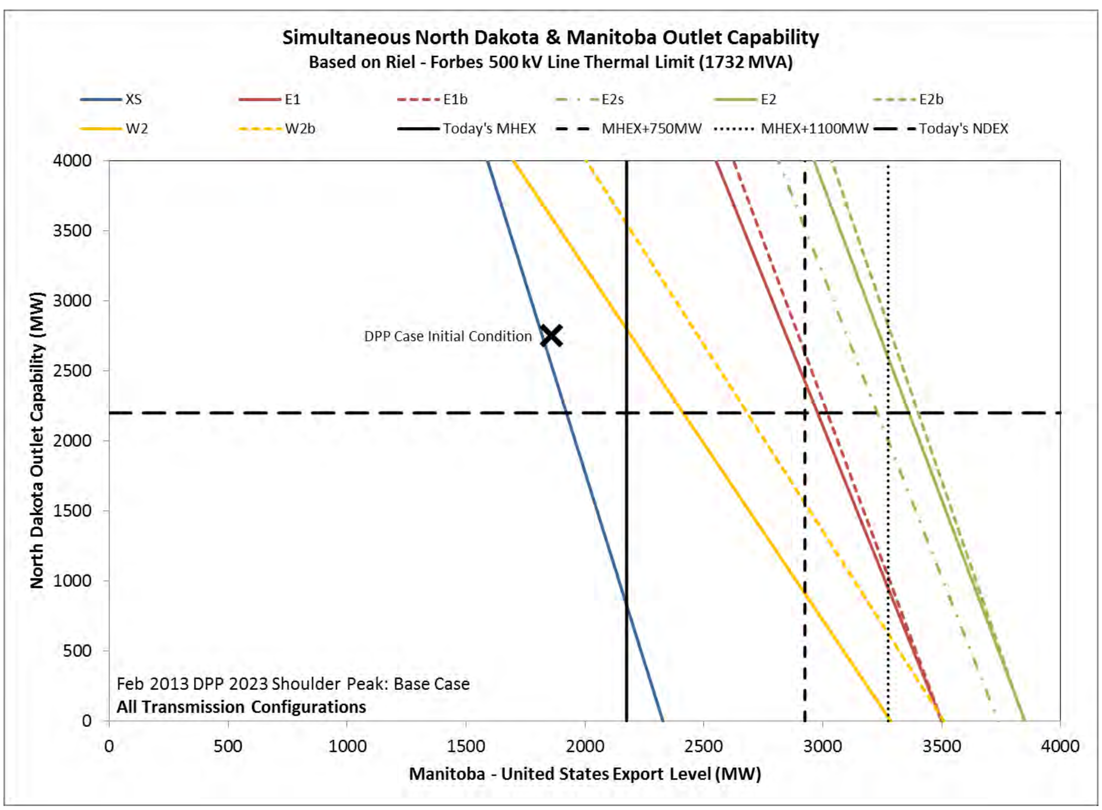


Figure 70: Simultaneous North Dakota & Manitoba Outlet Capability (DPP Case)

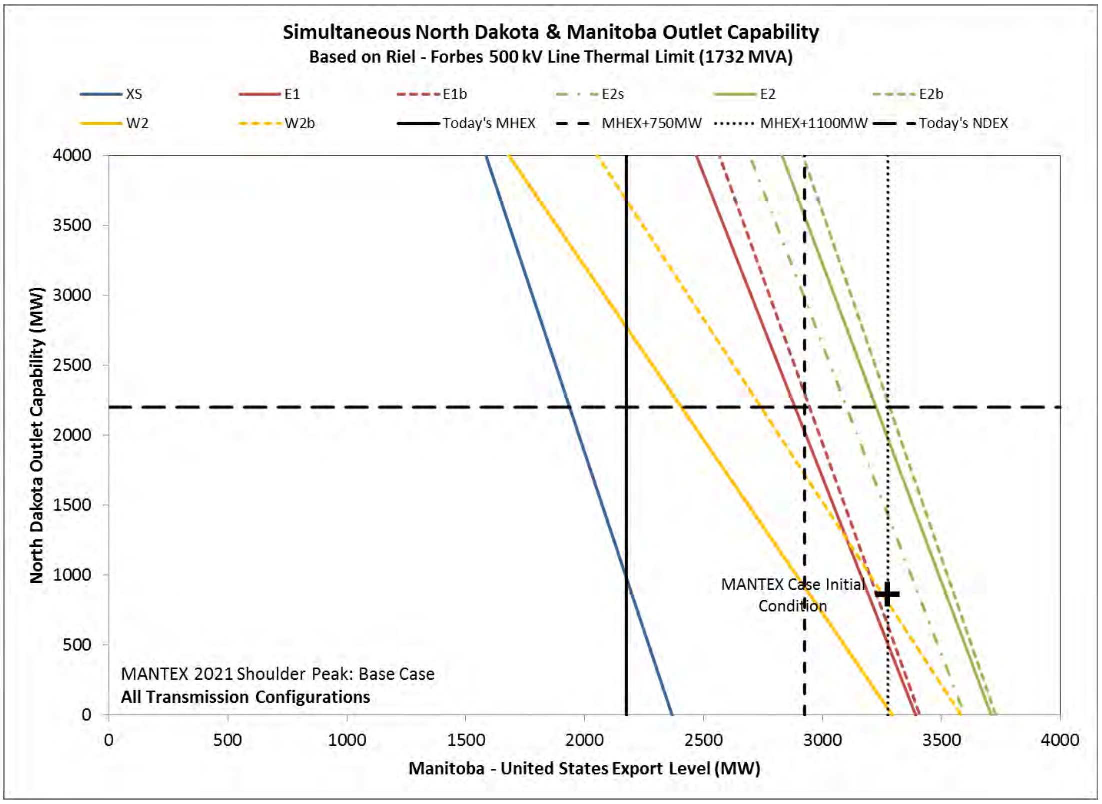


Figure 71: Simultaneous North Dakota & Manitoba Outlet Capability (MANTEX Case)

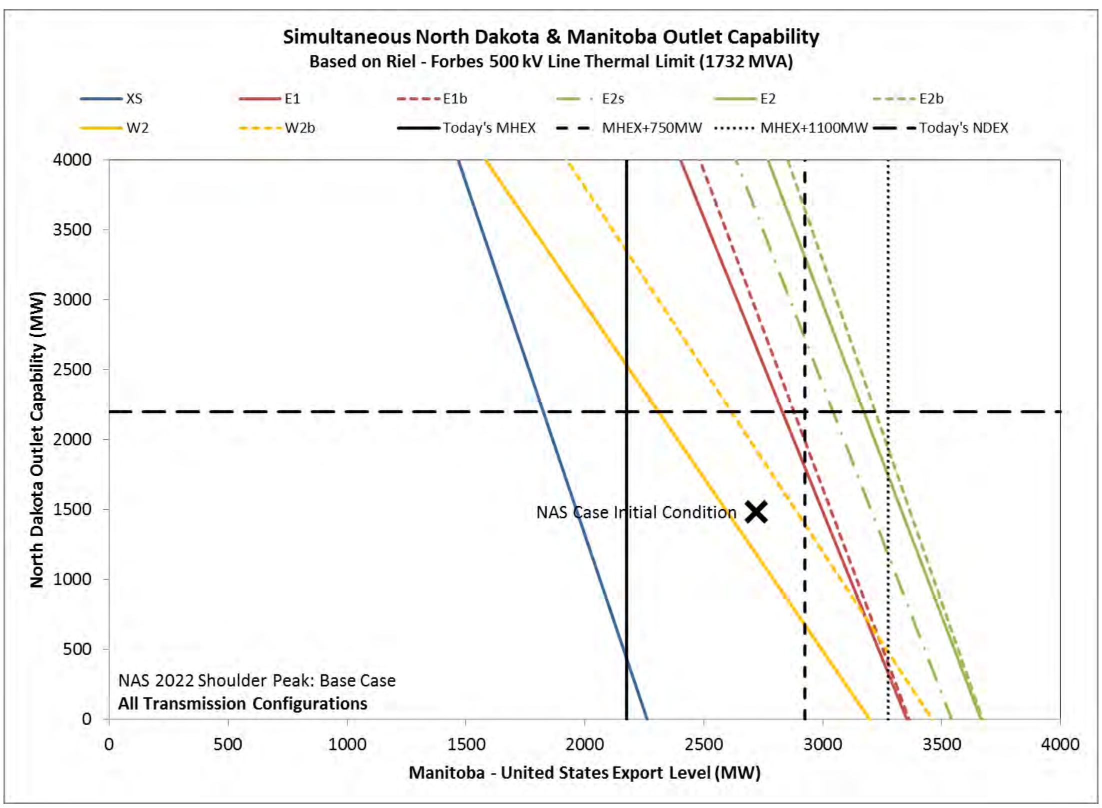


Figure 72: Simultaneous North Dakota & Manitoba Outlet Capability (NAS Case)

Appendix H: Additional Nomogram Observations

Comparing the nomogram results for the various transmission configurations, four general observations were made from Figure 33 in the Simultaneous North Dakota and Manitoba Outlet Capability section of the Report:

1. Both the Eastern and Western plans provide increased simultaneous North Dakota and Manitoba outlet capability compared to the Existing System
2. The Eastern Plan configurations generally provide more potential simultaneous North Dakota and Manitoba outlet capability than the Western Plan configurations
3. The addition of a double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) is a more effective solution than a single circuit Iron Range – Arrowhead 345 kV Line (configuration E2s) for further increasing the potential simultaneous North Dakota and Manitoba outlet capability available from the Eastern Plan (configuration E1)
4. The addition of a second circuit on the Fargo – Monticello 345 kV Line (configuration W2b, E1b, or E2b) also further increases potential simultaneous North Dakota and Manitoba outlet capability, though the impact is more pronounced for the Western Plan

The first two observations, which provide very useful insight into the general loop flow impact of the Eastern Plan and the Western Plan, were discussed in further detail in the main text of the Report. The last two observations, which provide more secondary insight into the loop flow impact of the Iron Range – Arrowhead and Fargo – Monticello 345 kV lines, will be discussed in further detail in this Appendix.

Iron Range – Arrowhead 345 kV Addition

The addition of a double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) is a more effective solution than a single circuit Iron Range – Arrowhead 345 kV Line (configuration E2s) for further increasing the potential simultaneous North Dakota and Manitoba outlet capability available from the Eastern Plan (configuration E1).

The capability of the basic Eastern Plan (configuration E1), the combined Eastern Plan and single circuit Iron Range – Arrowhead 345 kV Line (configuration E2s), and the combined Eastern Plan and double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) to facilitate the longer-term need for 1100 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is shown in Figure 73 below.

As discussed above, configuration E1 is potentially[10] capable of facilitating up to 2613 MW of North Dakota outlet capability at the desired level of 750 MW incremental Manitoba to United States transfer capability. Ignoring other system constraints that may arise when the Manitoba to United States transfer level is increased beyond the desired 750 MW level, Figure 73 shows that configuration E1 could facilitate up to 1112 MW of North Dakota outlet capability simultaneously with 1100 MW of incremental Manitoba to United States transfer capability before overloading the Riel – Forbes 500 kV Line. The addition of a single circuit Iron Range – Arrowhead 345 kV Line would increase North Dakota outlet capability to 2107 MW, just under today's level of 2200 MW. As discussed in the main body of the report and shown in Figure 73, the addition of a double circuit Iron Range – Arrowhead 345 kV Line would increase North Dakota outlet capability well beyond today's level, potentially all the way up to 2743 MW.

