Langdon, ND
159 MW
Wind-Powered Generation Facility

System Impact Study

For Associated
Generation & Transmission Additions

Report to the MAPP Design Review Subcommittee

Sponsor:
Minnkota Power Cooperative, Inc.
FPL Energy, Inc.

Prepared by:
Excel Engineering, Inc.
September 12, 2007

Principal Contributors:

Richard Gonzalez, PE
Michael Cronier

Table of Contents

Listing of Tables and Figures

Listing of Appendices

0.0 Certification

I hereby certify that this plan, specification, or report was prepared by me or under my direct supervision and that I am a duly Licensed Professional Engineer under the Laws of the State of Minnesota

Richard Gonzalez
Registration Number 18938
September 12, 2007

1.0 Executive Summary

Minnkota Power Cooperative, Inc. is seeking approval from the Mid-Continent Area Power Pool (MAPP) Design Review Subcommittee (DRS) for generation interconnection of a 159 MW wind generating facility. The wind generation facility is planning to interconnect to the existing 115 kV substation near Langdon, North Dakota, which is owned by Minnkota Power Cooperative (MPC). The proposed in-service date is December of 2007. The participation in the output of this project is by Minnkota Power Cooperative (99 MW) and Otter Tail Power Company (60 MW).

Associated with the generation addition is a new 115 kV line from Langdon to Hensel. This new 35-mile line will provide the Langdon generation a second 115 kV transmission outlet, which ultimately connects to the Drayton 230/115 kV substation. Also included are upgrades to the existing Langdon area 115 kV lines and application of “wind rating” methods to these circuits.

The power flow analysis performed at the 160 MW Langdon generation level identified two limiting conditions:

1. During an outage of one of the 115 kV outlet lines from Langdon, flow on the remaining in-service circuit may exceed its thermal or voltage stability limit. For an outage of any section of the Langdon-Hensel-Drayton 115 kV line, the Langdon-Sweetwater-Devils Lake 115 kV line may become loaded beyond its thermal limit and introduce voltage stability issues in the local Langdon area. For an outage of the Langdon-Sweetwater-Devils Lake 115 kV line, the Hensel-Drayton 115 kV line may become loaded beyond its thermal limit. A special protection system will be required at Langdon to restrict the wind generation output to maintain acceptable loadings on these local area transmission lines. The amount of generation reduction required, and number of line segment outages for which the protection scheme is needed is dependent on whether an earlier-queued 39 MW generation interconnection request at Hanks Corner (MISO Project G651 on the 69 kV system between Hensel and Langdon) proceeds. If G651 is not in service, the only requirement of the SPS is to limit flow on the Langdon-Sweetwater-Devils Lake 115 kV line for outages along the Langdon–Hensel–Drayton 115 kV line.

2. The addition of the Langdon-Hensel 115 kV line makes it possible for excessive post-contingent loading to occur on the existing 84 MVA Ramsey 230/115 kV transformer during winter peak conditions, following a trip of the Ramsey-Prairie 230 kV line. The overload will only occur when power output from the Langdon generation is at a low level. A special protection system is proposed as a temporary solution. The SPS will trip the Devils Lake East breaker when an overload is detected on the Ramsey transformer. This action will separate Langdon (and Sweetwater) from the Devils Lake area. The long-term solution will be identified as part of a load-serving study for the Devils Lake area recently initiated by the local load-serving entities. Currently, several options are being evaluated through the load serving study, including the replacement of the existing or an addition of a second Ramsey 230/115 kV transformer. This project will coordinate with that study to ensure that an acceptable long-term solution is implemented for both

load serving needs and generation outlet needs. This study also shows that the addition of Langdon generation and Langdon-Hensel 115 kV line provides an additional source to the Devils Lake area.

During the dynamic stability analysis, it was observed that the Langdon generation addition resulted in transient under-voltage violations on the Wahpeton 115 kV bus (0.80 pu minimum allowed) during the "NMZ[1]" disturbance. Upon further review of the stability case, it was determined that the Forbes–Chisago 500 kV line was severely overloaded in the pre-disturbance stability case (~1900 MVA as compared to 1765 MVA rating). Reducing the flow on this line to its flowgate limit and re-running the NMZ disturbance did not result in transient voltage violations during the NMZ disturbance; therefore, this transient voltage issue at Wahpeton is not valid since real-time system dispatch will not allow the Forbes-Chisago 500 kV line flow to exceed its operational limit of 1765 MVA.

For informational purposes, constrained interface analysis was performed during this system impact study to provide insight into potential delivery issues that could occur during subsequent transmission studies for granting firm transmission service for this project. This analysis has determined that this project's impact exceeds the 5% PTDF threshold on the Forbes – Chisago 500 kV line. The Arrowhead–Stone Lake–Gardner Park 345 kV line (scheduled for March or April, 2008 in-service) will substantially unload this interface and significantly alter the PTDF calculation for this project. Constrained interface impacts will be re-evaluated with the Arrowhead–Stone Lake–Gardner Park 345 kV line during the separate delivery service studies for this project.

[1] "NMZ" is a three-phase fault at Chisago Co on the Chisago Co – Forbes 500 kV line.

2.0 Introduction

The Langdon Wind Project is a 159 MW wind-powered generating facility ("wind farm") that will be located 9 miles southeast of Langdon, North Dakota in Cavalier County. The map below in Figure 2.0.1, shows the approximate location of the wind farm with respect to the bulk transmission facilities in the area.

This diagram has been removed because it contains either Merchant Sensitive Information or Critical Energy Infrastructure Information.

Figure 2.0.1 – Map of the Local Bulk Transmission System

Ownership of this 159 MW generation facility will be:

FPL	118.5	MW
OTP	40.5	
	159.0	MW

The 118.5 MW output from FPL's ownership will be delivered to MPC and OTP in the following proportion:

MPC	99.0	MW
OTP	19.5	
	118.5	MW

The resultant aggregate power deliveries are therefore 99.0 MW to MPC, and 60.0 MW to OTP.

The wind farm will consist of 106 GE 1.5 MW 60 Hz turbines for a total nameplate capacity of 159 MW. The GE machines are equipped with a doubly fed (wound rotor) asynchronous induction generator with slip rings for the rotor connections, and an electronic power converter to provide variable-frequency excitation for the rotor circuit. These generators have the ability to adjust rotor circuit current, which allows them the flexibility of providing variable MVAR output. This feature allows the turbines to be a voltage-controlling source to the power system, similar to conventional synchronous machines. This capability is due to the rotor circuit power converter being capable of operation in all four quadrants of the P-Q plane.

The interconnection of the wind farm will be at the existing Minnkota Power Cooperative, Inc. (MPC) Langdon 115 kV substation. Along with the generation addition, a proposed 35-mile 115 kV line addition from Langdon to Hensel is also included in this development. This line addition will

- assist with Langdon generation outlet capability needs;
- provide looped service to Langdon and Hensel;
- improve Devils Lake area load-serving capability.

3.0 Study Development and Assumptions

3.1 Study Description

Excel Engineering, Inc. was engaged in this project to perform a system impact study for this proposed 159 MW wind generation facility. The technical studies for this project were performed at the 160 MW output level.

The purpose of this study is to demonstrate the adequacy of the proposed transmission improvements with respect to supporting the interconnection of the 159 MW generation addition. The output was modeled as being delivered to MPC (~100 MW) and OTP (60 MW).

Initial feasibility studies indicated that the existing 115 kV transmission at Langdon is inadequate to support a 159 MW generation addition. System intact and first-contingency conditions have shown thermal and voltage stability limitations for a wind farm of this magnitude at this location with the existing system.

To facilitate the interconnection of the Langdon generation, it is proposed to construct a new 35-mile 115 kV transmission line between the existing Langdon and Hensel substations. This line will be constructed with T2-477 ACSR conductor. Additionally, transmission line work is being done to increase the ratings on the two existing 115 kV lines from Langdon connected to the Devils Lake and Drayton substations.

Associated with the above generation and transmission additions, both Langdon and Hensel 115 kV substations will be converted into four-position ring buses. Figure 3.1.1 is a one-line diagram showing the new wind farm interconnection, the proposed Langdon-Hensel 115 kV addition, and breaker layout for both the Langdon and Hensel Substations.

This diagram has been removed because it contains either Merchant Sensitive Information or Critical Energy Infrastructure Information.

Figure 3.1.1 – One-Line Diagram of Langdon and Hensel Substations

Both MPC and OTP will be the recipients of the generation's output with the MPC share being 100 MW (nominal) and the OTP share being 60 MW (nominal). Since MPC and OTP are both the sinks for the generation output, re-dispatching existing generation was modeled within the North Dakota Export (NDEX) interface.

The Langdon Wind Farm has two queue positions within the Minnkota Power Cooperative's generation interconnection queue: the first entry for 100 MW on September 11, 2006 and a second entry for an additional 60 MW on November 13, 2006. These interconnection requests have been coordinated with the MISO interconnection queue. They are posted as MISO Projects G786 and G787 with queue numbers of 38971-03 and 39034-01, respectively. The projected operational date for the total wind farm is December 2007.

3.2 Study Procedure

To evaluate the impact that this wind farm may have on the existing transmission system within the northern MAPP region, the following types of analysis have been included as part of this system impact study:

- Contingency analysis;
- Voltage stability analysis;
- Transient stability analysis; and
- Short circuit analysis

More details of each of these analyses can be found in subsequent sections of this report.

This analysis was performed primarily using the Siemens Power Technologies, Inc. (PTI) PSS/E digital computer powerflow program, both Versions 29 and 30. PTI's MUST program was used for contingency analysis to evaluate post-contingent loadings and voltages for single- and double-contingency conditions throughout the region. As needed, further PSS/E cases were developed to investigate particular system limitations.

For the limiting contingencies identified, V-Q analyses were performed to determine generation output limits and investigate reactive power margins. Furthermore, P-V analysis was performed to verify a safe operating limit for contingency conditions requiring a generator reduction at Langdon.

4.0 Analysis

4.1 Models employed

To encompass all relevant combinations of load levels with this generation project, this study utilized three 2006 base cases: summer off-peak, summer peak, and winter peak. The models were based on the 2006 Northern MAPP Operating Review Working Group (NMORWG) set of models and programs known as the NMORWG Study Package.

The summer off-peak condition is modeled with the NDEX interface flow at 2080 MW, which is the new transfer limit being requested through the WAPA OASIS postings. This case also has the Northern MAPP generation set at the maximum achievable (or URGE) levels. The base case used for this study can be found in the NMORWG study package (pkg2006) as urg-s706aa.uzvV424.sav. A summer peak condition was then created from the off-peak case by scaling loads and generation in the MAPP region.

A winter peak case with high northward transfers (MHEX = -700 MW) was already available in the study package; it is named nrt-wp06aa.sav. The cases originated from the MAPP model building process, with the summer case being from the 2004 series, and the winter case being from the 2006 series. A list of all model revisions and topology changes is provided in Appendix A.

The MHEX and NDEX loadings within the various study cases were at the following MW values for the post-project cases:

Condition	MHEX	NDEX
Summer off-peak	2175	2080
Summer peak	2175	1560
Winter peak	-700	620

Definitions of the MHEX and NDEX quantities are given in Appendix B.

Review of the WAPA and MISO generation interconnection queues revealed that the pre-project cases should be updated to include three prior-queued generation facilities in north-central North Dakota that may have interaction with the Langdon Project. These generators were added to each model and their outputs were dispatched to Zone 90 (North Dakota scalable) load. These prior-queued generation projects and their status are:

- 150 MW at OTP Rugby 230 kV; MISO Project G380 (In Suspension);
- 16 MW at NSP Minot [McHenry-Souris 115 kV]; MISO Project G408 (In Service);
- 39 MW at OTP Hanks Corner [connected back to Hensel 69 kV]; MISO Project G651 (Under Study).

The proposed Hanks Corner generation is electrically very close to the Langdon site. Although the Hanks Corner generation has an earlier interconnection queue position than Langdon, its proposed in-service date is later than that of Langdon. Consequently, several subsequent sections of this report provide results “with” and “without” the Hanks Corner generation in service.

The Langdon wind farm has been modeled as a single equivalent generator connected to a 575 V bus with a single 575V/34.5 kV generator step-up transformer. This representation is used to collectively represent the parallel combination of the 106 wind turbines throughout the wind farm. A 34.5/115 kV transformer was connected directly to the Langdon 115 kV bus to connect the collector system to the transmission system.

The dynamic model for the GE wind turbines was provided as a PSS/E user-written model. This model was incorporated into the NMORWG "pkg2006" program for dynamics simulations.