[10] Depending on what other thermal or stability constraints may exist with MHEX = 2925 and NDEX = 2613

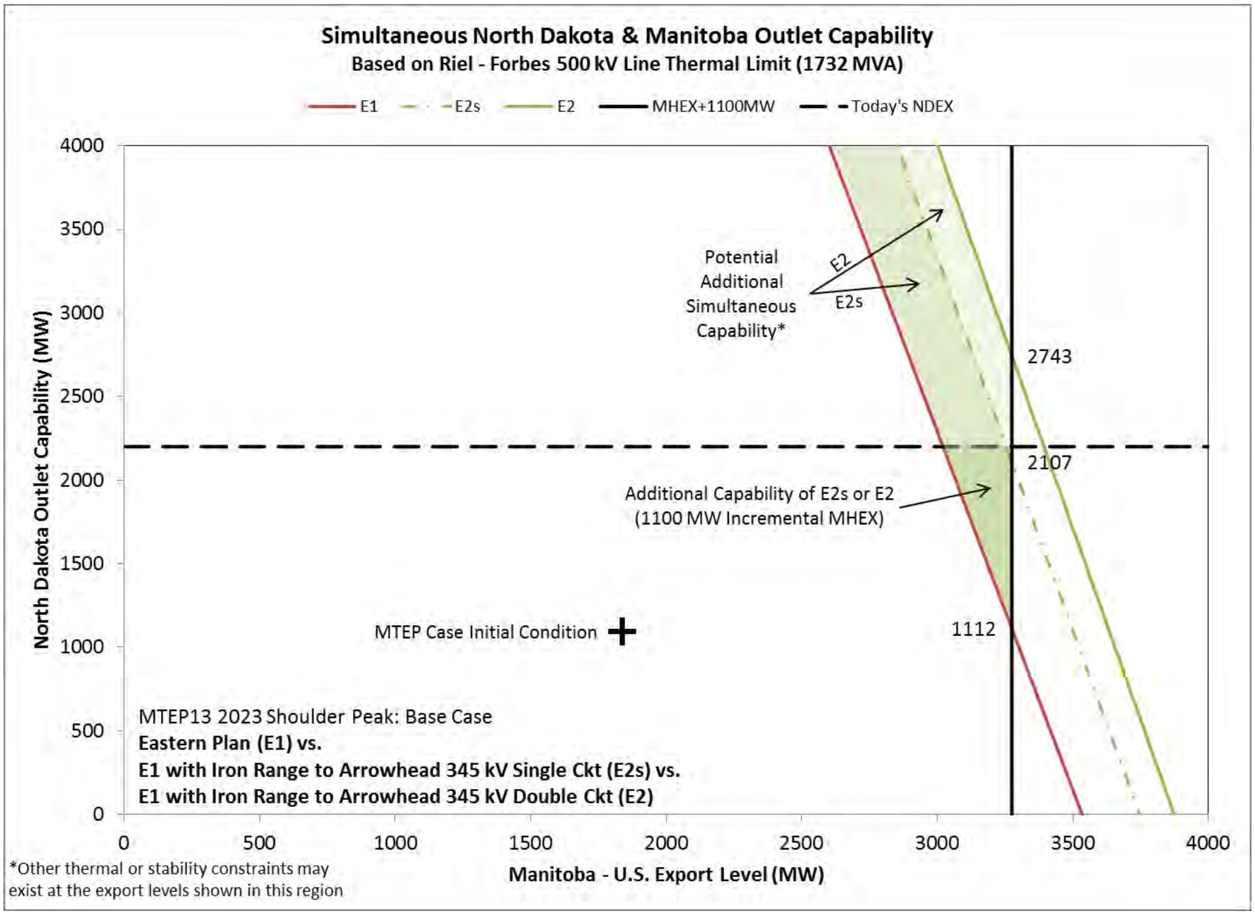


Figure 73: Simultaneous North Dakota & Manitoba Outlet Capability – E1 vs. E2s vs. E2

Comparing the simultaneous North Dakota and Manitoba outlet capability afforded by the three Eastern Plan configurations at the 1100 MW incremental Manitoba to United States transfer level, it appears that the double circuit Iron Range – Arrowhead 345 kV Line is the most effective solution for providing the desired incremental capability from Manitoba without limiting North Dakota outlet capability. While the single circuit Iron Range – Arrowhead 345 kV Line provides considerable additional simultaneous outlet capability compared to the basic Eastern Plan, the resulting North Dakota outlet capability is just below today's level. Therefore, in a consideration of simultaneous North Dakota and Manitoba outlet capability at the 1100 MW incremental Manitoba to United States transfer level, the double circuit is to be preferred over the single circuit for the Iron Range – Arrowhead 345 kV Line.

Fargo – Monticello 345 kV Line Addition

The addition of a second circuit on the Fargo – Monticello 345 kV Line (configuration W2b, E1b, or E2b) also further increases potential simultaneous North Dakota and Manitoba outlet capability, though the impact is more pronounced for the Western Plan.

The capability of the Western Plan (configuration W2) and the combined Western Plan and a second circuit on the Barnesville – Alexandria – Quarry – Monticello 345 kV Line (configuration W2b) to facilitate either the near-term need for 750 MW or the longer-term need for 1100 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is shown in Figure 74 below.

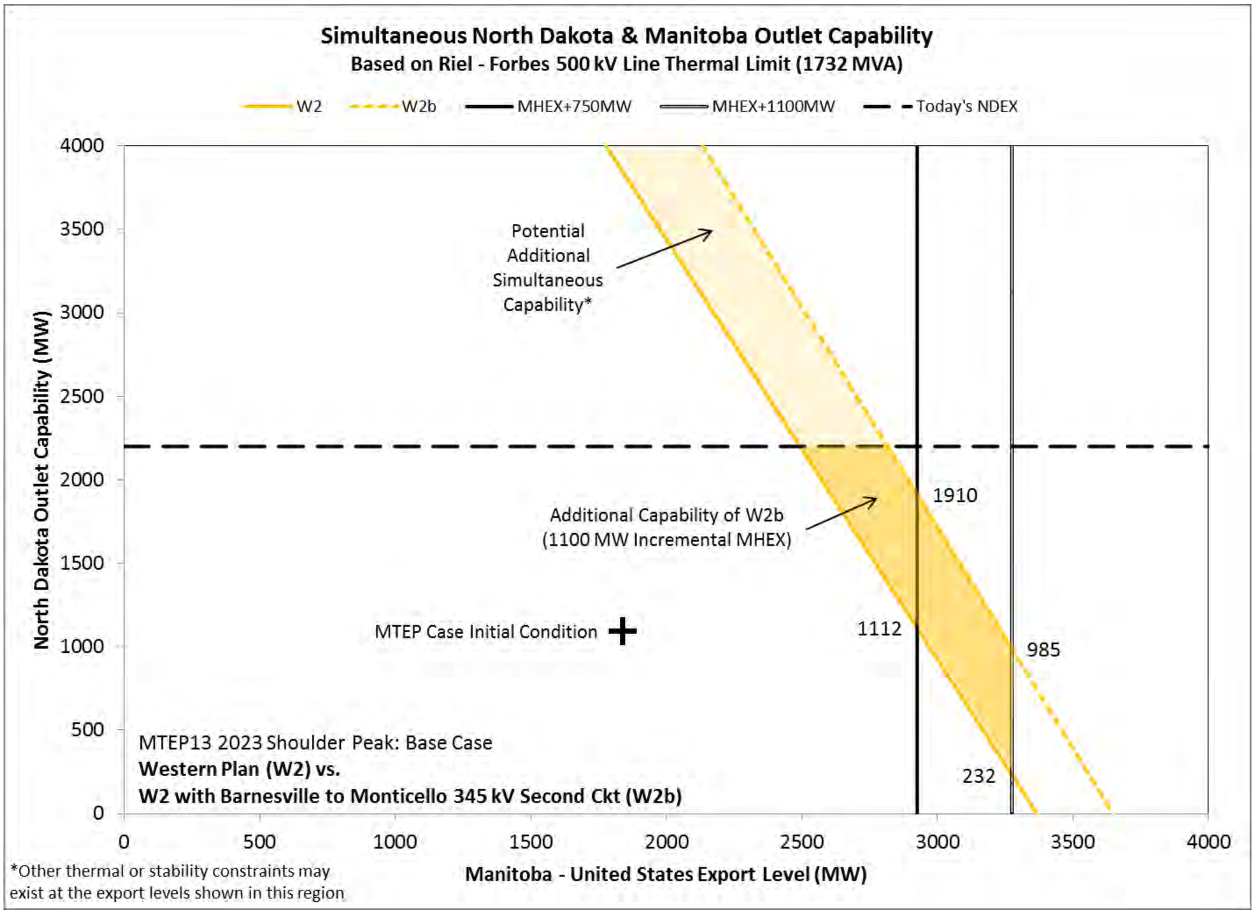


Figure 74: Simultaneous North Dakota & Manitoba Outlet Capability – W2 vs. W2b

As discussed in the main body of the report, configuration W2 would limit North Dakota outlet capability to 1112 MW and 232 MW, respectively, at the 750 MW and 1100 MW incremental Manitoba to United States transfer levels based on the M602F constraint. At the 750 MW incremental Manitoba transfer level, the addition of a second circuit on the Barnesville – Monticello 345 kV Line would increase North Dakota outlet capability by nearly 800 MW, to 1910 MW total. At the 1100 MW incremental Manitoba transfer level, the addition of the second circuit on the Barnesville - Monticello 345 kV Line would increase North Dakota outlet capability by 753 MW, to 985 MW total. In both cases, the resulting North Dakota outlet capability would still be less than today's level of 2200 MW. This does, however, demonstrate that the addition of the second circuit on the Barnesville – Monticello 345 kV Line increases the potential simultaneous North Dakota and Manitoba outlet capability considerably for the Western Plan.

The capability of the Eastern Plan (configuration E1) and the combined Eastern Plan and a second circuit on the Bison – Monticello 345 kV Line (configuration E1b) to facilitate the near-term need for 750 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is shown in Figure 75 below.

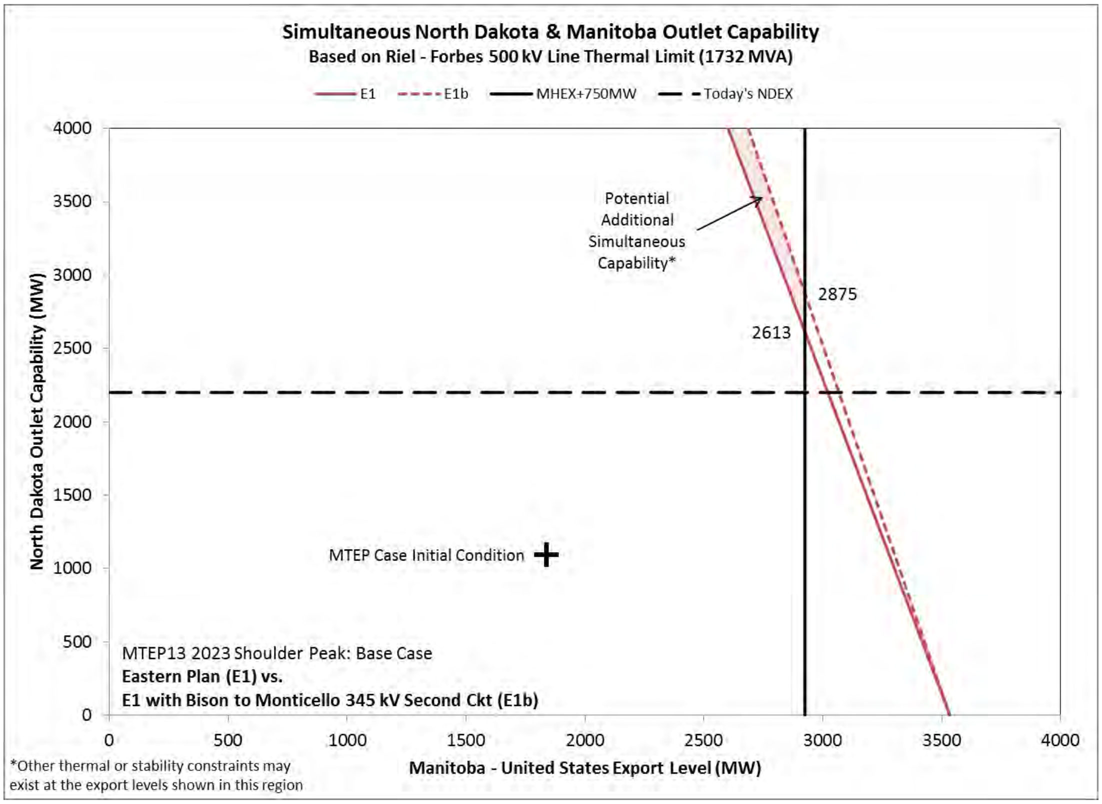


Figure 75: Simultaneous North Dakota & Manitoba Outlet Capability – E1 vs. E1b

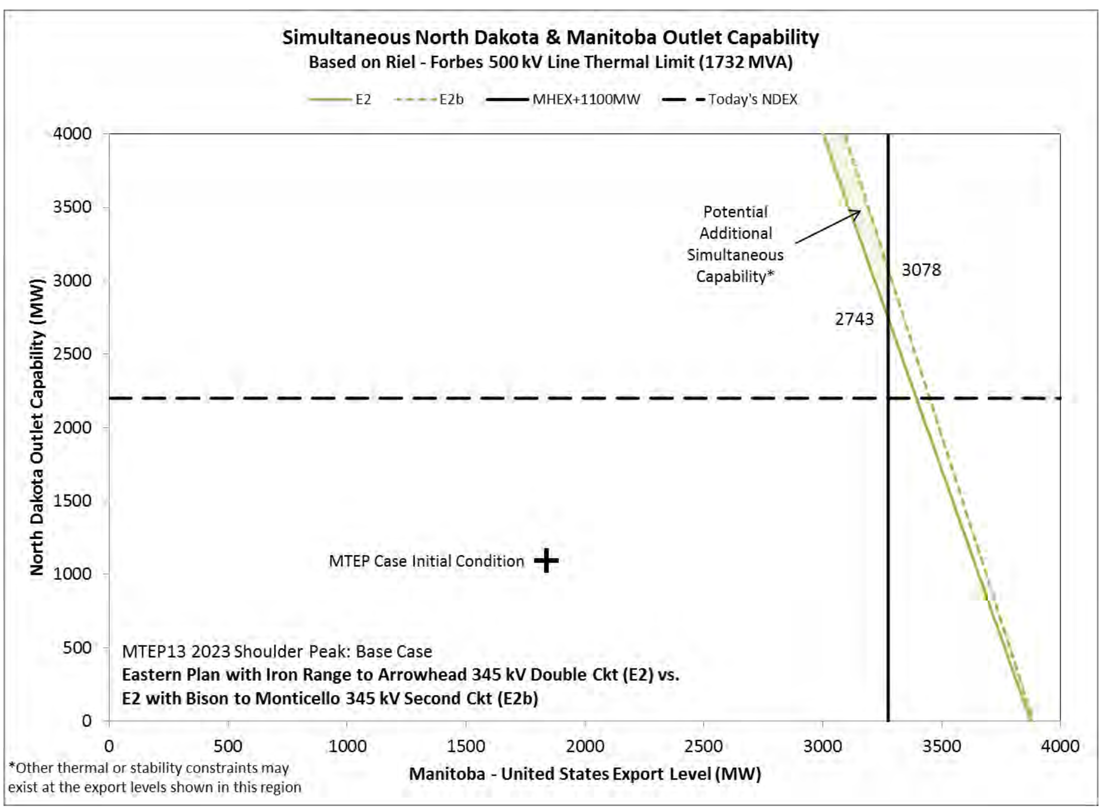


Figure 76: Simultaneous North Dakota & Manitoba Outlet Capability – E2 vs. E2b

As discussed in the main body of the report, configuration E1 is potentially[11] capable of facilitating up to 2613 MW of North Dakota outlet capability at the desired level of 750 MW incremental Manitoba to United States transfer capability. This alone represents an increase of 413 MW over today's North Dakota outlet capability level. The addition of a second circuit on the Bison – Monticello 345 kV Line would further increase potential North Dakota outlet capability by 262 MW, to 2875 MW total.

The capability of the combined Eastern Plan and double circuit Iron Range – Arrowhead 345 kV Line (configuration E2) and the combined Eastern Plan, double circuit Iron Range – Arrowhead 345 kV Line, and a second circuit on the Bison – Monticello 345 kV Line (configuration E2b) to facilitate the longer-term need for 1100 MW of incremental transfer capability from Manitoba to the United States without limiting North Dakota outlet capability is shown in Figure 76 above. As discussed in the main body of the report, configuration E2 is potentially[12] capable of facilitating up to 2743 MW of North Dakota outlet capability at the desired level of 1100 MW incremental Manitoba to United States transfer capability. This alone represents an increase of 543 MW over today's North Dakota outlet capability level. The addition of a second circuit on the Bison – Monticello 345 kV Line would further increase potential North Dakota outlet capability by 335 MW, to 3078 MW total.

This demonstrates that the second circuit of the Bison – Monticello 345 kV does have potentially considerable value for incrementally increasing North Dakota outlet capability when combined with the Eastern Plan and associated transmission configurations. However, even without the addition of the second circuit on the Bison – Monticello 345 kV Line, the Eastern Plan configurations alone are fully capable of maintaining and even potentially increasing North Dakota outlet capability simultaneous with the expected Manitoba Hydro export levels without overloading M602F.

[11] Depending on what other thermal or stability constraints may exist with MHEX = 2925 and NDEX = 2629
[12] Depending on what other thermal or stability constraints may exist with MHEX = 3275 and NDEX = 2769

Appendix I: Additional Series Capacitor Upgrade Sensitivity Results

As discussed in the Roseau Series Capacitor Upgrade sensitivity section of the report, all four benchmark cases used for the Loop Flow Impact Study produce very similar results. Therefore the series capacitor upgrade sensitivity results from the DPP, MANTEX, and NAS cases were omitted from the main text of the report, which focused solely on the results from the MTEP case. Roseau Series Capacitor Upgrade sensitivity results from the DPP, MANTEX, and NAS cases are provided below, alongside the MTEP results provided in the report.

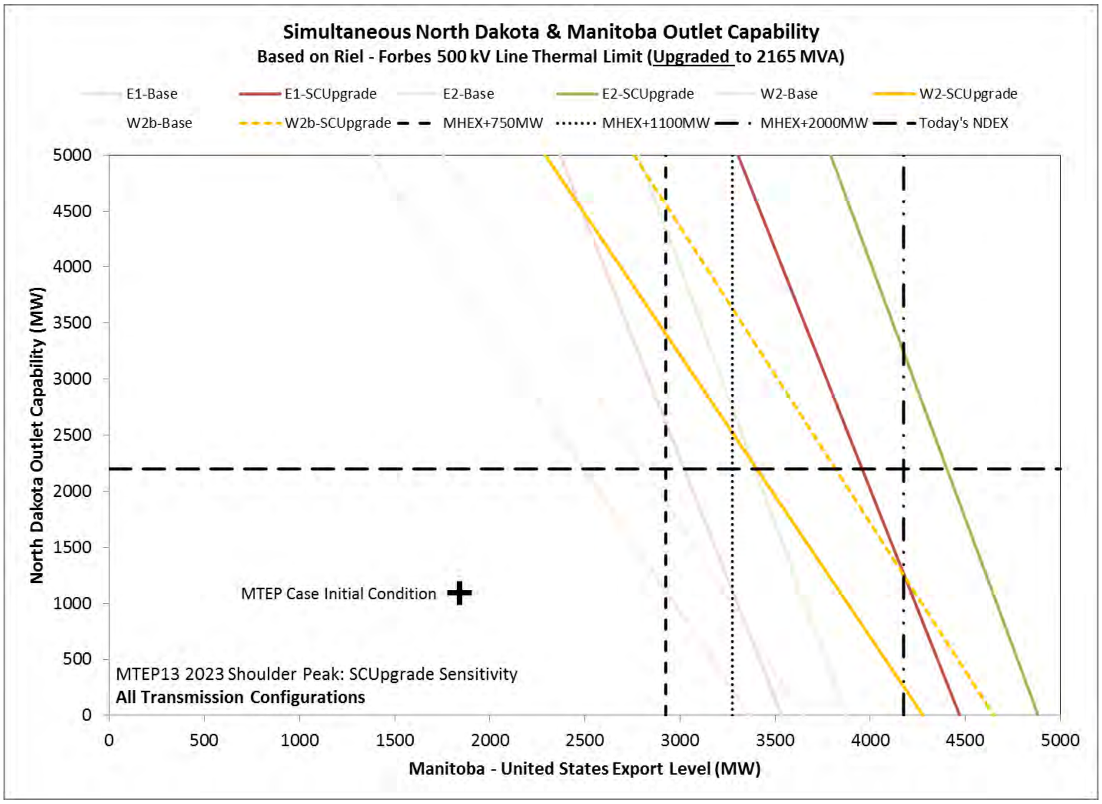


Figure 77: Simultaneous North Dakota & Manitoba Outlet Capability – SCUpgrade Sensitivity (MTEP Case)

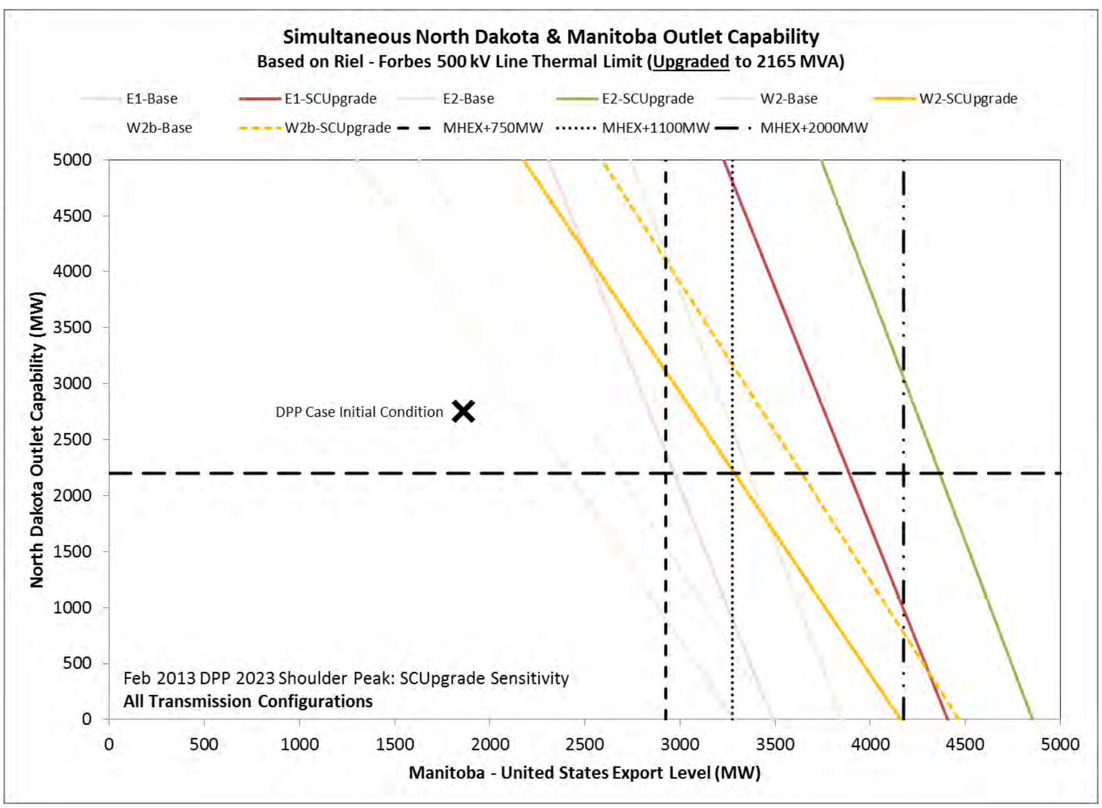


Figure 78: Simultaneous North Dakota & Manitoba Outlet Capability – SCUpgrade Sensitivity (DPP Case)

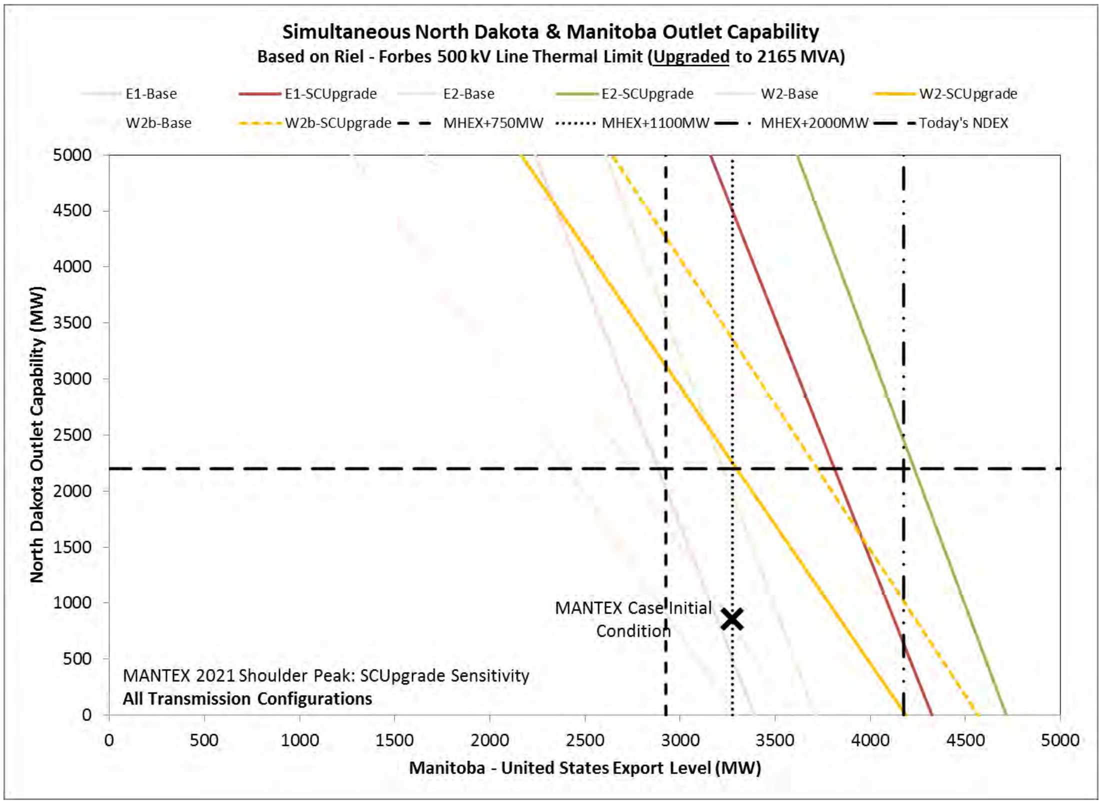


Figure 79: Simultaneous North Dakota & Manitoba Outlet Capability – SCUpgrade Sensitivity (MANTEX Case)

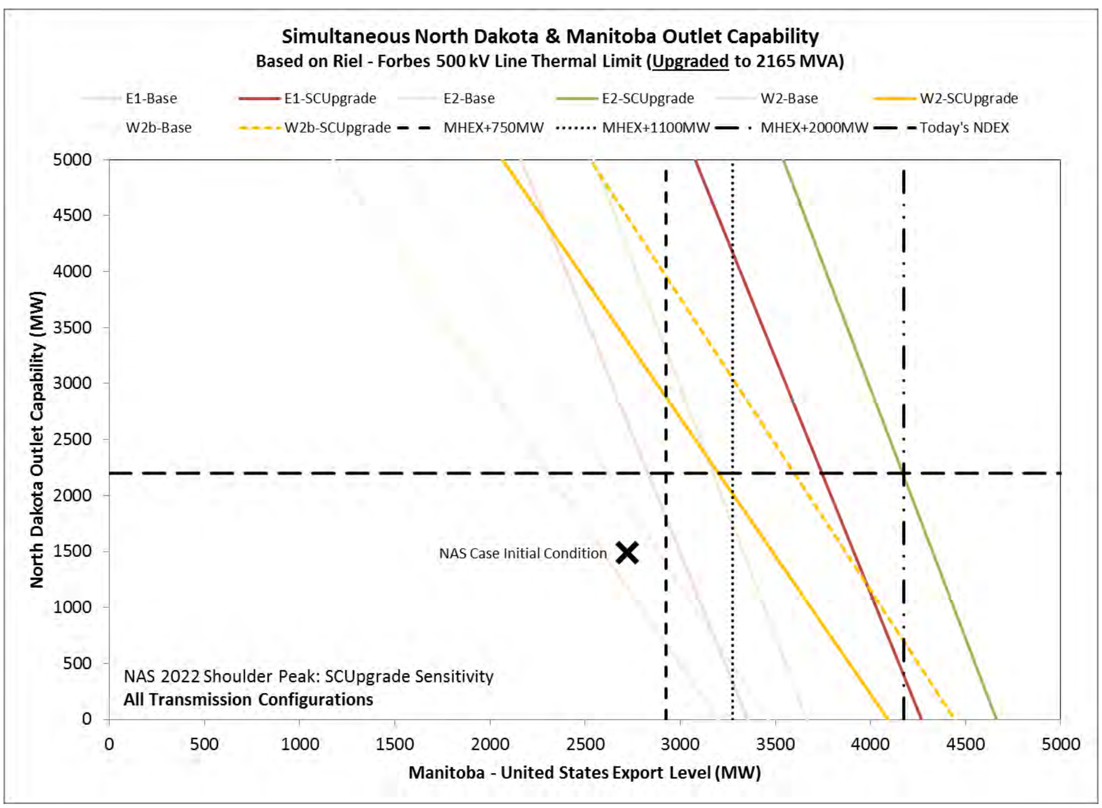


Figure 80: Simultaneous North Dakota & Manitoba Outlet Capability – SCUpgrade Sensitivity (NAS Case)

Appendix J: Additional Glenboro Phase Shifter Sensitivity Results

The Glenboro Phase Shifter sensitivity section of the report focused on the North Dakota and Manitoba outlet capability available at specific levels of MHEX and NDEX, respectively. The nomogram plots from which this information was derived are provided below for each transmission configuration.