4.2 Conditions studied

Four transmission configurations were studied for each model. The configurations studied are:

- "000" refers to the existing system
- "00H" refers to the existing system with the Langdon-Hensel 115 kV line addition, but without the Langdon generation
- "16H" refers to the addition of the Langdon 159 MW generation project dispatched to existing generation with the Langdon-Hensel 115 kV line addition
- "16L" refers to the same case as "16H", but with the Langdon generation sunk to load (dynamics only)

Throughout this report, these studied conditions will be referenced in various tables and graphs as "000", "00H", "16H", and "16L", respectively. This includes the sensitivity in the dynamic stability analysis for the 2015 condition

The Langdon generation was dispatched by displacing MPC (Young 2) and OTP (Hoot Lake Units 2 & 3) generation for steady state analysis and the majority of the dynamic stability analysis.

A "generation to load" dispatch was also evaluated for a comparative dynamic stability analysis. The load that was scaled was the MPC and OTP load selected by load ID in the cases. MPC's load in northern Minnesota that is served from the Moranville and Running substations was excluded.

Different titles were used for the sensitivities including "16C" for reducing the flows on the Forbes-Chisago Co 500kV line. "E00", "E0H", and "E16" were used in the Ellendale sensitivity to separate the three configurations.

4.3 Contingencies and monitored facilities

Contingencies studied:

- Single contingencies in the following control areas:
  - GRE (115 kV & above)
  - MH (115 kV & above)
  - MP (115 kV & above)
  - OTP (115 kV & above)
  - WAPA (115 kV & above)
  - XCEL (115 kV & above)
- Double contingencies limited to double elements in the local area.
- Multiple-circuit lines over 1 mile, at least one circuit 115 kV or higher included within the standard northern MAPP contingency file.

Monitored facilities:

- In the following control areas:
  - GRE (69 kV & above)
  - MH (69 kV & above)
  - MP (69 kV & above)
  - OTP (69 kV & above)
  - WAPA (69 kV & above)
  - XCEL (69 kV & above)
- Flag overloads above 100% of their respective continuous ratings for all conditions.
- Flag voltages outside 0.95 p.u. and 1.05 p.u. for all conditions.

4.4 Performance criteria

Power system performance was evaluated against the MAPP/NERC Planning Standards, with respect to meeting system performance standards for Categories A, B, C, and D contingencies. These planning standards are provided in Appendix C. A brief explanation of the different types of NERC contingencies are:

- Category A relates to “system intact” conditions
- Category B relates to first contingency (“n-1”) conditions
- Category C was used to the extent that it relates to loss of two separate components within the study area at least 115 kV or above.
- Category D was studied to address the extreme event of loss of multiple components within the study area at least 115 kV or above.

Thermal performance was judged to be acceptable if system intact loadings were within the continuous ratings, and if post-contingent loadings were within the applicable emergency ratings if there were operating procedures available to adequately unload a facility within 30 minutes. Overloads were flagged and discussed within this report if facilities were loaded beyond these criteria. Voltage performance was judged to be acceptable if voltages satisfied the transmission owners’ specific criteria as specified in the “MAPP Members Reliability Criteria and Study Procedures Manual” dated November 19, 2004.

5.0 Results of Detailed Analyses

In order to assess any potential impacts upon the bulk electric power system in MAPP, a thorough AC contingency analysis was performed for the previously mentioned contingencies in the Northern MAPP area. The current Northern MAPP contingency file was used as the base set of contingencies as well as N-1 and N-2 contingencies described in Section 4.4. Appendix D give the power flow documentation while Appendix E provides nine sets of powerflow maps and summary sheets for the following combinations of load and transfer patterns:

Configurations

- "existing system" (no Langdon generation)
- "with Langdon-Hensel 115 kV line addition" (no Langdon generation)
- "Langdon 160 MW generation addition and Langdon-Hensel 115 kV line"

Load level/transfer patterns

- Summer off-peak
- Summer peak
- Winter peak

Each of the nine sets of powerflow diagrams illustrates the flows and bus voltages for the system intact (base case) condition and nine local 115 kV and 230 kV contingencies of interest. Also included in Appendix E is a list of "Significantly Affected Facilities" derived from a comparison of the "before" and "after" contingency outputs.

5.0.1 Langdon 115 kV Line Ratings

During initial feasibility analysis, review of local 115 kV lines identified that the existing 115 kV system is not adequate to handle the 160 MW Langdon generation addition, particularly during summer off-peak conditions when loads in the Langdon / Hensel area are at their lowest levels. It was decided to upgrade the Langdon-Sweetwater-Devils Lake East 115 kV line to increase the continuous rating from 69 MVA to 130 MVA. This will be accomplished by:

- applying wind-adjusted ratings
- increasing the permissible conductor operating temperature to 80° C for the MPC portion of the line (northern portion) by increasing ground clearance, while the OTP portion (southern) will be increased to 90° C by increasing the ground clearance and removing overhead distribution line clearance conflicts.

Similarly, the Hensel-Drayton 115 kV line will also have its permissible conductor temperature increased to 80° C, which will, in conjunction with wind-adjusted ratings, result in an increase in the continuous rating from 72 MVA to 129 MVA.

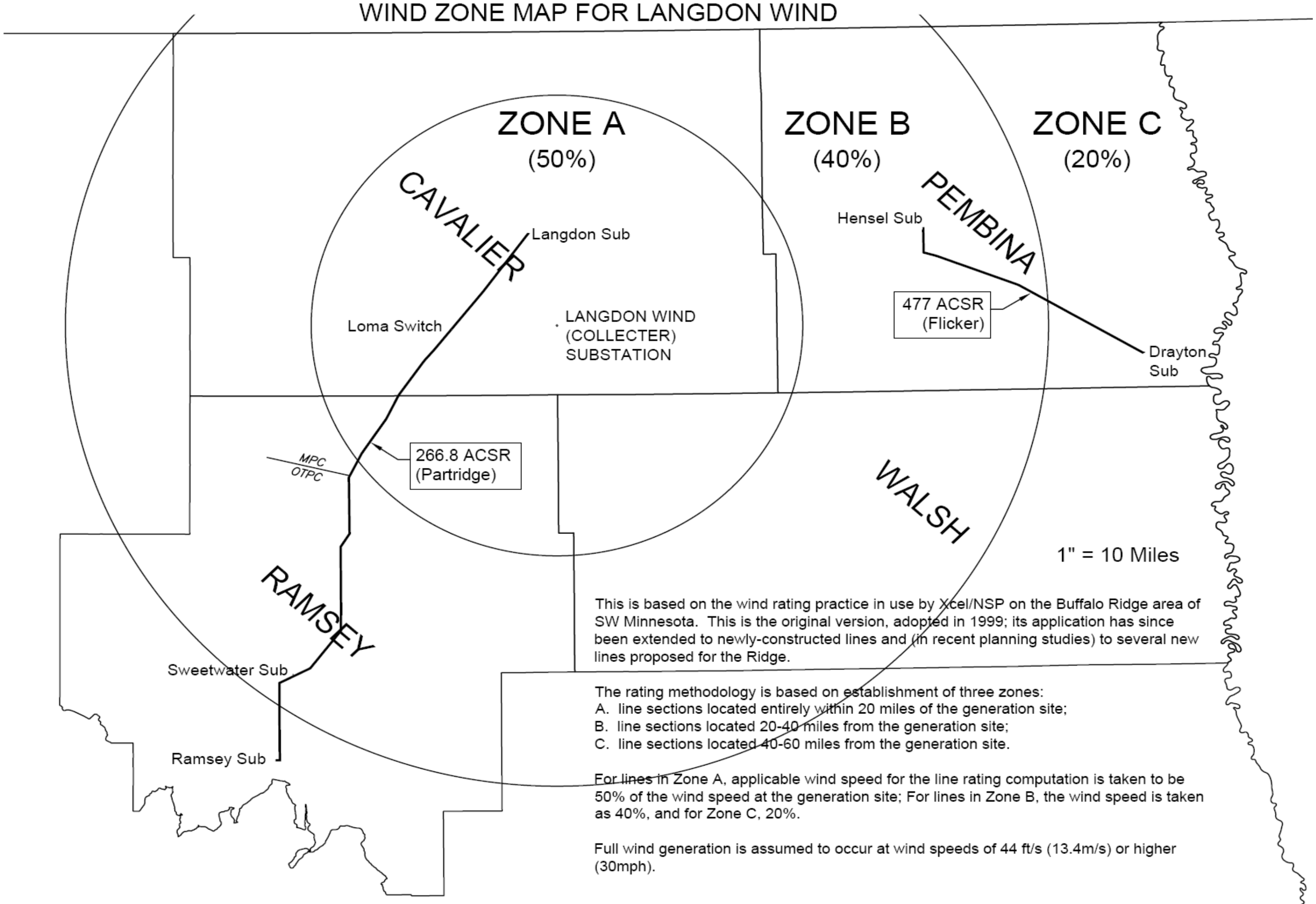


Figure 5.0.1 – Wind Zone Map for Langdon Wind

Each circuit will also have an emergency rating of 110% of its continuous rating.

The wind-adjusted ratings used on these lines will be similar to what was previously reviewed by the DRS for use by NSP (now Xcel Energy) in the Buffalo Ridge area of southwest Minnesota. This wind rating methodology incorporates IEEE standard 738 and establishes three zones for different wind assumptions:

- Zone A - Line sections located entirely within 20 miles of the generation site
- Zone B - Line sections located entirely 20-40 miles of the generation site
- Zone C - Line sections located entirely 40-60 miles of the generation site

For lines in Zone A, applicable wind speed for the line rating computation is set to be 50% of the wind speed at the generation site; for lines within Zone B, the wind speed is taken as 40%, and for Zone C, 20%. Full wind generation is assumed to occur at wind speeds of 44 ft/s (13.4 m/s or 30 mph). For the rating assumptions used from this increase in wind speed, lines within Zone A have a rating multiplier of 1.86, lines within Zone B have a rating multiplier of 1.74, and Zone C has a rating multiplier of 1.43.

The concept of wind adjusted ratings used in this study and being adopted by MPC and OTP was based on work completed by Northern States Power Company for the Buffalo Ridge area. The map in Figure 5.0.1 illustrates the transmission system in the vicinity of the wind farm that was used in deriving the wind adjusted ratings on the area 115 kV facilities near Langdon.

5.1 System Intact Analysis

During Summer Off-peak, high transfer conditions with both NDEX and MHEX at their maximum simultaneous transfer limits (2080 MW and 2175 MW respectively), both the Dorsey-Forbes 500 kV line and the Forbes – Chisago Co 500 kV line are loaded beyond their 1732 MVA ratings during system intact conditions.

The Dorsey-Roseau Co-Forbes line is limited by series capacitors at Roseau County, and terminal equipment at Dorsey. The Forbes-Chisago Co line is limited by the Chisago series capacitors. The Chisago Co series capacitors will have a reduction in flow due to the Arrowhead–Stone Lake–Gardner Park 345 kV line, which was not modeled in this analysis.

Resolution of the Dorsey-Forbes-Chisago Co 500 kV line overload during this extreme transfer condition is an outstanding issue with Manitoba Hydro for numerous interconnection projects presently under consideration. This line overload is not considered an interconnection related upgrade and therefore will only be addressed if it would happen to appear during the transmission service approval process for this project.

5.2 Contingency Analysis

Reviewing the contingency analysis results for the three load level/transfer patterns studied had led to the following conclusions:

- No voltage impacts were identified as a result of this project for any of the conditions studied.
- Summer Off-peak conditions have several post-contingent loading violations on the local Langdon 115 kV outlet lines. Further details are provided in Section 5.2.1.
- Summer peak has no post-contingent loading violations beyond criteria.
- Winter peak has only one post-contingent violation. The Ramsey 230/115 kV transformer is subject to overload following outage of the Ramsey-Prairie 230 kV line. This overload is due to the addition of the Langdon-Hensel 115 kV line, and not the Langdon generation. Further details are provided in Section 5.2.2.

5.2.1 Langdon Area 115 kV Line Loadings

Table 5.2.1 shows the system intact and N-1 loadings for the 115 kV lines in the Langdon vicinity (all line sections between the Ramsey and Drayton 230/115 kV stations) during the Summer Off-peak conditions when the load on the system is at its lowest therefore corresponding to the highest amount of flow onto the system from the generation. Also included are the proposed line ratings (achieved through thermal upgrades and application of wind ratings) proposed to be used in conjunction with the Langdon generation addition.