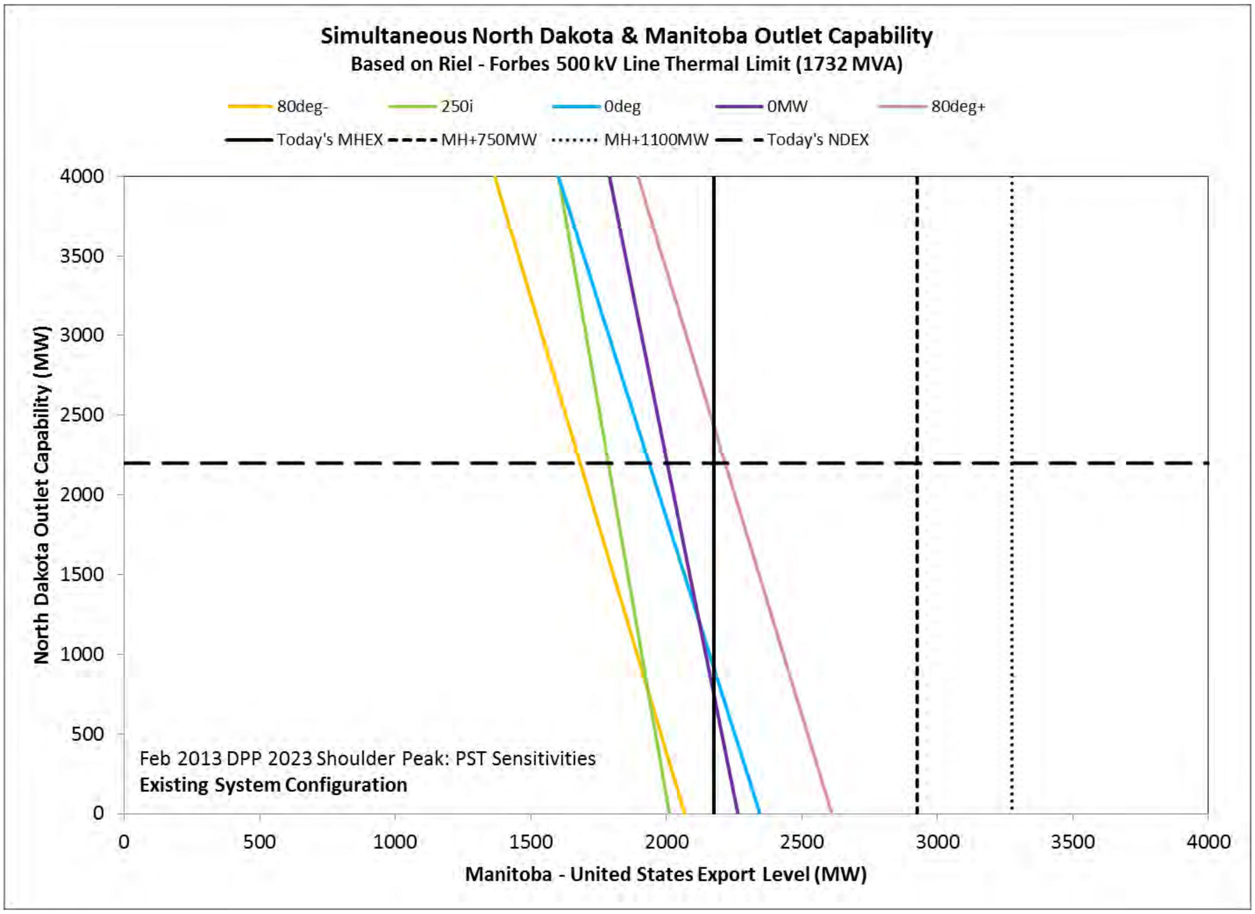


Figure 81: Simultaneous North Dakota & Manitoba Outlet Capability – Glenboro PST Sensitivity (XS)

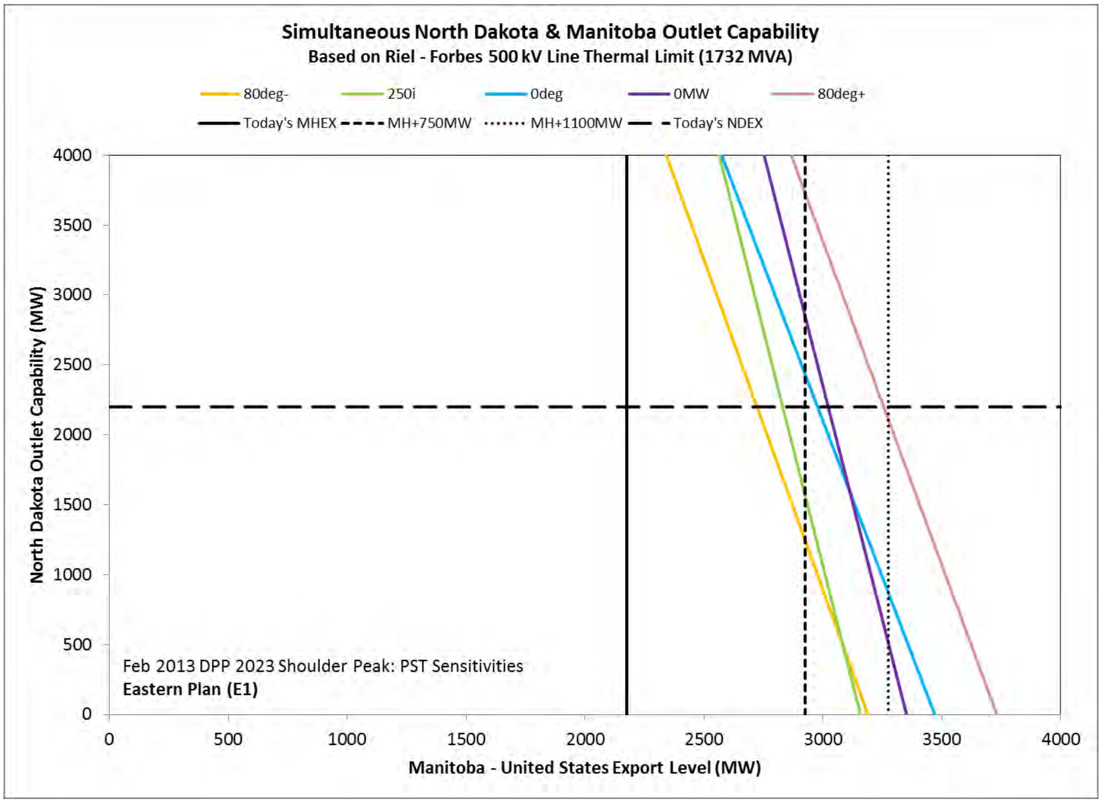


Figure 82: Simultaneous North Dakota & Manitoba Outlet Capability – Glenboro PST Sensitivity (E1)

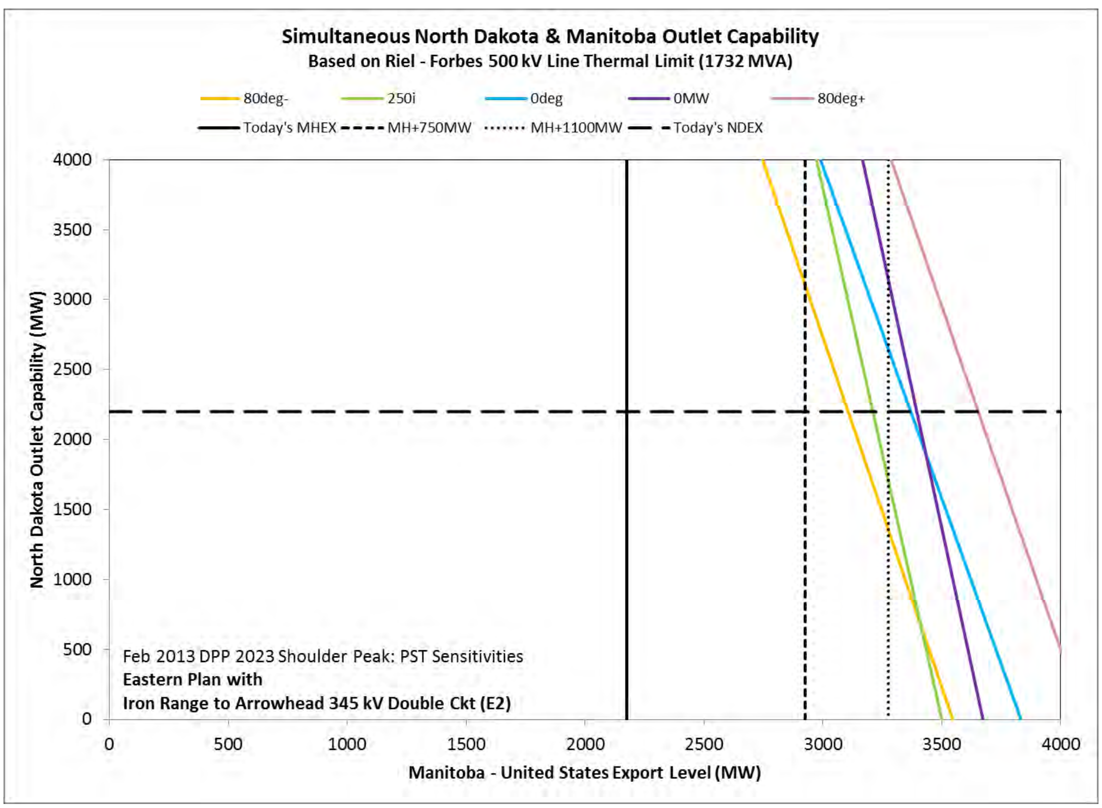


Figure 83: Simultaneous North Dakota & Manitoba Outlet Capability – Glenboro PST Sensitivity (E2)

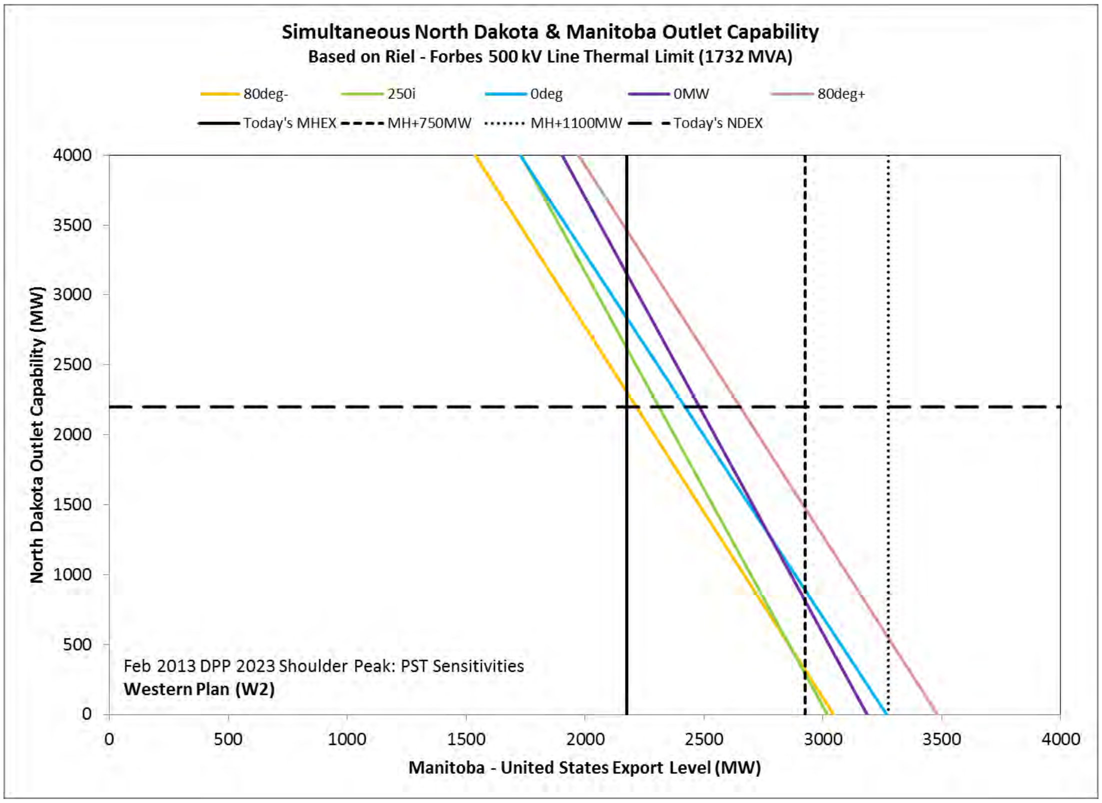


Figure 84: Simultaneous North Dakota & Manitoba Outlet Capability – Glenboro PST Sensitivity (W2)