A review of Table 5.2.1 reveals that prior to the Hanks Corner generation going into service, these new line ratings are adequate to accommodate the Langdon generation addition's system intact and post-contingent loadings, except for the outage of the Langdon-Hensel 115 kV line, where the post-contingent loadings of 149 MVA on the Langdon-Sweetwater 115 kV would exceed the new 130 MVA continuous and the corresponding 143 MVA emergency line ratings. This is not an actual problem, however, because consideration of the voltage stability limit (discussed in the next section) requires a 40 MW generation reduction at Langdon for this contingency, which will directly reduce the flow on the Langdon – Sweetwater 115 kV line.

To accommodate the increased capacity needed for the Hanks Corner generation, the Hensel-Drayton 115 kV line rating would need to be increased further. The Langdon project (along with OTP and MPC) will monitor generation development through the MISO interconnection process to determine when any further upgrades will be required for these lines as a result of the Hanks Corner generation project (MISO Project G651).

Table 5.2.1 – Langdon Area 115 kV Line Thermal Limits and Loadings
(Summer Off-Peak condition; NDEX = 2080 MW)

Outage	Monitored Element	Continuous Rating Present (MVA)	Continuous Rating Proposed (MVA)	Loading, MVA with Hanks Corner 39.1MW	Loading, MVA without Hanks Corner 39.1MW
(System Intact)	Langdon-Sweetwater-Devils Lake 115 kV	69	130	59	49
	Langdon-Hensel 115 kV line	N/A	230	92	101
	Hensel-Drayton 115 kV line	72	129	107	79
Langdon-Sweetwater 115 kV	Langdon-Sweetwater-Devils Lake 115 kV	69	130	-	-
	Langdon-Hensel 115 kV line	N/A	230	148	148
	Hensel-Drayton 115 kV line	72	129	**162**	**125**
Langdon-Hensel 115 kV	Langdon-Sweetwater-Devils Lake 115 kV	69	130	**149***	**149***
	Langdon-Hensel 115 kV line	N/A	230	-	-
	Hensel-Drayton 115 kV line	72	129	19	24
Hensel-Drayton 115 kV	Langdon-Sweetwater-Devils Lake 115 kV	69	130	**162***	**126**
	Langdon-Hensel 115 kV line	N/A	230	15	25
	Hensel-Drayton 115 kV line	72	129	-	-
Ramsey 230/115 Tx	Langdon-Sweetwater-Devils Lake 115 kV	69	130	53	45
	Langdon-Hensel 115 kV line	N/A	230	98	106
	Hensel-Drayton 115 kV line	72	129	**112**	**83**
DL SW-DL Jct 115 kV	Langdon-Sweetwater-Devils Lake 115 kV	69	130	53	45
	Langdon-Hensel 115 kV line	N/A	230	97	105
	Hensel-Drayton 115 kV line	72	129	**111**	**83**

***** These Langdon-Sweetwater-Devils Lake 115 kV line loadings result from Langdon generation levels (159 MW) that are in excess of the voltage stability limit (120 MW) applicable to these line outages. Refer to Section 5.3 for details on voltage stability considerations. Observance of the Langdon generation restrictions arising from voltage stability considerations will reduce the post-contingent loadings by approximately 40 MW. This 40 MW loading reduction prevents the post-contingent loadings from exceeding the proposed Langdon-Sweetwater-Devils Lake 115 kV circuit rating of 130 MVA.

5.2.2 Ramsey 230/115 kV Transformer Loadings

The system intact loadings on the Ramsey transformer were determined to evaluate the impacts of additional Langdon facilities on the Ramsey 84 MVA transformer. Table 5.2.2 shows the Ramsey transformer flows for the relevant combinations of system conditions.

Table 5.2.2 – Ramsey Transformer Flows – System Intact Conditions

	Flows, MVA (% of 84 MVA) Summer Peak	Flows, MVA (% of 84 MVA) Summer Off-peak	Flows, MVA (% of 84 MVA) Winter Peak
Existing System	36.0 (42%)	18.5 (22%)	38.6 (46%)
Add Langdon-Hensel 115 kV	35.4 (42%)	19.6 (23%)	50.7 (60%)
Add Langdon-Generation 160 MW **Add Langdon-Hensel 115 kV**	42.7 (51%)	23.4 (28%)	28.2 (34%)

Table 5.2.2 shows that the Langdon-Hensel 115 kV line addition has a negligible effect on Summer peak and Summer Off-peak loadings, and causes a 12.4 MW loading increase during Winter peak conditions.

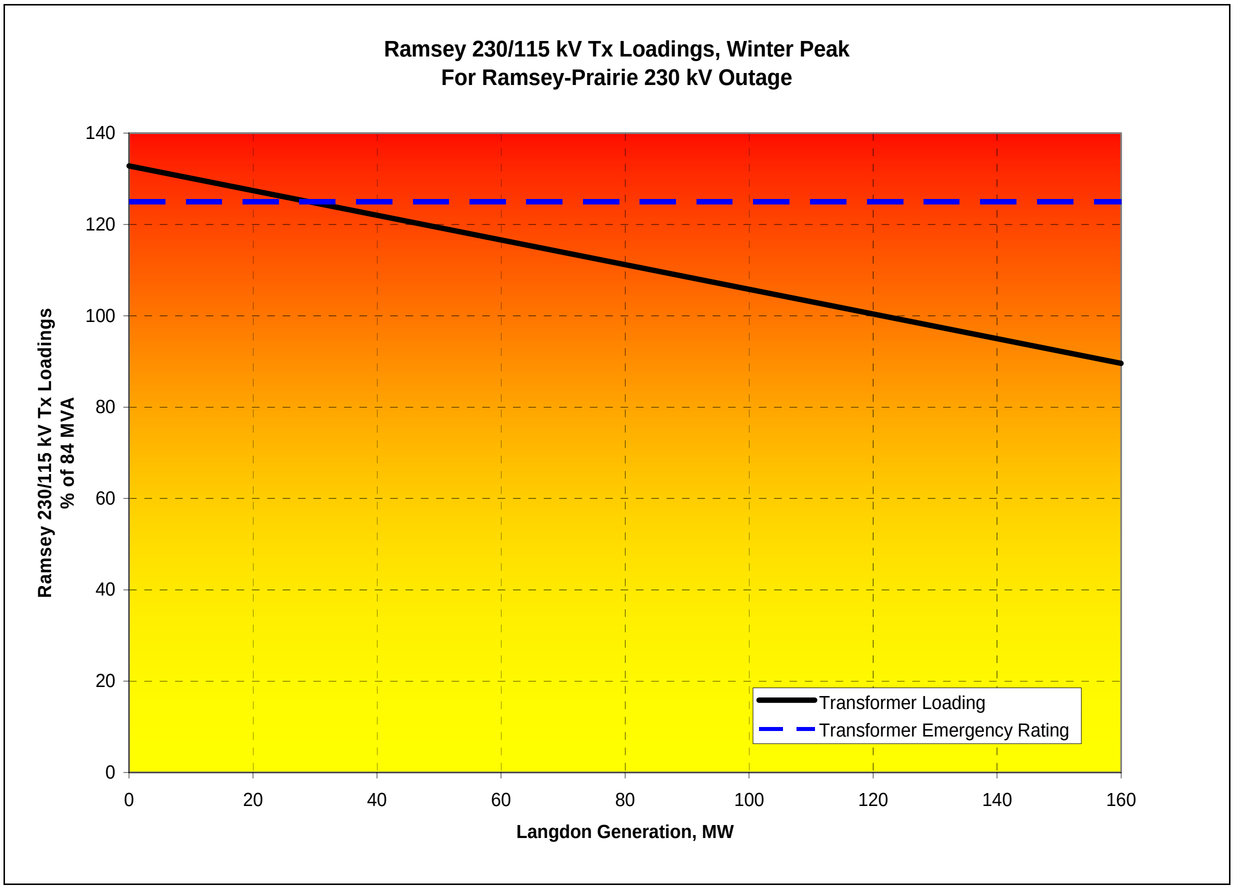
The contingency analysis shows that with the addition of the Langdon-Hensel 115 kV line, it is now possible to have excessive loading (over 125 % of continuous) on the 84 MVA Ramsey 230/115 kV transformer following outage of the Ramsey-Prairie 230 kV line (outage #9) during Winter peak and Summer peak conditions.. This occurs because the Langdon-Hensel line addition completes a parallel 115 kV path from Ramsey to the east (to the Drayton Substation).

It was initially suspected that the Ramsey transformer's post-contingent loading would be sensitive to both MHEX northward loading and the Langdon generation level. Subsequent analysis has revealed that the loading is essentially independent of the MHEX level. Table 5.2.3 illustrates the Ramsey 230/115 kV transformer loading for the different cases evaluated as part of this system impact study.

Table 5.2.3 – Ramsey Transformer Flows (Ramsey-Prairie 230 kV Outage)

	Flows, MVA (%)		
	Summer Peak	**Summer Off-peak**	**Winter Peak**
Existing System	75.6 (90%)	59.1 (70%)	38.1 (99%)
Add Langdon-Hensel 115 kV	86.0 (102%)	73.8 (88%)	50.5 (134%)
Add Langdon-Generation 160 MW **Add Langdon-Hensel 115 kV**	53.5 (64%)	40.7 (49%)	27.8 (89%)

Graph 5.2.4 shows that the Ramsey 230/115 kV transformer's post-contingent loading is very sensitive to the Langdon generation level. Post-contingent loadings exceeding the transformer's applicable emergency rating (125% of its continuous rating) are only observed when Langdon generation output is approximately 30 MW or less. A three-dimensional graph at the end of Appendix E shows the Ramsey transformer loading in relation to both MHEX and Langdon generation.



Graph 5.2.4 – Ramsey 230/115 Transformer Loadings

The short-term solution to address the post-contingent Ramsey transformer loading during periods of low or zero Langdon generation is implementation of a Special Protection Scheme (SPS) which involves tripping the Devils Lake East 115 kV breaker thereby opening the parallel 115 kV loop between Ramsey and Drayton. This scheme will create a separation between Langdon (Sweetwater) and the Devils Lake area. This breaker opening will then isolate the impacts of Langdon (Sweetwater) loads and generation along with through flow on the Langdon-Hensel 115 kV line. The SPS is intended to operate only if the actual post-contingent loadings exceed permissible loading criteria on the transformer.

Determination of a long-term solution for the Devils Lake area is currently underway by the load-serving entities in that area. Currently several options are being evaluated through this separate load-serving study, including the replacement of the existing or an addition of a second Ramsey 230/115 kV transformer. The Langdon project will coordinate with the load-serving study to ensure that an acceptable long-term solution is implemented for both load serving and generation needs.

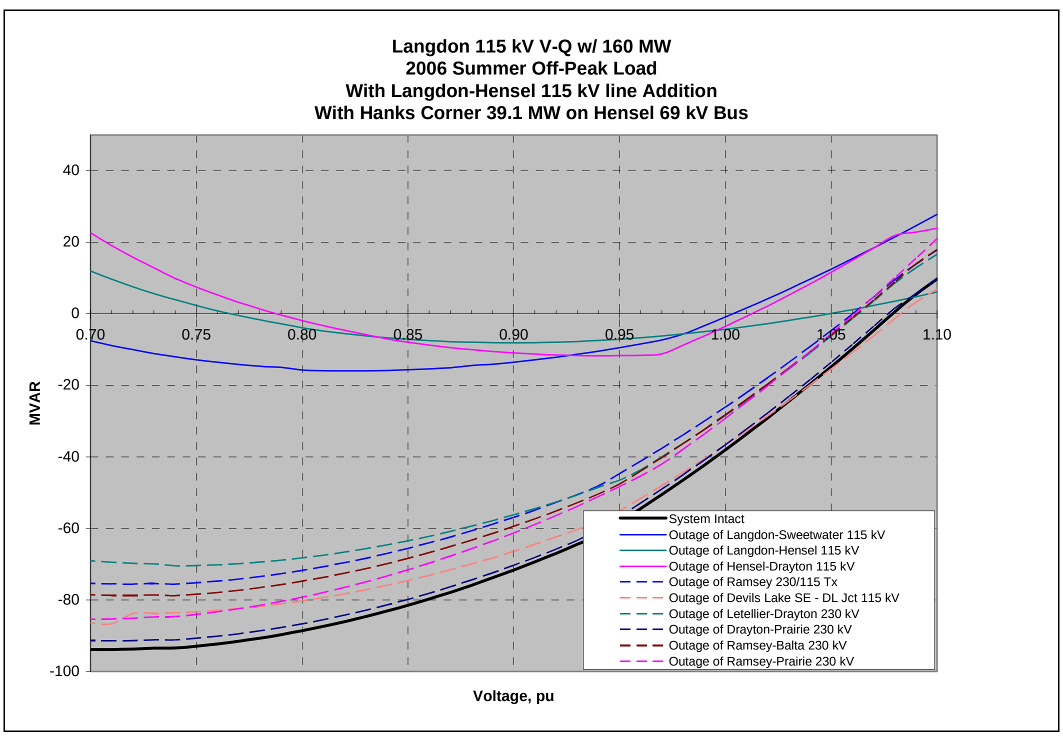
5.3 Voltage Stability Analysis

Local and regional voltage stability impacts were studied by the use of V-Q and P-V analysis.

5.3.1 Langdon Area Analysis

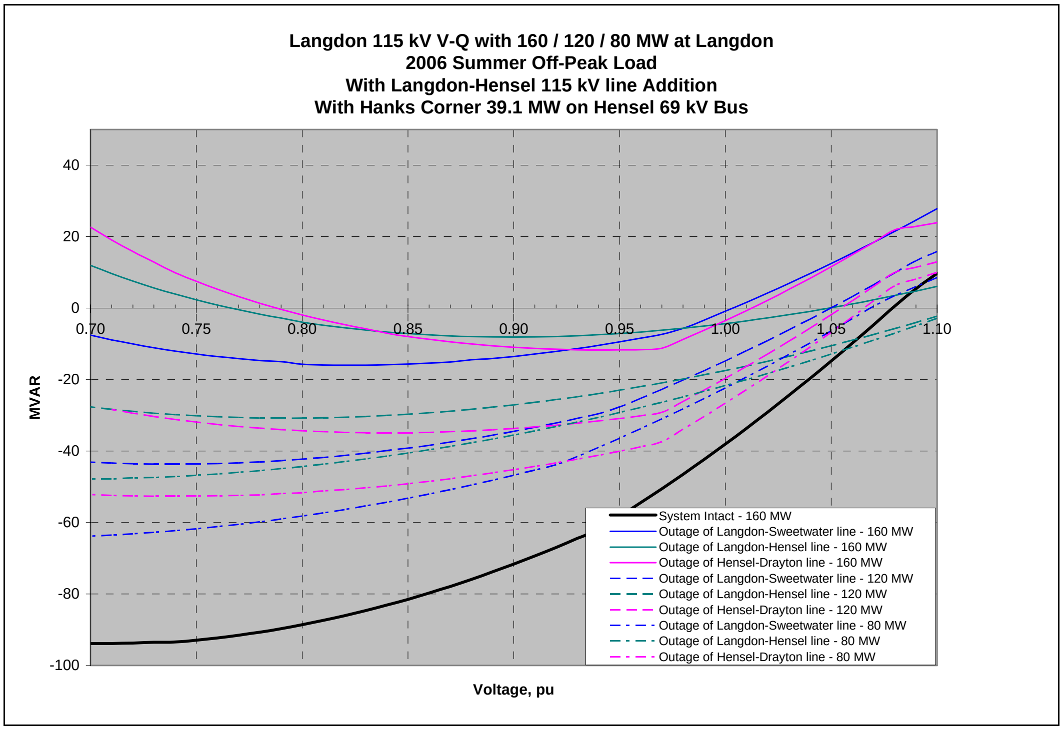
Voltage stability analysis was performed for the Langdon 115 kV bus during system intact and various single contingencies to determine reactive requirements, margins, and critical voltages. This analysis was performed for both Langdon and Hanks Corner generation additions, in order to define the degree to which the results are linked to changes in generation levels.

Graph 5.3.1 shows that the three most severe Langdon area single contingencies are the loss of Langdon-Sweetwater 115 kV line, Langdon-Hensel 115 kV line, and Hensel-Drayton 115 kV line. All three contingencies produce rather shallow V-Q curves, whereas the other contingencies produce curves with the desirable positive-slope characteristic. From this graph it was concluded that outage of either the Langdon-Hensel 115 kV line or the Hensel-Drayton 115 kV line yields an unacceptably-high critical voltage. Consequently, a generation reduction is required to ensure a stable post-contingent operating condition.



Graph 5.3.1 – V-Q Analysis of Langdon 115 kV bus

Graph 5.3.2 shows that a 120 MW generation restriction for these two problematic outages (Langdon generation reduced from 160 MW to 120 MW) produces satisfactory V-Q curve characteristics: this is shown by the dashed lines.



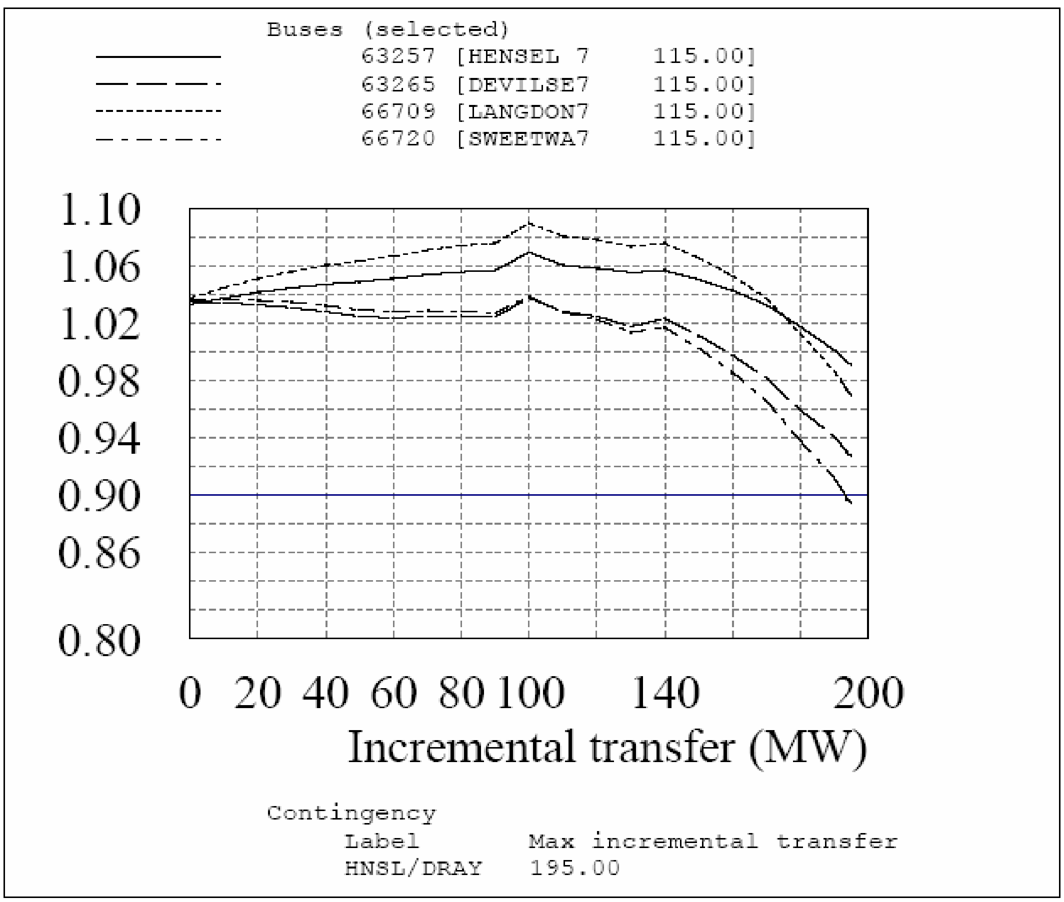
Graph 5.3.2 – V-Q Analysis with Various Generation Levels

The Hanks Corner generation introduces a complication to this voltage stability analysis. All the analysis was performed to represent "worst-case" conditions, which correspond to the Hanks Corner generation being on line at full output (39.1 MW).

- The generation restriction required for the Langdon-Hensel 115 kV line outage (120 MW) is independent of the Hanks Corner generation status, because this line outage separates the Langdon and Hanks Corner generation.
- In contrast, in the case of the Hensel-Drayton 115 kV outage, the amount of Langdon generation reduction required is directly related to the Hanks Corner generation output. With Hanks Corner generation on line at 39 MW, the 40 MW Langdon generation post-contingency reduction is required. If Hanks Corner generation is not in service, no Langdon generation reduction is required, since the amount of generation reduction is equivalent to the Hanks Corner generation output.

Given the amount of performance improvement noted in Graph 5.3.2 for a 40 MW Langdon post-contingent generation restriction (i.e. generation limited to 120 MW), it is evident that the only Langdon generation reduction required prior to the Hanks Corner 39 MW generation addition is that in response to the Langdon-Hensel 115 kV outage. Following the Hanks Corner generation addition (should it occur), the Langdon generation restriction (120 MW) would also be required for the Hensel-Drayton 115 kV line outage. It is not necessary to restrict Langdon generation during system intact conditions, but rather the generation needs to be reduced following one of the previously mentioned critical contingencies. Additional V-Q graphs from the voltage stability analysis can be found in Appendix F.

P-V analysis was performed to verify that the 120 MW generation restriction at Langdon was sufficient to meet regional criteria for voltage stability margins during various contingencies determined by V-Q analysis. Incremental transfer was adjusted by a dispatch from Langdon generation to Young and Hoot Lake generation. Graph 5.3.3 shows the incremental generation addition at Langdon during the outage of Hensel-Drayton 115 kV line. This P-V analysis does include Hanks Corner generation on line at 39 MW, which as discussed previously, requires a generation restriction to 120 MW. The presence of this generation with the Hensel-Drayton 115 kV line outage is more severe than the Langdon-Hensel 115 kV line outage. This is confirmed by viewing critical voltage levels for these two conditions on the V-Q curves in Figure 5.3.2.



Graph 5.3.3 – P-V Analysis (Outage of Hensel-Drayton line)

A summary of the P-V analysis results is shown in Table 5.3.4. According to these results, a 40 MW generator reduction at Langdon is within the voltage stability margin of ensuring a 10% margin of the voltage collapse point as set forth in the MAPP region.

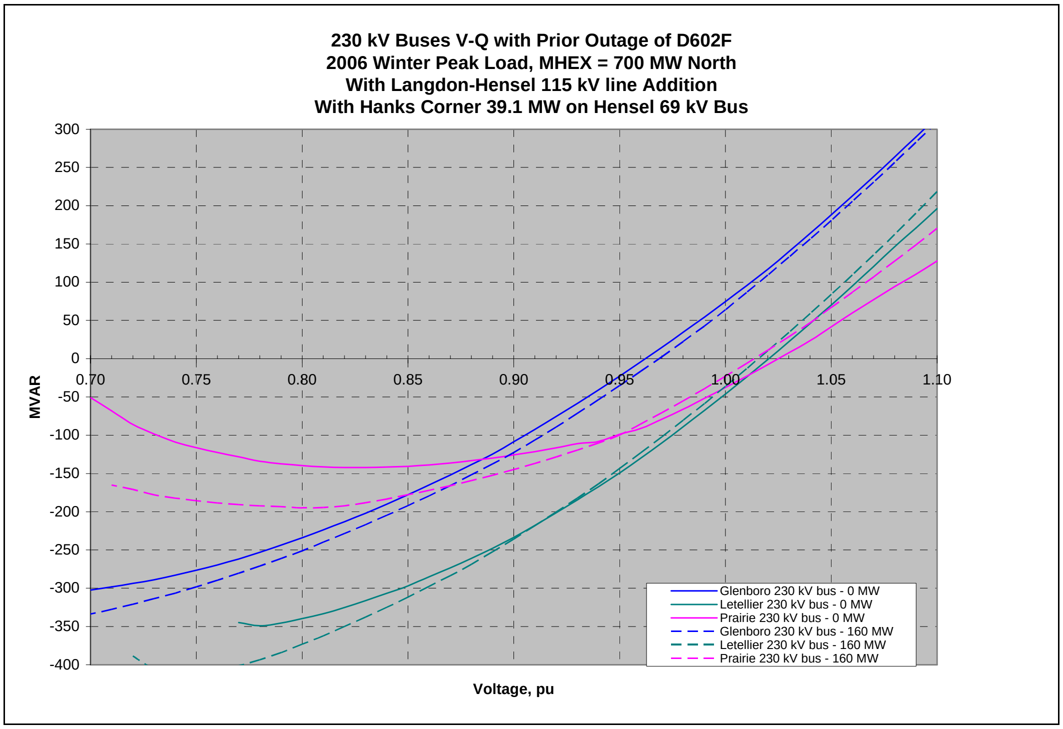
Table 5.3.4 – P-V Limits (Hensel-Drayton outage)

Location	Limit	10% Margin	Safe Operating Limit
Hensel 115 kV	195 MW	19.5 MW	175.5 MW
Devils Lake East 115 kV	190 MW	19.0 MW	171.0 MW
Langdon 115 kV	195 MW	19.5 MW	175.5 MW
Sweetwater 115 kV	195 MW	19.5 MW	175.5 MW

A special protection system is proposed to limit Langdon generation output, so that the identified voltage stability limit of the Langdon-Devils Lake line is not exceeded. The system will measure this line flow, and issue a signal to the Langdon wind farm when flow exceeds an acceptable level. The signal will cause a trip of enough wind generators so that total output from the farm cannot exceed the allowable limit.