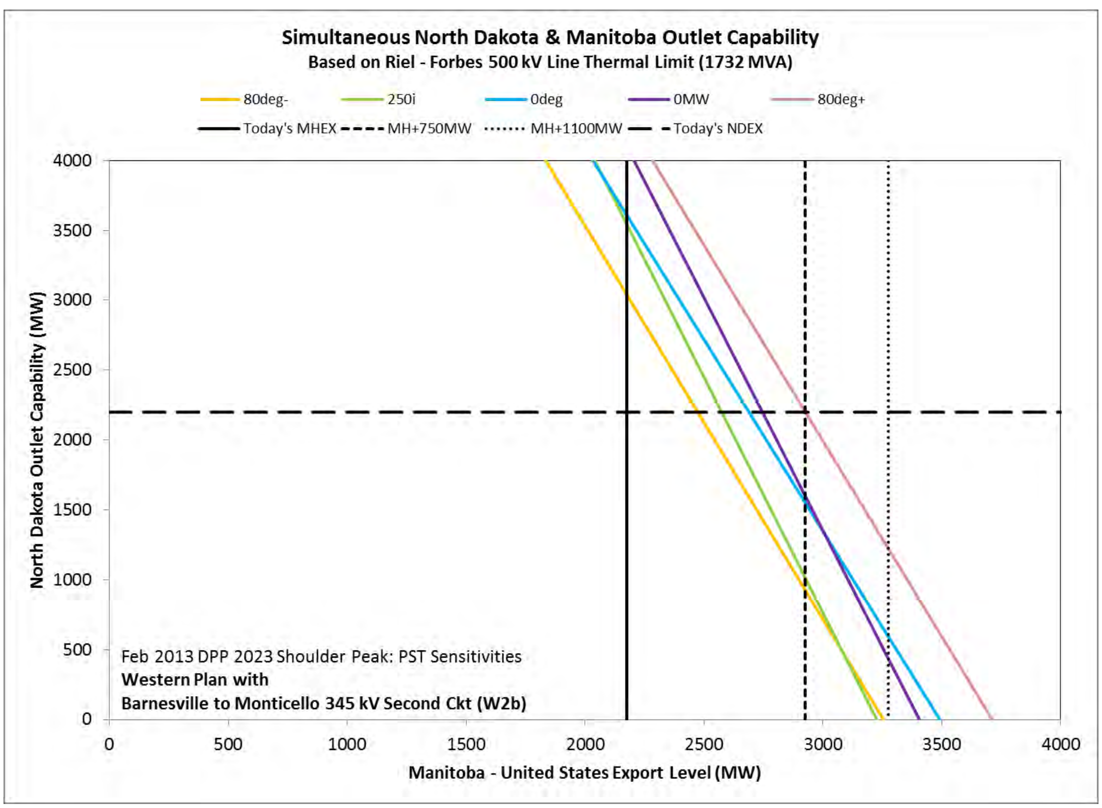


Figure 85: Simultaneous North Dakota & Manitoba Outlet Capability – Glenboro PST Sensitivity (W2b)

Appendix K: Certificate of Need Application Excerpt

The following is an excerpt from pages 95-100 of Minnesota Power's Application for a Certificate of Need for the Great Northern Transmission Line (MPUC Docket No. E-015/CN-12-1163), which was filed on October 21, 2013. The text and diagrams summarize the preliminary results of the New Tie Line Loop Flow Impact Study. In the Certificate of Need Application, the Western Plan is referred to as "the Fargo Area Study Concept," while the Eastern Plan is referred to as "the Project"

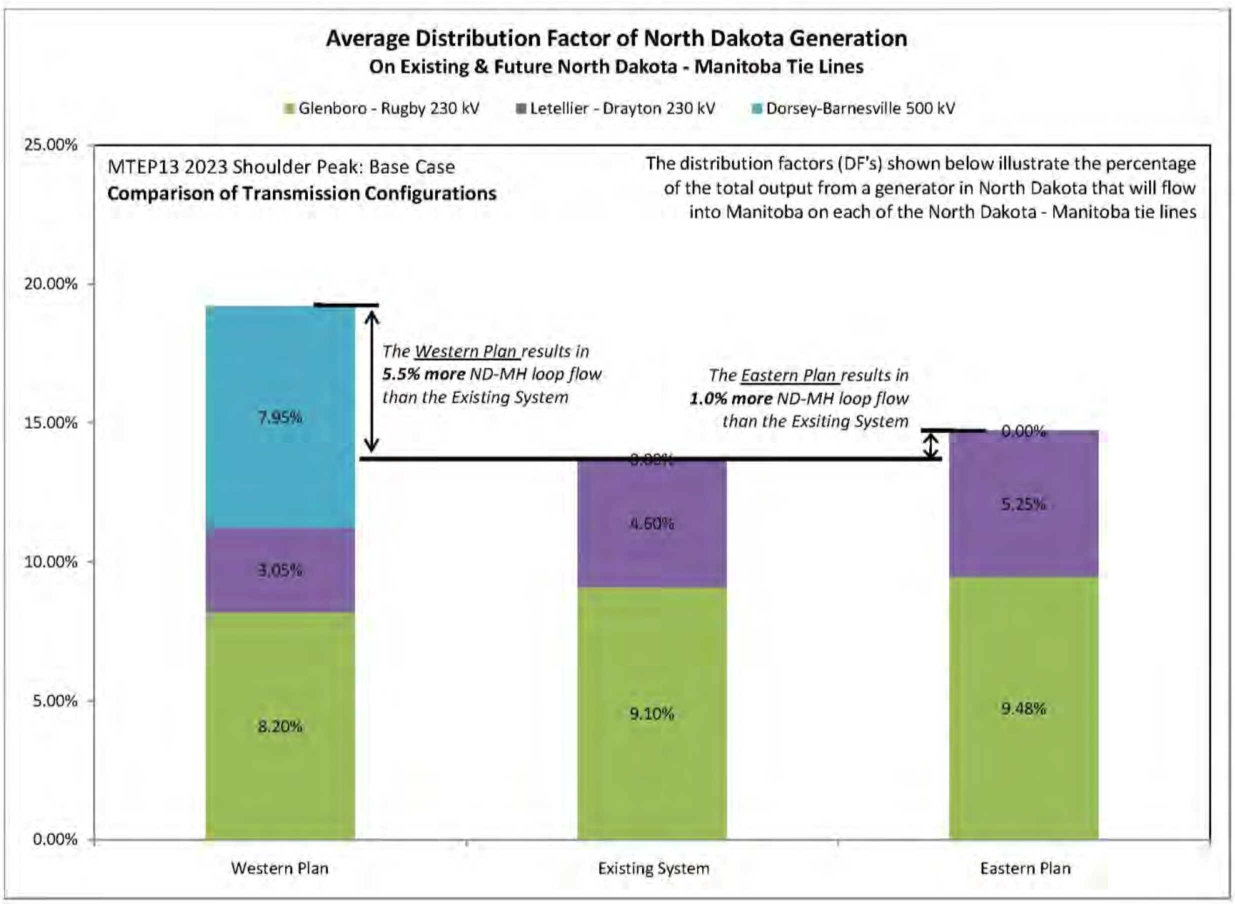
7.4.3.1.4.5. New Tie Line Loop Flow Impact Study

Minnesota Power recently kicked off the New Tie Line Loop Flow Impact Study ("Loop Flow Impact Study") to further investigate the nature of the North Dakota – Manitoba loop flow phenomenon and compare the impact that various configurations of a new 500 kV Manitoba – United States tie line have on loop flow. The Loop Flow Impact Study compares the performance of the existing system (i.e., no new tie line) with several different transmission configurations involving Western (Fargo Area Study Concept) and Eastern (the Project) 500 kV tie lines. Four different model series with widely varying initial MHEX and NDEX conditions are being used for the Loop Flow Impact Study with minimal modifications. While some initial results from the Loop Flow Impact Study are available and have been used to develop the discussion below, Minnesota Power does not expect that a final report will be available until January 2014.

Three general metrics will be used to evaluate the relative impact that each transmission configuration has on North Dakota – Manitoba loop flow. All three metrics are based on the calculation of distribution factors describing the percentage of the total output of a conceptual new generator in North Dakota that will flow on each of the existing and new Manitoba – United States tie lines. A composite North Dakota generation distribution factor will be calculated for each tie line based on the distribution factors for individual injection points (proxy new generators) at several locations in North Dakota.

The first metric being used to evaluate the relative loop flow impact of each transmission configuration is the total North Dakota – Manitoba loop flow associated with the configuration. The total loop flow can be calculated by totaling up the North Dakota generation distribution factors on all North Dakota – Manitoba tie lines (G82R, L20D, and a conceptual Dorsey-Barnesville 500 kV line). Initial results from the Loop Flow Impact Study confirm that the Fargo Area Study Concept causes more total North Dakota – Manitoba loop flow than either the existing system or the Project. Figure 7.4H illustrates this disparity. The Western Plan (Fargo Area Study Concept) causes 5.5 percent more loop flow than the existing system, while the Eastern Plan (the Project, with an additional 345 kV build to accommodate the full 1,100 MW of incremental transfer capability required by the original Transmission Service Requests) increases loop flow by only 1.0 percent compared to the existing system. The transmission configurations compared in the Figure are those which the respective proponents claim can enable 1,100 MW of incremental Manitoba – United States transfers.

Figure 7.4H: Comparison of Total Loop Flow Impact

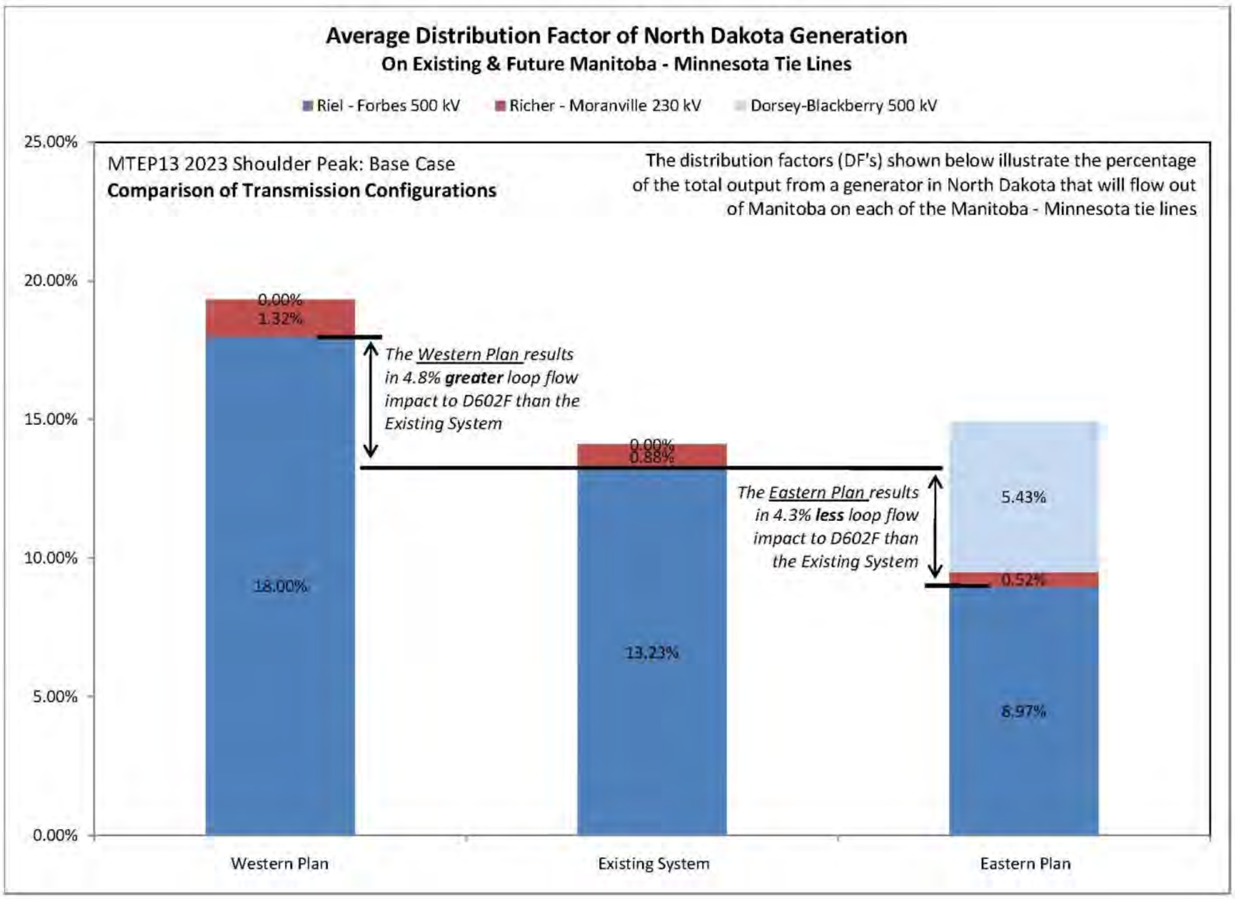


The second metric being used to evaluate the relative loop flow impact of each transmission configuration is the impact of loop flow on D602F loading. This metric is significant because, as discussed above, D602F is the main path that North Dakota – Manitoba loop flow causes congestion on during times of high simultaneous Manitoba and North Dakota export. Upgrading D602F beyond its current maximum rating of 1,732 MW would be highly complex, and upgrading it beyond 2,165 MW would be technically infeasible, as discussed above. The impact of loop flow on D602F is measured by calculating the North Dakota generation distribution factor on the line. Initial results from the Loop Flow

Impact Study confirm that the Fargo Area Study Concept would cause increased loading, and therefore increased congestion, on D602F due to loop flow while the Project actually relieves loading on D602F.

Figure 7.4I illustrates the difference in North Dakota generation distribution factors on D602F between the Western Plan (Fargo Area Study Concept), the existing system, and the Eastern Plan (the Project, with the additional 345 kV build mentioned above). The Western Plan would cause 4.8 percent more loading on D602F due to North Dakota – Manitoba loop flow than the existing system, while the Eastern Plan will reduce loading on D602F due to loop flow by 4.3 percent compared to the existing system.

Figure 7.4I: Comparison of Loop Flow Impact on D602F



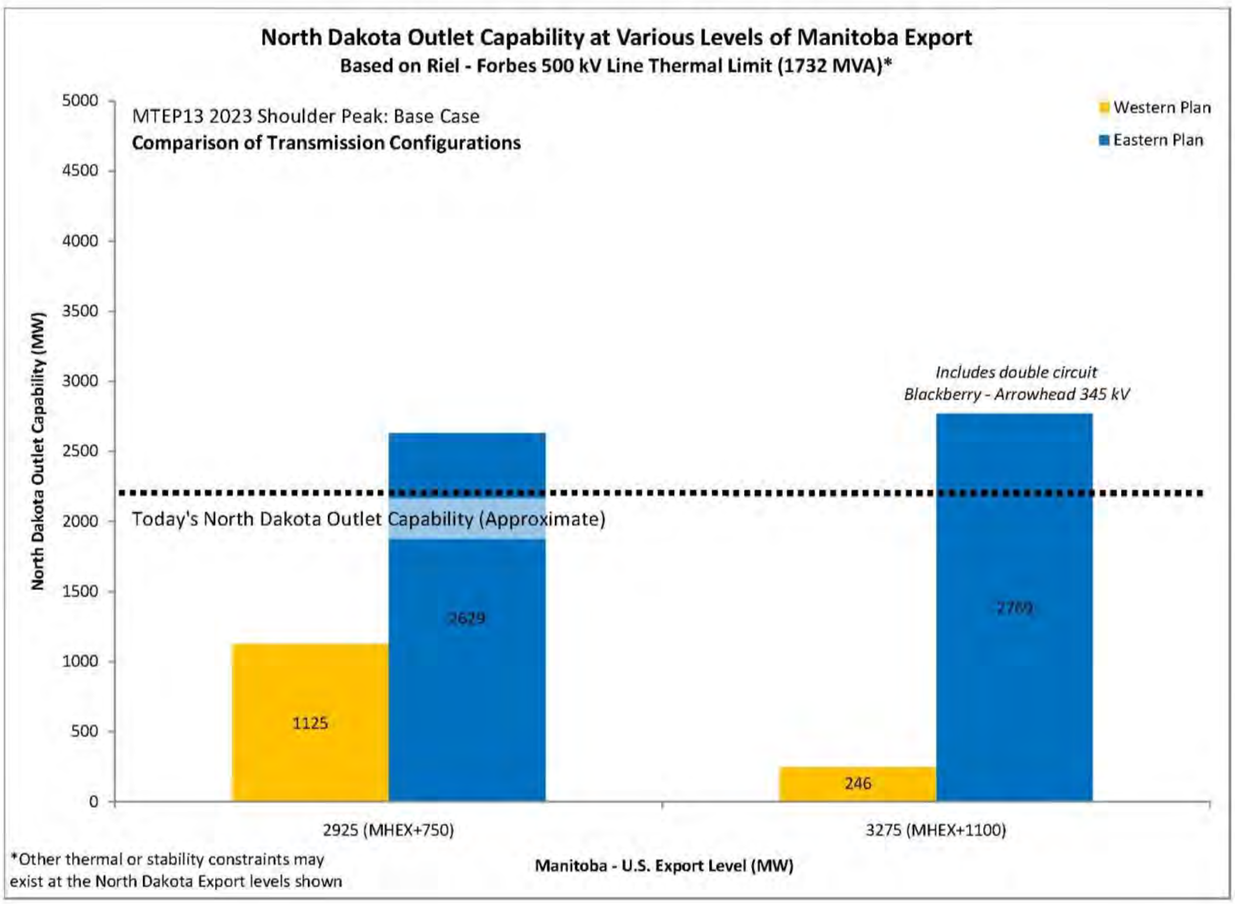
The third metric being used to evaluate the relative loop flow impact of each transmission configuration is the level of North Dakota outlet capability that can be achieved at the expected level of Manitoba export before the Roseau series capacitors on D602F are overloaded. This metric is a practical application of the first two, because it is a direct result of the total loop flow and the specific impact of loop flow on D602F loading. Using this metric will provide a good indication of the impact of the new tie line on regional generation outlet capability and overall system efficiency. The expected North Dakota outlet capability associated with a given transmission configuration will be determined by utilizing calculated distribution factors for proxy North Dakota and Manitoba generation to formulate an equation describing the relationship of increased power flows on the two interfaces.

While the Project is designed to facilitate 750 MW of incremental transfer capability from Manitoba to the United States (2,925 MW total), it can also be staged with a 345 kV build to the Duluth area to accommodate the incremental 1,100 MW of transfer capability (3,275 MW total) required by the original

Transmission Service Requests, if the need arises. The Concept has been described as a single 500 kV build that can facilitate 1,100 MW of incremental Manitoba to United States transfers. Initial results from the Loop Flow Impact Study confirm that the Concept severely limits North Dakota outlet capability at both levels of increased Manitoba export if the Roseau series capacitors are not upgraded. The Project, on the other hand, maintains North Dakota outlet capability at or above today's levels simultaneous with the corresponding increase in Manitoba export capability, without requiring an expensive and complex upgrade of D602F.

Figure 7.4J compares the expected North Dakota outlet capability at MHEX levels of 2,925 MW and 3,275 MW for the Western Plan (Fargo Area Study Concept), which is the same configuration for incremental transfers of 750 MW and 1,100 MW, and the Eastern Plan (the Project), which requires additional 345 kV transmission to achieve 3,275 MW on MHEX. It is obvious that the Concept requires either an upgrade of the Roseau series capacitors or some other transmission project to mitigate heavy loading of D602F due to loop flow at either of the desired levels of Manitoba export capability.

Figure 7.4J: Comparison of North Dakota Outlet Capability at Expected MHEX Levels



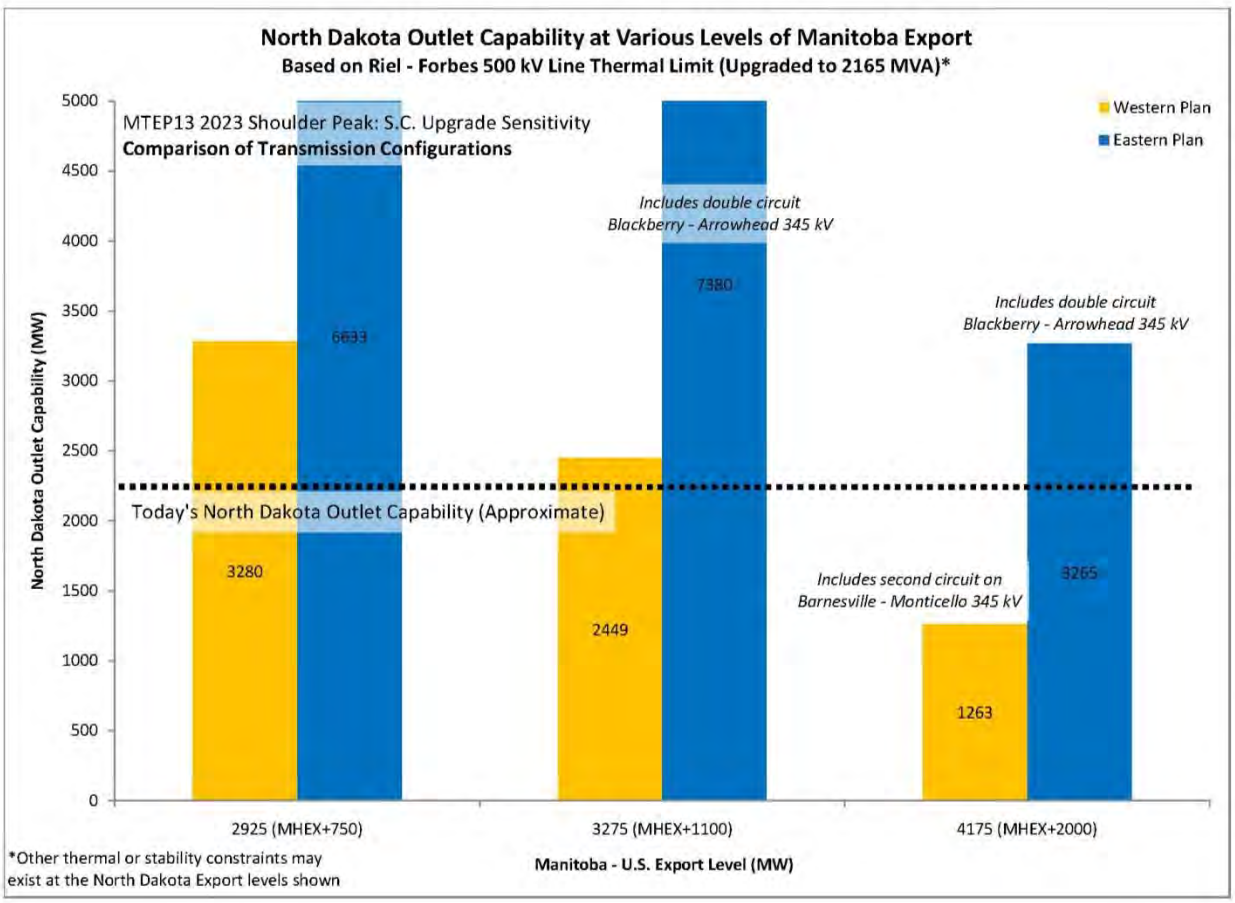
If the Roseau series capacitors are upgraded and the rating of D602F is increased to 2,165 MW, additional North Dakota outlet capability would be possible with both plans. However, initial results from the Loop Flow Impact Study confirm that the Concept would continue to be more limiting for North Dakota than the Project even after upgrading the Roseau series capacitors.

Figure 7.4K compares the theoretical North Dakota outlet capability at MHEX levels of 2,925 MW, 3,275 MW, and 4,175 MW (2,000 MW incremental) for the Western Plan (Fargo Area Study Concept) and the

Eastern Plan (the Project with the additional 345 kV build mentioned above). A second 500/345 kV transformer at Barnesville and second circuit on the Barnesville – Monticello 345 kV line have been added for the Western Plan at the 4,175 MW Manitoba export level, as prescribed by the MANTEX studies.

The results clearly show that the long-term impact of the Concept would be to limit simultaneous North Dakota and Manitoba export capability by causing more North Dakota loop flow on D602F. Since the rating of D602F cannot be increased beyond 2,165 MW, it also becomes apparent that the Concept would not be able to facilitate 2,000 MW of increased Manitoba – United States transfers without significantly limiting North Dakota export capability due to loop flow. On the other hand, while there may be other thermal or stability constraints that need to be mitigated, increased loading on D602F due to loop flow is not a limiting issue for the Project. Even after enabling 2,000 MW of incremental Manitoba – United States transfers, the Project with the additional 345 kV build mentioned above would maintain North Dakota outlet capability at or above today's levels if the Roseau series capacitors were upgraded.