5.3.2 Regional Analysis

Further voltage analysis was performed at the Glenboro, the Letellier, and the Prairie 230 kV buses for both pre- and post-project cases to determine the impact of the Langdon project on existing regional voltage stability concerns. The results of this analysis are included in Graph 5.3.5. The post Langdon generation addition of 160 MW is shown in Graph 5.3.5 by the dashed lines. This voltage analysis has confirmed that the voltage stability concerns introduced by the Langdon generation do not have a significant impact on voltage stability performance in the northern MAPP region during Winter peak conditions.



Graph 5.3.5 – V-Q Analysis during Winter Peak

5.4 Loss Analysis

Transmission system loss analysis is typically performed to evaluate demand (MW) losses. Table 5.4.1 shows on-peak losses for the relevant combinations of system conditions for the entire Eastern Interconnection.

Table 5.4.1 – Total System Losses – Generation to Generation Dispatch

	Losses, MW	
	Summer Peak	**Winter Peak**
Existing System	12741.1	10727.0
Add Langdon-Hensel 115 kV	12741.1	10729.9
Reductions: (MW)	0.0	-2.9
Add Langdon-Generation 160 MW	12750.6	10711.3
Add Langdon-Hensel 115 kV		
Reductions: (MW)	-9.5	15.7

The table above shows that the Langdon-Hensel 115 kV line addition has no effect on Summer peak losses, and causes a 2.9 MW increase during Winter peak conditions.

The subsequent 160 MW incremental Langdon generation addition reverses the situation: it causes a 9.5 MW loss increase during Summer peak conditions, and yields a net loss reduction of 15.7 MW during Winter peak conditions.

Detailed loss analysis for each control area is presented in Appendix G.

5.5 Constrained Interface Impact Evaluation

The Langdon generation addition's impacts upon MAPP constrained paths ("flowgates") were evaluated using the summer off-peak high transfer cases with the "dfcalc.ipl" program. This program compares the pre- and post-transfer scenarios and creates a tabular output showing the impact of the transfer upon the various MAPP constrained interfaces. The complete results can be found in Appendix H along with the tie line definition file. Also evaluated in a similar manner were MISO's constrained interfaces. The constrained interface analysis included within this study is for informational purposes since this is not a delivery study.

OTP is a MISO member and therefore has made a Transmission Service Request (TSR) on the MISO OASIS for delivery of its 60 MW share of the Langdon generation project (MISO Project A364). Constrained interface analysis for delivery of the OTP share of the project will be evaluated through a separate MISO process.

Constrained interface analysis has determined that this project's impact exceeds the 5% PTDF threshold on the Forbes – Chisago 500 kV line. The Arrowhead–Stone Lake–Gardner Park 345 kV line will substantially unload this line and significantly alter the PTDF calculation for this project. An interim solution could be needed for delivery of this generation from the Langdon wind farm to MPC for the first several months of planned operation if firm transmission service is desired for this wind farm.

5.5.1 Manitoba Hydro-U.S. Interface Impacts

Table 5.5.1 shows the "before" and "after" flows on the Manitoba-U.S. transmission interconnections for the Langdon generation addition using generation to generation dispatch.

Table 5.5.1 – Manitoba-U.S. Tie Line Loadings
(Summer off-peak condition; NDEX = 2080 MW)

		Loading, MW			DF
Tie Line	kV	before	after	diff	
Glenboro-Rugby	230	-27.5	-23.5	4.0	0.025
Letellier-Drayton	230	267.7	235.8	-31.9	-0.199
Richer-Roseau Co	230	137.5	139.7	2.2	0.014
Dorsey-Roseau Co	500	1795.9	1825.4	29.5	0.184
Total MHEX		2173.6	2177.4	3.8	0.024

Table 5.5.1 shows, as expected, relatively little net impact on the MHEX loading. Considering the nature of the MHEX interface, and the fact that both the source and the sinks involved in the transactions are external to the MH system, the net MHEX impact should be zero. However, differences in losses, and flow variations due to discrete phase shifter tap steps result in the residual 2.4% distribution factor indicated. In any case, the DF on the MHEX interface is under 5% and therefore within criteria.

It is noted from Table 5.5.1, that the tie line sharing of the southward MHEX loading is modified. Due to the Langdon generation's proximity to Drayton, there is a shifting of flow from the Letellier-Drayton 230 kV line primarily to the Dorsey-Roseau Co 500 kV line. This MHEX impact will be addressed separately by MPC and OTP because these entities have different relationships with respect to the Manitoba-U.S. transmission interface.

A number of potential improvements were tested to determine future options for reducing the Dorsey-Roseau Co 500 kV line flow. Improvements studied include series compensation of the Drayton-Prairie 230 kV line, the Richer-Moranville-Shannon 230 kV line along with building a new 230 kV line from Langdon to Prairie. The summer off-peak high transfer case was used for each of the options studied.

Table 5.5.2 shows a sensitivity of the MH-US tie line loadings along with the Drayton-Prairie 230 kV line and Forbes-Chisago Co 500 kV line. The sensitivity analysis results are shown in Tables 5.5.3 – 5.5.5. It should be noted that the flow on the Dorsey – Forbes 500 kV line (D602F) is higher in the pre-project cases due to NDEX being increased to 2080 MW along with the addition of the prior queued generation (particularly G380 at Rugby).

In the following tables, the "NDEX-1950" cases are taken directly from the NMORWG 2006 study package. They were not modified in the derivation of these tables. The "NDEX-2080" cases were modified as described in Section 4.2 (000 = existing system, 00H = with new Langdon-Hensel line, 16H = with new Langdon-Hensel line and the Langdon generation).

Table 5.5.2 – Manitoba-U.S. Tie Line Sensitivity
(Summer off-peak condition)

		Loading, MW				
		NDEX - 1950		NDEX – 2080		
Tie Line	kV	CRUISE	URGE	000	00H	16H
Glenboro-Rugby	230	14.6	11.0	-28.4	-27.5	-23.5
Letellier-Drayton	230	273.9	281.2	269.0	267.7	235.8
Richer-Roseau Co	230	132.0	131.6	137.5	137.5	139.7
Dorsey-Roseau Co	500	1754.9	1751.9	1795.6	1795.9	1825.4
Total MHEX		2175.4	2175.7	2173.7	2173.6	2177.4

		Loading, MVA				
		NDEX - 1950		NDEX – 2080		
Line	kV	CRUISE	URGE	000	00H	16H
Glenboro-Rugby	230	17.7	16.4	35.7	34.8	31.2
Letellier-Drayton	230	273.9	281.3	269.0	267.7	235.8
Richer-Roseau Co	230	132.3	131.9	138.0	138.0	140.3
Dorsey-Roseau Co	500	1790.0	1788.9	1843.1	1843.3	1878.6
Drayton-Prairie	230	160.9	162.8	179.7	181.7	214.6
Forbes-Chisago Co	500	1832.7	1850.5	1883.8	1884.0	1900.9

		Loading, Amps				
		NDEX - 1950		NDEX – 2080		
Line	kV	CRUISE	URGE	000	00H	16H
Glenboro-Rugby	230	43	40	86	84	75
Letellier-Drayton	230	670	692	658	655	573
Richer-Roseau Co	230	325	324	340	340	346
Dorsey-Roseau Co	500	2002	2002	2069	2069	2099
Drayton-Prairie	230	399	408	446	451	528
Forbes-Chisago Co	500	2108	2136	2194	2194	2213

Table 5.5.3 – Series Comp Drayton-Prairie 230 kV Line Sensitivity

60% Series Comp Drayton-Prairie 230 kV (gen to gen)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-33.9	-6.4	-0.040
Letellier-Drayton	230	267.7	265.3	-2.4	-0.015
Richer-Roseau Co	230	137.5	138.3	0.8	0.005
Dorsey-Roseau Co	500	1795.9	1802.4	6.5	0.041
Total MHEX		2173.6	2172.1	-1.5	-0.009
Drayton-Prairie	230	178.9	267.3	88.4	0.553
Forbes-Chisago Co	500	1881.8	1883.5	1.7	0.011

60% Series Comp Drayton-Prairie 230 kV (gen to load)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-37.4	-9.9	-0.062
Letellier-Drayton	230	267.7	285.3	17.6	0.110
Richer-Roseau Co	230	137.5	137.1	-0.4	-0.003
Dorsey-Roseau Co	500	1795.9	1792.2	-3.7	-0.023
Total MHEX		2173.6	2177.2	3.6	0.022
Drayton-Prairie	230	178.9	274.9	96.0	0.600
Forbes-Chisago Co	500	1881.8	1873.8	-8.0	-0.005

As shown above, the series compensation of the Drayton-Prairie 230 kV line works well for reducing the distribution factor (DF) on D602F.

* The 00H case was assumed to be the “base case” due to the minimum difference between the 000 case (existing system) as shown in the previous tables. This would also emphasis only the impacts of the Langdon Wind Generation and not the 115 kV line addition between Langdon and Hensel.

Table 5.5.4a – Series Comp Richer-Moranville-Shannon 230 kV Line Sensitivity

50% Series Comp Moranville-Running 230kV (gen to gen)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-23.8	3.7	0.023
Letellier-Drayton	230	267.7	232.9	-34.8	-0.218
Richer-Roseau Co	230	137.5	157.1	19.6	0.123
Dorsey-Roseau Co	500	1795.9	1811.2	15.3	0.096
Total MHEX		2173.6	2177.4	3.8	0.024
Drayton-Prairie	230	178.9	211.7	32.8	0.205
Forbes-Chisago Co	500	1881.8	1896.9	15.1	0.094

50% Series Comp Moranville-Running-Shannon 230kV (gen to gen)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-27.8	-0.3	-0.002
Letellier-Drayton	230	267.7	227.5	-40.2	-0.251
Richer-Roseau Co	230	137.5	194.0	56.5	0.353
Dorsey-Roseau Co	500	1795.9	1781.2	-14.7	-0.092
Total MHEX		2173.6	2174.9	1.3	0.008
Drayton-Prairie	230	178.9	207.9	29.0	0.181
Forbes-Chisago Co	500	1881.8	1895.9	14.1	0.088

50% Series Comp Richer-Roseau-Moranville-Running-Shannon 230kV (gen to gen)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-31.5	-4.0	-0.025
Letellier-Drayton	230	267.7	222.2	-45.5	-0.284
Richer-Roseau Co	230	137.5	224.1	86.6	0.541
Dorsey-Roseau Co	500	1795.9	1756.9	-39.0	-0.244
Total MHEX		2173.6	2171.7	-1.9	-0.012
Drayton-Prairie	230	178.9	204.3	25.4	0.159
Forbes-Chisago Co	500	1881.8	1895.0	13.2	0.083

This analysis indicates that series compensation on both the Moranville-Running 230 kV line and the Running-Shannon 230 kV line portions are needed to get the DF on D602F below 5%. However, the distribution factor on the Forbes – Chisago 500 kV (F601C) is still above the 5% cut-off level for compensation of these 230 kV lines.

* The 00H case was assumed to be the "base case" due to the minimum difference between the 000 case (existing system) as shown in the previous tables. This would also emphasis only the impacts of the Langdon Wind Generation and not the 115 kV line addition between Langdon and Hensel.