Figure 7.4K: Comparison of North Dakota Outlet Capability after Roseau Series Capacitor Upgrade



Appendix L: Conceptual Loop Flow Impact of the Western Plan

The following is an excerpt from pages 86-89 of Minnesota Power's Application for a Certificate of Need for the Great Northern Transmission Line (MPUC Docket No. E-015/CN-12-1163). The text and diagrams illustrate the conceptual loop flow impact of the Western Plan, which is referred to as "the Fargo Area Study Concept," compared to the Eastern Plan, which is referred to as "the Project"

7.4.3.1.3. Impact of the Fargo Area Study Concept Line Compared to the Project

The Fargo Area Study Concept would introduce a new low-impedance path between North Dakota and Manitoba, which would dramatically aggravate the existing loop flow issue. One way to conceptualize the loop flow issue and the impact of a new 500 kV tie line is illustrated in the figures below. Conceptually, each of the Manitoba – U.S. tie lines can be thought of as a pipe. The size of the pipe corresponds to the relative impedance of the transmission line. Since lower impedance, higher voltage lines facilitate and draw more power flow, the largest pipe will represent the lowest impedance, highest voltage transmission line.

Figure 7.4E shows the path for loop flow in the existing system. This path is made up of two small pipes from within the North Dakota Export boundary into Manitoba (G82R and L20D), one small pipe from Manitoba into northeastern Minnesota (R50M), and one very large pipe from Manitoba into eastern Minnesota. (D602F). While D602F is a very low impedance path (a very large pipe) for loop flow, the amount of loop flow in the existing system is limited by the higher relative impedances of G82R and L20D (smaller pipes).

FIGURE 7.4E: Loop Flow Conceptualization (Existing System)

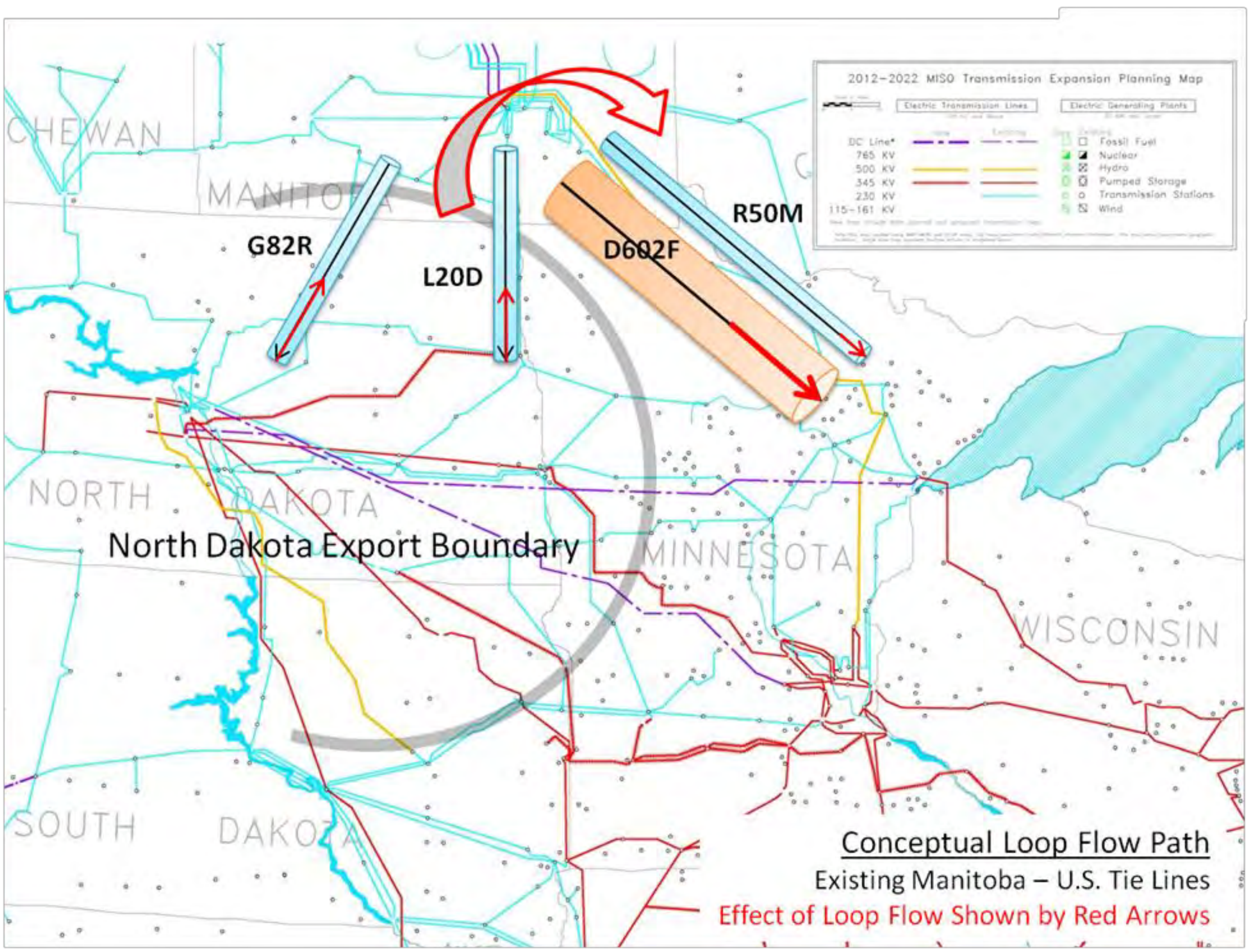
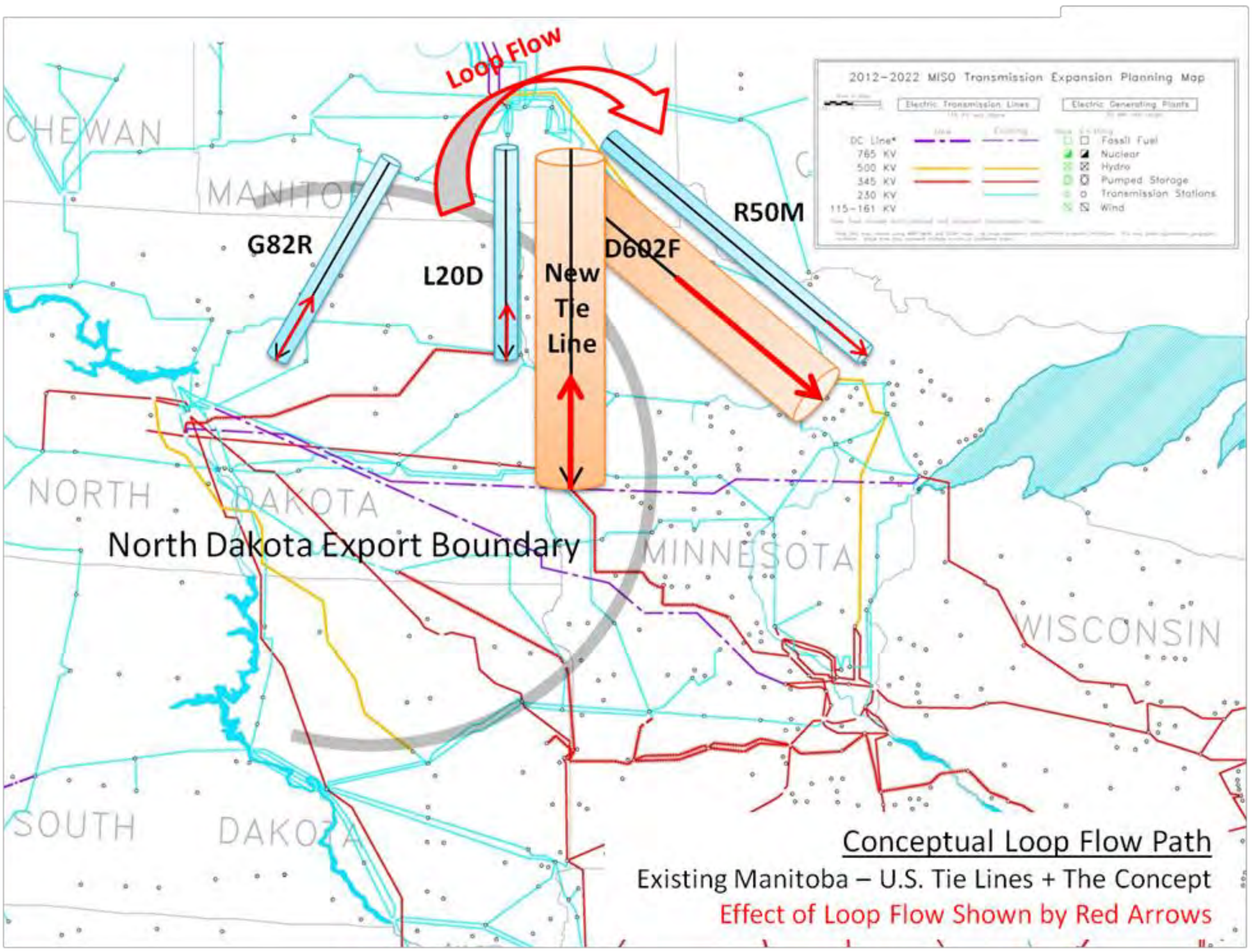


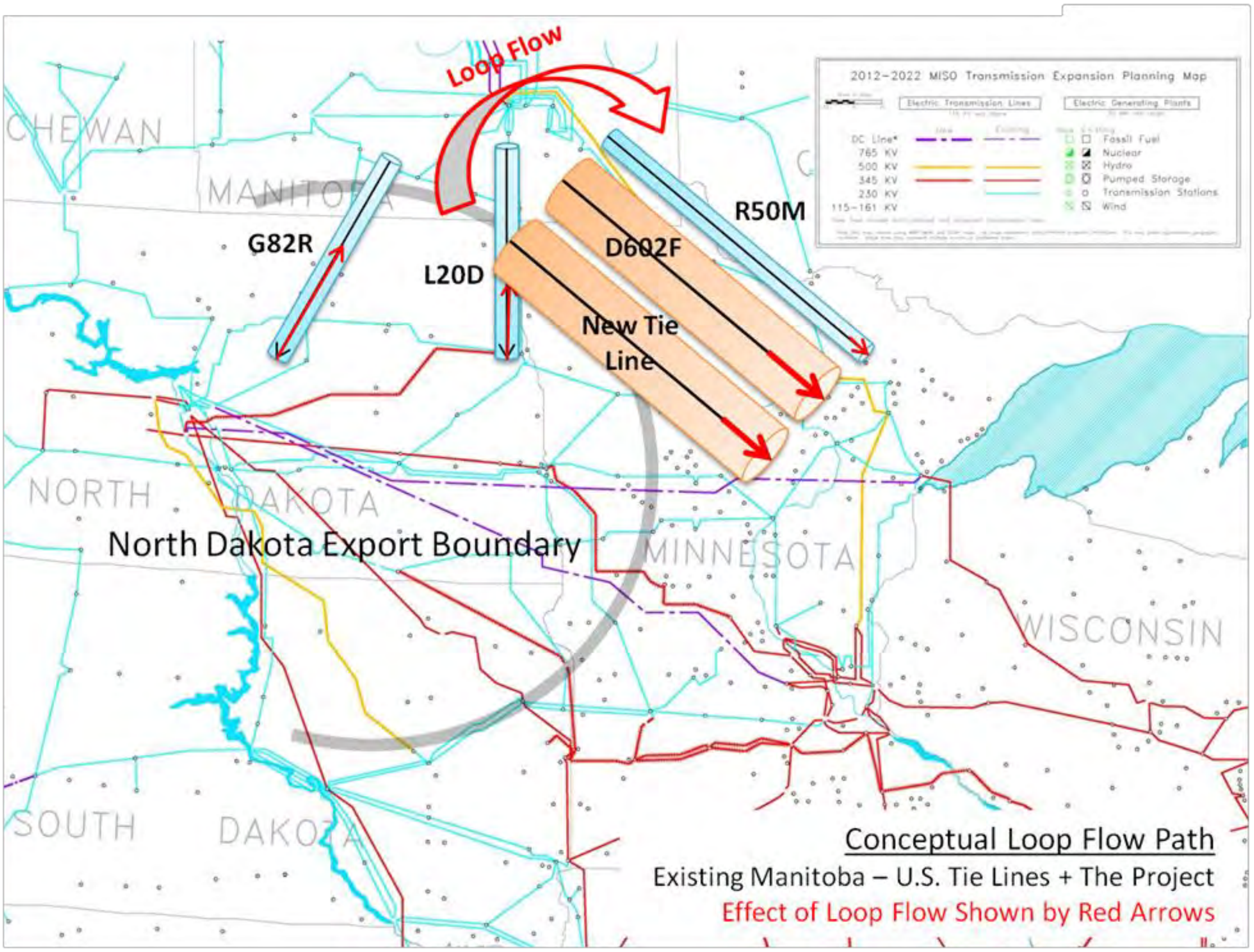
Figure 7.4F shows the path for loop flow with the addition of a new Dorsey – Barnesville 500 kV line (the Concept). The Fargo Area Study Concept would introduce a new, very large pipe from within the North Dakota Export boundary into Manitoba. Since the new tie line would strongly connect North Dakota and Manitoba, power generated in North Dakota would have one continuous very low impedance path (one long, very large pipe) to flow from North Dakota into Manitoba and then back in the United States. In practice, the result would be that the higher the North Dakota Export is, the less power a new Dorsey – Barnesville 500 kV line would carry from Manitoba to the United States. This would cause more power to flow on D602F, overloading the line much sooner than it would otherwise be overloaded if the new tie line did not connect North Dakota and Manitoba, and severely limiting simultaneous export capability absent any upgrades or new transmission development.