** Richer-Roseau Co-Moranville 230 kV line rating is 230 MVA

Table 5.5.4b – Series Comp Richer-Moranville-Shannon 230 kV Line Sensitivity

50% Series Comp Moranville-Running 230kV (gen to load)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-29.8	-2.3	-0.014
Letellier-Drayton	230	267.7	243.3	-24.4	-0.153
Richer-Roseau Co	230	137.5	156.8	19.3	0.121
Dorsey-Roseau Co	500	1795.9	1806.7	10.8	0.067
Total MHEX		2173.6	2177.0	3.4	0.021
Drayton-Prairie	230	178.9	211.2	32.3	0.202
Forbes-Chisago Co	500	1881.8	1889.2	7.4	0.046

50% Series Comp Moranville-Running-Shannon 230kV (gen to load)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-32.4	-4.9	-0.031
Letellier-Drayton	230	267.7	244.9	-22.8	-0.143
Richer-Roseau Co	230	137.5	192.3	54.8	0.343
Dorsey-Roseau Co	500	1795.9	1770.0	-25.9	-0.162
Total MHEX		2173.6	2174.8	1.2	0.008
Drayton-Prairie	230	178.9	213.1	34.2	0.214
Forbes-Chisago Co	500	1881.8	1884.9	3.1	0.019

50% Series Comp Richer-Roseau-Moranville-Running-Shannon 230kV (gen to load)

Tie Line	kV	Loading, MW 00H	16H	diff	DF
Glenboro-Rugby	230	-27.5	-34.9	-7.4	-0.046
Letellier-Drayton	230	267.7	241.2	-26.5	-0.166
Richer-Roseau Co	230	137.5	222.4	84.9	0.531
Dorsey-Roseau Co	500	1795.9	1747.9	-48.0	-0.300
Total MHEX		2173.6	2176.6	3.0	-0.019
Drayton-Prairie	230	178.9	210.5	31.6	0.198
Forbes-Chisago Co	500	1881.8	1886.0	4.2	0.026

* The 00H case was assumed to be the "base case" due to the minimum difference between the 000 case (existing system) as shown in the previous tables. This would also emphasis only the impacts of the Langdon Wind Generation and not the 115 kV line addition between Langdon and Hensel.

** Richer-Roseau Co-Moranville 230 kV line rating is 230 MVA

Table 5.5.5 – Impact of a New Langdon-Prairie 230 kV Line

Langdon-Prairie 230kV (gen to gen)

Tie Line	kV	Loading, MW 000	16P	diff	DF
Glenboro-Rugby	230	-28.4	-22.2	6.2	0.039
Letellier-Drayton	230	269.0	239.7	-29.3	-0.183
Richer-Roseau Co	230	137.5	139.2	1.7	0.011
Dorsey-Roseau Co	500	1795.6	1821.4	25.8	0.161
Total MHEX		2173.7	2178.1	4.4	0.028
Drayton-Prairie	230	176.8	149.3	-27.5	-0.172
Forbes-Chisago Co	500	1881.7	1897.7	16.0	0.100

Langdon-Prairie 230kV (gen to load)

Tie Line	kV	Loading, MW 000	16P	diff	DF
Glenboro-Rugby	230	-28.4	-26.9	1.5	0.009
Letellier-Drayton	230	269.0	256.4	-12.6	-0.079
Richer-Roseau Co	230	137.5	138.4	0.9	0.006
Dorsey-Roseau Co	500	1795.6	1804.8	9.2	0.058
Total MHEX		2173.7	2172.7	-1.0	-0.006
Drayton-Prairie	230	176.8	151.4	-25.4	-0.159
Forbes-Chisago Co	500	1881.7	1883.4	1.7	0.011

Connecting the wind generation directly to Prairie with a 230 kV line and not interconnecting with the existing Langdon 115 kV system still results in a 16% DF on D602F.

5.6 Dynamic Stability Analysis

5.6.1 Introduction

The development of the dynamic stability model for the evaluation of this wind farm was discussed earlier in section 4.1 entitled “Models Employed”. These models incorporate a user-written dynamics model for these specific GE turbines, and therefore should produce results which closely represent the actual operation of this wind farm with low voltage ride through (LVRT) capability.

To understand the impact of the proposed generation and transmission additions upon the performance of the northern MAPP transmission system, an extensive set of transient stability simulations was performed. Voltage profiles and system damping were reviewed to ensure that the transmission grid will function within acceptable levels following a transient event on the transmission system.

Stability analysis was performed initially on the base case with only the Langdon-Hensel 115 kV line addition to determine the effects of the transmission addition without the Langdon Wind Generation addition. Then stability analysis was performed to evaluate system performance after the 160 MW generation addition with both “generation to generation” and “generation to load” deliveries.

Table 5.6.1 lists the regional disturbances while Table 5.6.2 lists the local disturbances that were analyzed for this system impact study. Appendix I contains the description of all fault files that were included in the stability analysis and the dynamic models used for the new generation. The stability output plots for the various faults can be found in Appendices K and L, while the summary tables can be found in Appendix J.

Table 5.6.1 – Regional Disturbances

Fault Name	Faulted Bus	Fault Type	Clearing Time (cycles)	Initial Clearing	Backup Clearing (cycles)	Backup Clearing
AG1	Leland Olds 345kV	SLGBF	4	Leland Old-Ft Thompson line	11	FLTD Line
AG3	Leland Olds 345kV	3-phase	4	Leland Old-Ft Thompson line		
EI2	Coal Creek 230kV	fault	10	CU HVDC bipole	7	Coal Creek 1&2
EQ1	Coal Creek 230kV	SLGBF	4.5	CU HVDC #1	11	Coal Creek #2
MAD	Dorsey 500kV	3-phase	4	Dorsey – Forbes 500kV line		
MQS	Sherco	SLGBF	4	Sherco #3	9	Sherco-Benton Co
MTS	Monticello 345kV	SLGBF	5	Monticello-Elm Creek line	9	Monticello bus
NAD	Forbes 500kV	3-phase	4	Forbes – Dorsey 500kV line		100% DC reduction
NMZ	Chisago Co 500kV	3-phase	4	Chisago Co – Forbes 500kV line		100% DC reduction
PAS	Forbes 500kV	SLGBF	4	Forbes – Dorsey 500kV line	13	Forbes-Chisago Co
PCS	King 345kV	SLGBF	4	King – Eau Claire 345kV line	14	King-Chisago Co
PCT	King 345kV	Trip	-	King – Eau Claire 345kV line		
PYS	Prairie Island 345kV	SLGBF	4	Prairie Island - Byron 345kV line	14	PI 345/161 Tx
PYT	Prairie Island 345kV	Trip	-	Prairie Island - Byron 345kV line		
FD3	Squared Butte 230kV	3-phase	5	Square-Butte-Stanton 230kV line		
FD9	Squared Butte 230kV	3-phase	4	Square-Butte-Stanton 230kV line		
EF3	Stanton 230kV	3-phase	5	Stanton-Coal Ck-McHenry 230kV		
FDK	Squared Butte 230kV	SLGBF	5	Square-Butte-Stanton 230kV line	12	SB-DC & YNG2
FDL	Squared Butte 230kV	SLGBF	5	Square-Butte-Stanton 230kV line	12	SB-DC & YNG2
FVL	Squared Butte 230kV	SLGBF	5	Square-Butte-Stanton 230kV line	12	SB-DC & YNG2
FD1	Squared Butte 230kV	SLGBF	5	Square-Butte-Stanton 230kV line	11	Square Butte DC
FD4	Squared Butte 230kV	SLGBF	5	Square-Butte-Stanton 230kV line	12	Square Butte DC
FV5	Squared Butte 230kV	SLGBF	5	Square-Butte-Stanton 230kV line	12	Square Butte DC

Table 5.6.2 – Local Disturbances

Fault Name	Faulted Bus	Fault Type	Clearing Time (cycles)	Initial Clearing	Backup Clearing (cycles)	Backup Clearing
EM3	Drayton 230kV	3-phase	5	Drayton – Letellier 230kV line		
EMS	Drayton 230kV	SLGBF	5	Drayton – Letellier 230kV line	13	Drayton 230/115 Tx
MES	Drayton 230kV	SLGBF	5	Drayton – Prairie 230kV line	13	Drayton 230/115 Tx
RM3	Ramsey 230kV	3-phase	5	Ramsey - Balta 230kV line		
RMS	Ramsey 230kV	SLGBF	5	Ramsey - Balta 230kV line	13	Ramsey 230/115 Tx
MRS	Ramsey 230kV	SLGBF	5	Ramsey - Prairie 230kV line	13	Ramsey 230/115 Tx
TH3	Langdon 115kV	3-phase	6	Langdon – Hensel 115kV line		
THS	Langdon 115kV	SLGBF	6	Langdon – Hensel 115kV line	20	Langdon 115/69 Tx
TGS	Langdon 115kV	SLGBF	6	Langdon – Hensel 115kV line	20	Hensel 115/69 Tx
TW3	Langdon 115kV	3-phase	6	Langdon – Sweetwater 115kV line		
TWS	Langdon 115kV	SLGBF	6	Langdon – Sweetwater 115kV line	20	Langdon 115/69 Tx
TVS	Langdon 115kV	SLGBF	6	Langdon – Sweetwater 115kV line	20	Devils Lake Buses

“Prior outage” analysis was also performed for each of the Langdon 115 kV lines. Each prior outage condition was evaluated with three-phase and single-line-to-ground-breaker-failure faults on the 230 kV source for the remaining Langdon 115 kV line (Ramsey or Drayton).

5.6.2 Results

During the disturbances, the generation and transmission additions generally have minimal effect on both the system's damping and voltages, and the power system responds without system performance criteria violations for the disturbances evaluated. The only exception found involves the NMZ disturbance (fault at Chisago Co 500 kV, trip of Chisago-Forbes & Forbes-Roseau-Dorsey 500 kV) during off-peak conditions. This fault was found to cause a power system dynamic response outside criteria due to the Langdon generation addition. This is due only to the Wahpeton 115 kV bus voltage experiencing a "first swing" voltage dip momentarily below the 0.80 pu criterion applicable to this bus.

Reviewing the stability analysis results, it is seen that prior to the Langdon generation addition, the Wahpeton 115 kV bus voltage swing minimally satisfies the 0.80 pu criterion; the minimum voltage is 0.804 pu. Following the Langdon generation addition at the 160 MW net output level, the Langdon 115 kV bus voltage is observed to dip to 0.79 pu. The physical explanation for this incremental impact is that the addition of generation at Langdon shifts the NDEX flows slightly southward, causing increased loading on the Heskett-Wishek-Ellendale-Hankinson-Wahpeton-Fergus Falls 230 kV path. This is confirmed by observing the Hankinson-Wahpeton 230 kV and Wahpeton-Fergus Falls 230 kV loadings as shown in Table 5.6.3. The latter increase in loading is also attributed to generation reduction at Hoot Lake due to its use as a generation sink for the Langdon Generation addition's OTP-directed component of output.

Table 5.6.3 – Wahpeton 230 kV Line Loadings

	Loading, MVA	
Condition	**Hankinson-Wahpeton**	**Wahpeton-Fergus Falls**
Existing system	117.1	183.9
Langdon-Hensel 115 kV line	117.0	183.8
Langdon Generation (160 MW)	121.8	198.1

The slight increase in the Hankinson-Wahpeton 230 kV line loadings and larger increase on the Wahpeton-Fergus Falls 230 kV line loadings result in increased I^2X reactive power consumption. This increased reactive power consumption results in lower voltages. To address this Wahpeton voltage concern, increased dynamic reactive power supply is required.

It was observed that loading on the Wahpeton system does have a direct relation to the Forbes-Chisago Co 500 kV line loading. When the flow on the Forbes-Chisago Co 500 kV line is reduced to within its respective operating limit of 1765 MVA, the Wahpeton 115 kV voltage stays at 0.83 pu during the NMZ disturbance with the Langdon generation in-service, which is above the 0.80 pu criteria.

Except for the Wahpeton 115 kV voltage issue for the NMZ disturbance when the Forbes – Chisago 500 kV line is overloaded, performance for all other disturbances was satisfactory. Graphs 5.6.4 -5.6.7 show the Langdon 115 kV voltage for four disturbances during the summer off-peak for “Existing System”, “Langdon-Hensel 115 kV Addition”, and “Langdon Generation Addition” conditions. These four disturbances include AG1, EI2, EM3, and RM3. The fault definitions for these 4 disturbances were shown in Tables 5.6.1 and 5.6.2.

5.6.3 Sensitivity Analysis Including Additional Prior Queued Projects

Additional dynamic stability analysis was performed to determine if any other near-term prior queued projects not previously included in the initial analysis had an interaction with the Langdon Wind Farm. This sensitivity analysis focused primarily on sensitivity to MISO Project G132 (180 MW at Ellendale), which came out of suspension after this study started. However, other known prior queued projects with in-service dates between 2007 and 2009 were also included in this stability analysis. These prior queued projects were:

- 180 MW at Ellendale 230 kV; G132;
- 50 MW at Oliver County (1); G502;
- 50 MW at Oliver County (2); GS659;
- 10 MW at Antelope Valley 1; GI-101
- 10 MW at Antelope Valley 2; GI-101

This sensitivity analysis included an abbreviated list of faults determined to be the most limiting from the generation interconnection studies already completed for G132 and GS659. These faults included NMZ, EI2, and FD3 which have descriptions listed in Table 5.6.1.

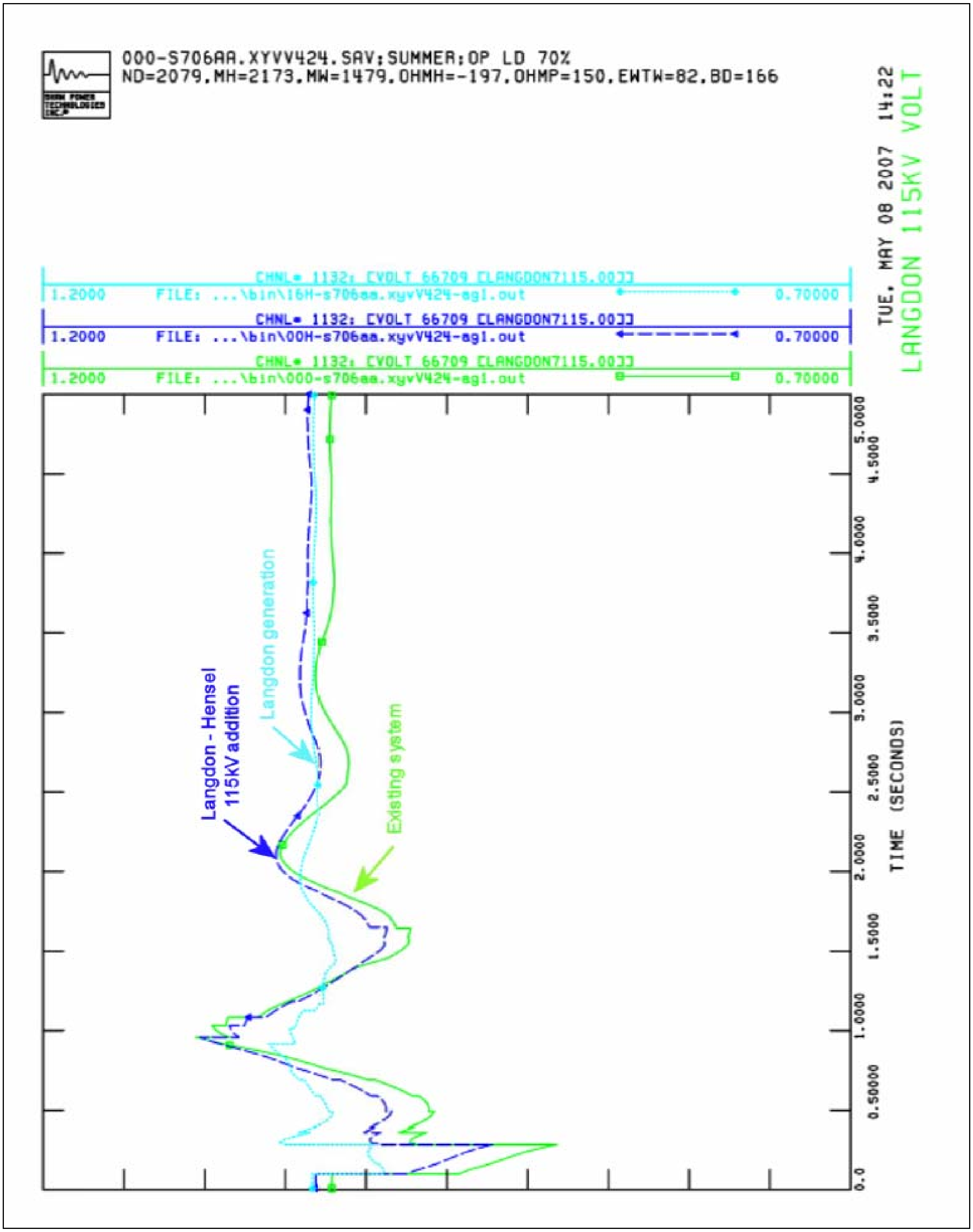
This additional stability analysis has shown performance for the known limiting disturbances to be satisfactory with the Langdon generation not aggravating any of the previously known issues for G132 and GS659. Stability tables and plots are in Appendices J and K.

5.6.4 Sensitivity Analysis – NORDAGS and Oliver County 2 Cases

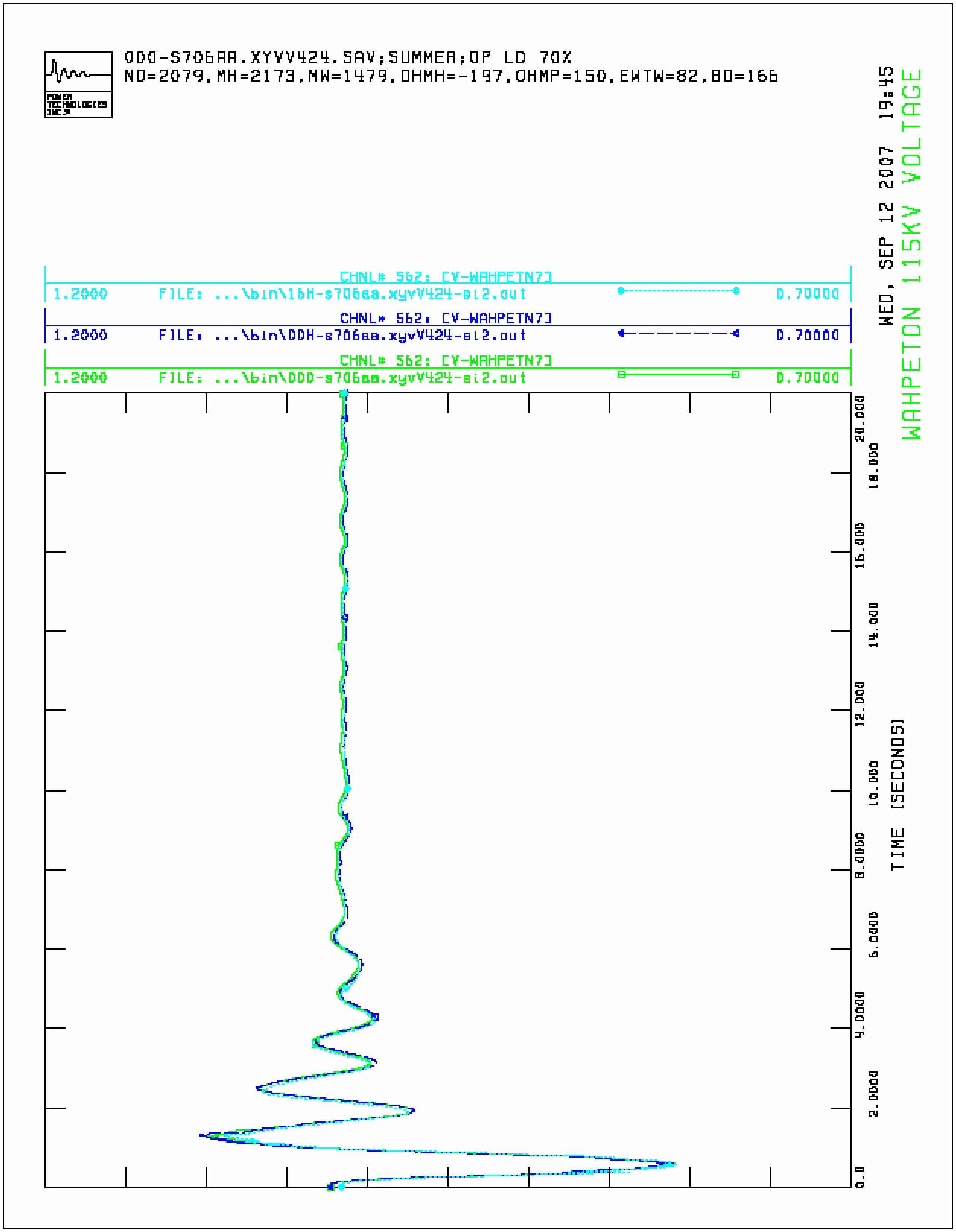
Further dynamic stability analysis was performed on a 2015 summer off-peak case with the North Dakota Group Study I projects (NORDAGS) and the Oliver County 2 project (2nd 50 MW wind project at Center) in-service. The additional stability analysis particularly evaluated the FD3 disturbance, which is a 5 cycle three-phase fault at the Square Butte 230 kV bus on the Stanton line resulting in a trip of the Square Butte-Stanton 230 kV line. From other studies in the region, it is known that this disturbance causes a voltage violation at the Jamestown 345 kV bus. However, the Langdon generation addition improves the Jamestown voltages slightly due to the fact that it reduces the pre-contingent flows (and reactive power consumption) along the Center – Jamestown 345 kV line.

Stability tables and plots are in Appendices J and K.

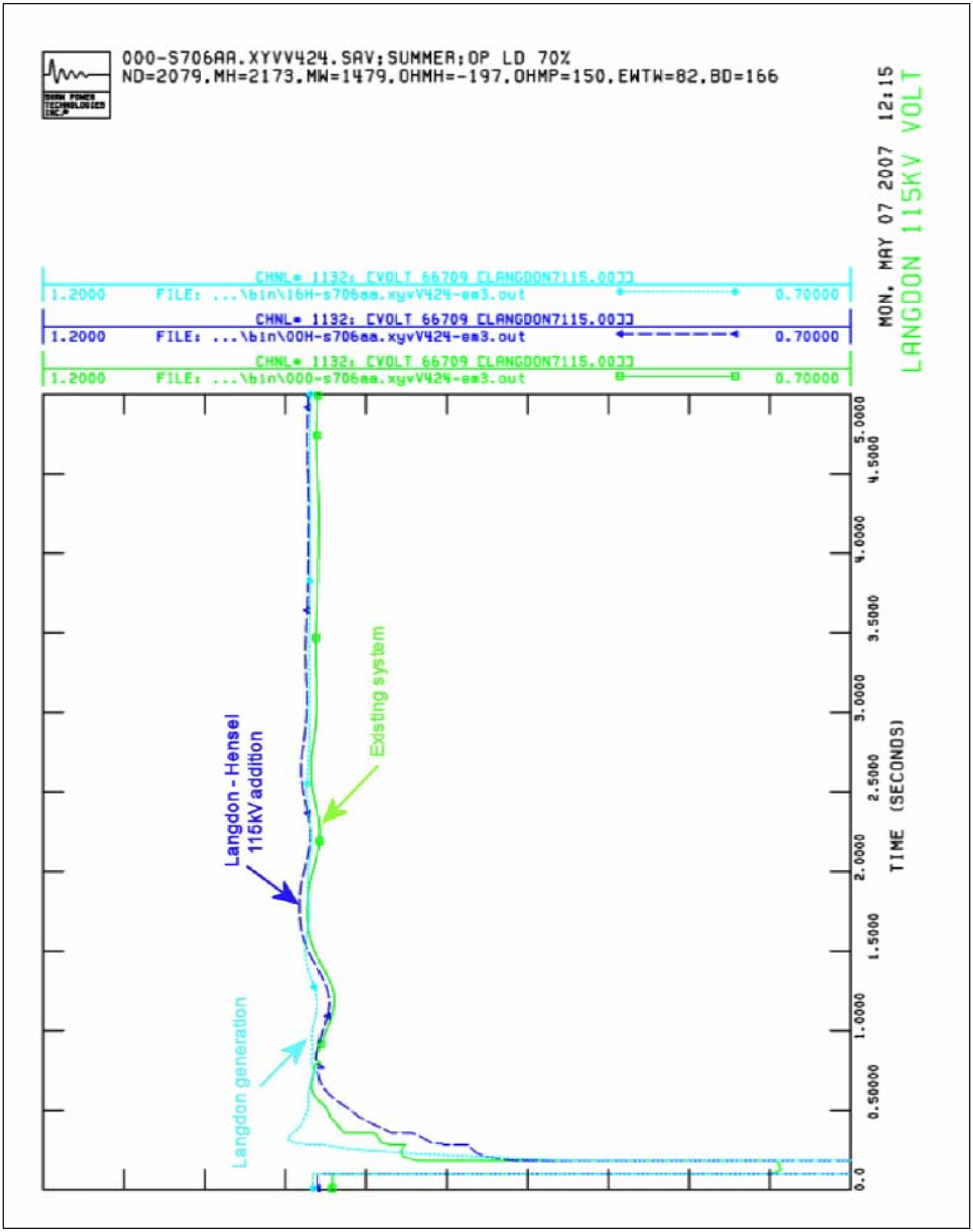
Graph 5.6.4 – Langdon 115 kV Voltage for the AG1 Disturbance