Figure 7.4F: Loop Flow Conceptualization (Fargo Area Study Concept)



Finally, Figure 7.4G shows the path for loop flow with the addition of a new Dorsey – Blackberry 500 kV line (the Project). The Project introduces a new, very large pipe electrically parallel with D602F from Manitoba to the east, outside the North Dakota Export boundary. Even though D602F and the Dorsey – Blackberry 500 kV line together provide a very low impedance path (two very large pipes) for loop flow, the amount of loop flow facilitated by the Project is still limited by the higher relative impedances of G82R and L20D (smaller pipes), the only tie lines from North Dakota to Manitoba. In practice, the result is less interaction between power generated in North Dakota and power generated in Manitoba, and higher simultaneous export capability absent additional transmission development.

Figure 7.4G: Loop Flow Conceptualization (Project)



Appendix M: Concerns with the Roseau Series Capacitor Upgrade

The following is an excerpt from pages 73-75 of Minnesota Power's Application for a Certificate of Need for the Great Northern Transmission Line (MPUC Docket No. E-015/CN-12-1163). The text appeared in the "Transmission System Alternatives" section under the heading "Upgrades of Existing Transmission or Generation." It discusses the specific concerns with upgrading the Roseau series capacitor banks in order to increase the capability of the existing Riel – Forbes 500 kV Line (referred to throughout by its former designation "D602F").

Increased transfer levels from Manitoba to the United States with no new transmission tie lines across the interface would require additional capacity on some or all of the existing tie lines. Since D602F is the largest, lowest impedance line on the interface, the majority of incremental transfers from Manitoba to the United States will flow on this line, requiring increased capacity on the line. Currently, the flow limit on D602F is based on the 2,000 amp (1732 MVA) rating of the Roseau series capacitors and line terminal equipment. While it is technically feasible to increase the rating of D602F from 2,000 amps to 2,500 amps (2165 MVA) by upgrading the Roseau series capacitors, this upgrade would be highly complex and raise a number of potential issues relating to the operation of the line and terminal equipment as well as the reliability of the regional transmission system. Many of the specific concerns outlined below were set forth in a July 10, 2013 "White Paper" written by Manitoba Hydro titled "Summary of Potential Issues with Increasing the Rating of D602F (M602F) from 2000 Amp to 2500 Amp" ("White Paper on Series Capacitor Upgrade Issues") and all result from the electrical inefficiencies of increasing utilization of D602F beyond its existing capacity.

Historically, D602F has only had electromagnetic transient studies completed at the 2000 amp operating level. At 2500 amps, the circuit breaker transient recovery voltage and arrester energy capability would need to be confirmed. Due to higher transient recovery voltages and increased arrester energy, equipment may need to be replaced at the Forbes and Chisago substations.[13]

Increasing the power flow on D602F would also increase the amount of reactive power consumed by the line, while an in-place series capacitor upgrade may actually result in decreased reactive power supply from the Roseau series capacitors. A detailed transient stability study would be needed to determine the steady-state and dynamic reactive power requirements of the upgraded line. Costly upgrades of the Forbes Static VAR System (SVS) would likely be required to provide additional reactive power support for the line at its increased capacity. System transient stability issues may further increase the scope of work required at Forbes if a second static VAR compensator (SVC) is required to provide increased dynamic range.[14]

When any of the four Manitoba – United States tie lines trips, the existing Manitoba Hydro HVDC Reduction Scheme Special Protection System (SPS) initiates a power order reduction on the high voltage direct current (HVDC) lines connecting Winnipeg to hydroelectric generation in Northern Manitoba. This HVDC power order reduction is equal to 100 percent of the flow on the line or lines that are being tripped. If a 100 percent HVDC reduction level is maintained in the SPS, the flow limit on D602F could not be increased beyond 1732 MW, even if all the limiting equipment was upgraded. This is because MISO will not allow an increase in the amount of HVDC or generation runback on an existing SPS beyond its current maximum level. Simply put, for an existing SPS, transmission or generation additions cannot make the worst runback scenario (in terms of generation loss) worse. This requirement would limit the maximum HVDC reduction and potentially the rating of D602F to 1732 MW. It would be possible to

[13] White Paper on Series Capacitor Upgrade Issues.
[14] White Paper on Series Capacitor Upgrade Issues.

modify the SPS to limit HVDC reduction to 1732 MW, allowing flow on D602F to be increased to 2165 MW. However, the impact of this SPS modification on system transient stability, dynamic reactive power requirements, and the underlying transmission system would almost certainly increase the cost and complexity of the project as well as the overall risk to the reliability of the system. [15]

Finally, loss of D602F and the associated HVDC reduction is currently the largest single contingency in MISO. In the current system, the maximum reduction in Manitoba – United States transfers is 1500 MW. This is calculated as the difference between the system intact transfer limit of the interface (2175 MW) and steady-state transfer limit of the interface after loss of D602F (675 MW), which is often referred to as the prior outage limit. Increasing the rating of D602F in order to increase the total system intact transfer limit on the Manitoba – United States interface would therefore require a corresponding increase in the prior outage transfer limit of the interface for loss of D602F in order to avoid increasing the size of the largest single contingency in the MISO footprint. Depending on the level of increased firm capability required, it may not be possible to increase the prior outage transfer limit without building a new Manitoba – United States tie line. [16]

[15] Id.
[16] Id.

Appendix N: History and Significance of NDEX

This Appendix is intended to provide a brief overview of the history of the North Dakota Export (NDEX) interface, as well as its current and potential future significance.

Most recently, NDEX has been defined as consisting of 19 transmission lines that are generally located between North Dakota and northern South Dakota, western Minnesota, and southern Manitoba. Many of these transmission lines originate in North Dakota; those that do not directly originate in North Dakota, such as the Boswell – Cass Lake 230 kV Line, are part of a larger transmission path that extends from North Dakota well into an adjoining state. The area inside the NDEX interface is also bounded on the west by the Miles City Converter Station back-to-back DC tie, which connects to the Western Interconnect system, and the Tioga – Boundary Dam 230 kV tie line and phase shifting transformer, which connects to Saskatchewan Power. Historically, the NDEX interface was a stability-limited interface, representing the location where North Dakota separated from the rest of the regional power system due to instability caused by certain system events. The NDEX area includes a large amount of generation in the North Dakota coal field area that is remote from major load centers, and periods of low load levels inside the NDEX boundary have historically resulted in high exports from North Dakota to the south and east. Transmission system investments have been made over the years to increase the level of North Dakota export capability based on the needs of utilities in the region. Today, NDEX has a studied export limit of 2080 MW, though at least one recent study has indicated that it may be possible to reliably achieve higher levels of NDEX due to several transmission system improvements made over the last decade.

Recent and anticipated changes on the system and in the industry, including significant load growth in western North Dakota, two new tie lines across the historical NDEX boundary, and the development of operating horizon tools enabling the evaluation of system stability in real time have largely eliminated the need for the historical NDEX as a stability interface. In the planning horizon, however, NDEX remains a useful tool for understanding the condition of the power system, even absent the historical stability limits that were associated with the interface. The level of NDEX is still widely understood as an indicator of the amount of stress in a power system model by transmission planners with utilities in North Dakota, Manitoba, Minnesota, and South Dakota, as well as Iowa and Wisconsin. Similarly, NDEX remains a good proxy for measuring the total generation export (or import) from North Dakota to the rest of the system as well as the impact of this export on other interfaces like the Manitoba Hydro Export (MHEX) or Minnesota-Wisconsin Export (MWEX). This point is particularly relevant in light of the recent and continuing large-scale development of wind generation inside the historical NDEX boundary. This is well illustrated by the unprecedented level of NDEX – 2752 MW – observed in the February 2013 DPP model used for this study (see Appendix A: Detailed Comparison of Benchmark Cases), which is undoubtedly related to the number and size of generator interconnection requests inside the NDEX area. Such high levels of NDEX cause significant amounts of North Dakota – Manitoba loop flow, which creates congestion on the Manitoba Hydro interface as discussed in this Report, and also tends to aggravate stability issues on the MWEX interface, as demonstrated in the CapX2020 study report "Impact of CapX Facilities on North Dakota Export for the Year 2016."

At the same time, recent and continuing load growth in the oil fields of western North Dakota is changing the landscape of the power system in North Dakota. Where North Dakota load was historically sparse and minimal compared to the copious amounts of generation in the resource-rich region, development of the oil fields has driven load to unprecedented levels in western North Dakota. While this load growth has led to a general decrease in the average North Dakota export as might be expected, historical data does not support the conclusion that the maximum level of North Dakota export has been significantly diminished in recent years. In fact, a comparison of load data from 2008 and 2013 – shown in Figure 86 below – suggests that just the opposite is true.

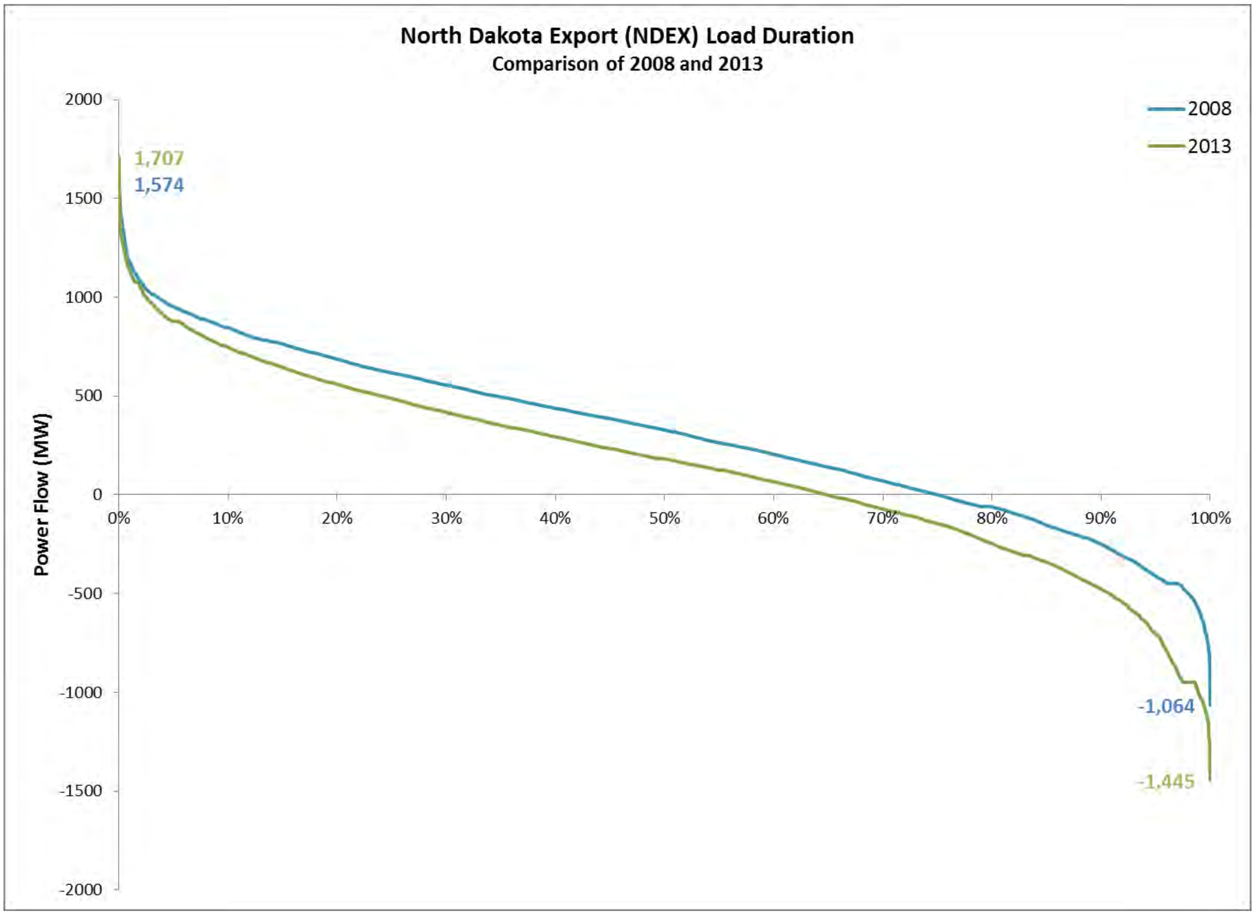


Figure 86: North Dakota Export Load Duration Curve 2008 v/ 2013

Comparing duration curves from 2008 and 2013, it is evident that North Dakota exported less power on average in 2013 than it did in 2008. In fact, the percentage of hours when North Dakota was actually importing increased from approximately 25 percent in 2008 to approximately 35 percent in 2013, and the maximum import increased from 1,064 MW in 2008 to 1,445 MW in 2013. However, in spite of this general decrease in North Dakota export, the maximum North Dakota export actually increased from 1,574 MW in 2008 to 1,707 MW in 2013. This demonstrates that North Dakota still has the capability to export considerable amounts of power that approach historical peak levels on the NDEX interface even after massive load expansion in western North Dakota. While an in-depth analysis of this intriguing fact is outside the scope of the intent for this Appendix, it is perhaps reasonable to say that the large-scale development of wind energy resources in North Dakota – which has happened essentially in parallel with the growth of the oil fields over the last decade – is contributing to these high NDEX levels.

In any case, the data appears to confirm that abundant and low-cost traditional and renewable energy resources in North Dakota will continue to make their way out of North Dakota to serve major load centers to the south and east for many hours per year well into the future, and that NDEX will remain a good proxy for understanding the behavior of the regional power system and the impact of the delivery of the resources on regional reliability.