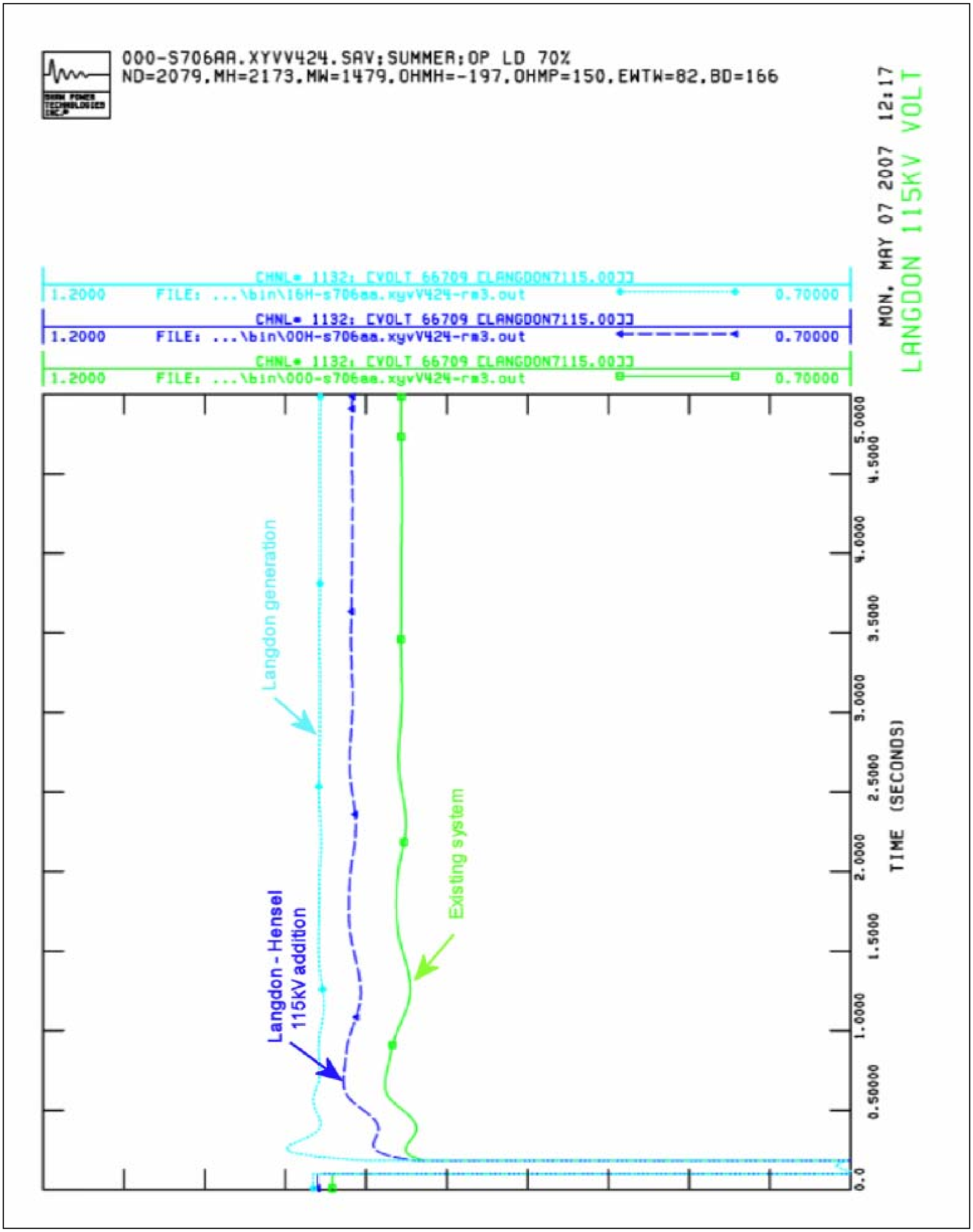
Graph 5.6.5 – Wahpeton 115 kV Voltage for the EI2 Disturbance



Graph 5.6.6 – Langdon 115 kV Voltage for the EM3 Disturbance



Graph 5.6.7 – Langdon 115 kV Voltage for the RM3 Disturbance



5.7 Devils Lake Load Serving

Further investigation of load serving concerns in the Devils Lake load area was performed to determine the impacts of the proposed Langdon-Hensel 115 kV line and Langdon generation addition could have to the Devils Lake load area. Currently, there are three sources to the Devils Lake area which are:

- Ramsey 230/115 kV transformer (84 MVA)
- Jamestown – Carrington 115 kV line (80 MVA)
- Rugby – Leeds 115 kV line (120 MVA)

Historically, the Devils Lake area has had issues during Winter peak conditions, particularly when one of the existing sources is out-of-service for an extended outage (i.e. maintenance). An extended outage of one source into the Devils Lake area requires real-time operations personnel ready to respond if another source trips out of service. It is loss of the next element during a prior outage condition which is a concern for the Devils Lake load area (worst case would be loss of 2 sources into the Devils Lake area). Table 5.7.1 shows the impact the Langdon-Hensel 115 kV line and Langdon generation will have to the Devils Lake area for outages of the primary sources into the Devils Lake area.

Table 5.7.1 – Devils Lake Load Serving Line Loadings
Winter Peak Load = 122.5 MW, 16.3 MVAR

		Loading, MVA		
Outage	Monitored	Existing System	Langdon-Hensel 115 kV line	Langdon 160 MW Langdon-Hensel
(System Intact)	RMSY TX	38.1 (46%)	50.5 (60%)	27.8 (34%)
	Jmst-Carngt	37.1 (45%)	42.2 (52%)	27.9 (34%)
	Rugby-Leeds	67.7 (56%)	74.3 (61%)	56.0 (46%)
Ramsey TX	Jmst-Carngt	49.2 (60%)	54.7 (67%)	29.6 (36%)
	Rugby-Leeds	83.4 (70%)	92.8 (77%)	58.2 (48%)
Jmst-Carngt	RMSY TX	57.1 (69%)	70.0 (83%)	34.0 (41%)
	Rugby-Leeds	78.5 (65%)	84.1 (70%)	62.9 (52%)
Rugby-Leeds	RMSY TX	78.1 (93%)	90.9 (107%)	45.4 (55%)
	Jmst-Carngt	51.2 (63%)	54.6 (67%)	38.1 (46%)
Ramsey TX Jmst-Carngt	Rugby-Leeds	*Unsolvable*	123.5 (105%)	75.2 (63%)
Ramsey TX Rugby-Leeds	Jmst-Carngt	*Unsolvable*	104.0 (126%)	60.1 (73%)
Jmst-Carngt Rugby-Leeds	RMSY TX	*Unsolvable*	132.0 (153%)	71.1 (85%)

As shown above, the addition of the Langdon – Hensel 115 kV line improves load serving ability in the Devils Lake area with an even greater improvement in system performance once the Langdon generation is in-service.

5.8 Reserve Call Impact

During prior outage of the Dorsey-Forbes 500 kV line, additional analysis of the Langdon generation project was completed to determine if this project impacts the reserve call due to the outage of the Dorsey–Forbes 500 kV line. An investigation of the dV/dP response on the Richer-Moranville 230 kV line (R50M) was performed to quantify potential impacts due to the Langdon wind project. During system intact conditions, the Langdon wind project has a 1.4% distribution factor on Richer-Moranville 230 kV line. The reserve call impact analysis was performed on the Summer Off-peak case in accordance with the procedures outlined in the 2004 MHEX Summer Operating Guides to reduce MHEX to 580 MW and set the flow on R50M to 230 MVA with the outage of the Dorsey-Forbes 500 kV line. The dV/dP analysis described in the MHEX 2002/2003 Winter Peak Operating Study Report (March 11, 2003) was used to confirm that 230 MVA on the Richer-Moranville 230 kV line remains the limit without violating the established criteria of a 0.3 kV voltage drop per incremental MW of power transferred across the line. This was also confirmed by observing the 3% voltage change criteria for switching the Running 230 kV capacitors. Table 5.8.1 shows the dV/dP performance for the Richer-Moranville 230 kV line.

Table 5.8.1 – Richer-Moranville 230 kV line dV/dP
MHEX=580 NDEX=2080

Condition	Running 230kV Voltage (kV)	Richer 230 kV Flow (MW)	dV/ dP (kV/MW)
Existing System	221.24	230.5	
	220.34	236.7	-0.15
Langdon Generation	220.77	230.5	
w/ Langdon-Hensel 115 kV line	219.41	238.3	-0.17

5.9 NDEX Sensitivity

North Dakota Export sensitivity was evaluated on the Summer Off-peak case to address the impacts the Langdon-Hensel 115 kV line with the Langdon generation addition have on the system. NDEX was lowered using the "setexports.ipl" program by only adjusting North Dakota generation and keeping the load constant to show consistency with load patterns between conditions. Lowering NDEX during a high MHEX south flow condition (2175 MW) has the effect of transferring power flow from the Dorsey-Forbes 500 kV line to the Glenboro-Rugby and the Letellier-Drayton 230 kV lines. This is of particular interest for flows and outages of the Drayton-Prairie 230 kV line or the Drayton-Donaldson 115 kV lines.

5.9.1 System Intact (Summer Off-Peak Case)

A sensitivity was conducted with NDEX=0 MW.

Table 5.9.1 shows a listing of the North Dakota-Manitoba Hydro 230 kV tie-loadings with NDEX=0 including the Drayton-Prairie 230 kV line flows. A voltage scan of northern MAPP buses is in Appendix M.

Table 5.9.1 – NDEX Sensitivity Line Loadings
Summer Off-Peak MHEX= 2175 NDEX=0

		Loading, MW			DF
Tie Line	kV	00N	16N	diff	
Glenboro-Rugby	230	124.5	127.6	3.1	0.019
Letellier-Drayton	230	419.7	397.7	-22.0	-0.138
Drayton-Prairie	230	267.1	309.9	42.8	0.268

5.9.2 Trip of Drayton-Prairie 230 kV Line (Summer Off-Peak Case)

For outage of the Drayton-Prairie 230 kV line with a MH DC run-back (100% of pre-contingent flow on the Letellier-Drayton 230 kV line), the emergency rating of the Drayton-Donaldson 115 kV line (200 MVA) may be exceeded. The flow may reach 209 MVA if the Hanks Corner generation is in service. With Hanks Corner generation out of service, the flow is 199 MVA, which is within the emergency limit.

When the Drayton-Prairie line is open, Minnkota Power has a system resectionalizing procedure that involves manual opening of the Warsaw-Oslo and Viking-Thief River Falls 115 kV lines to eliminate through-flows on the parallel 115 kV system. This also serves to reduce loading of the Drayton-Donaldson 115 kV line. As a result of this condition (Warsaw-Oslo 115 kV outage, Viking-Thief River Falls 115 kV outage, Drayton-Prairie 230 kV outage with DC reduction), the

Ramsey transformer and the Langdon-Sweetwater-Devils Lake East 115 kV line may overload if the prior queued Hanks Corner generation is in-service. A generator tripping scheme will be used to reduce generation at Langdon if this condition were to exist. However, this will not be a requirement unless the Hanks Corner generation is in-service.

5.9.3 Trip of Drayton-Donaldson 115 kV Line (Summer Off-Peak Case)

For outage of the Drayton-Donaldson 115 kV line, there is no runback of the MH DC system. The Drayton-Prairie 230 kV line says within its emergency limit.

5.9.4 Glenboro Area Flows, System Intact (Winter Peak Case)

A sensitivity was also evaluated for the Glenboro 230 kV lines during Winter peak conditions with low NDEX levels. This analysis was done due to overloads observed in previous operational studies. Glenboro area flows are shown in Table 5.9.2. A voltage scan of northern MAPP buses is in Appendix M.

Table 5.9.2 – NDEX Sensitivity Glenboro Area Loadings

Winter-Peak MHEX= -700 NDEX=0

St. Leon Wind 99 MW

		Loading, MW			DF
Tie Line	kV	00H	16H	diff	
Glenboro-Rugby	230	-267.0	-264.4	2.6	0.016
Glenboro-Cornwallis	230	253.0	256.1	3.1	0.019

For this analysis, the St. Leon wind generator was dispatched at full output in the case, due to its proximity to Glenboro. It was off line in the winter peak base case.

The analysis shows that the Langdon project has negligible impact on the Glenboro area transmission system.

5.10 Fault Analysis

Short-circuit calculations of fault currents were performed using the PSS/E program for the Langdon area. Three-Phase Fault Currents for Summer Off-peak conditions were determined at multiple substations in the vicinity of Langdon. 3 Phase fault currents were found to have the following values:

Table 5.10.1 – Three-Phase Fault Currents (Amps)

Bus	Existing System	Langdon-Hensel 115 kV line	Langdon Generation
Drayton 115 kV	6537	6791	6885
Hensel 115 kV	3214	3884	4300
Langdon 115 kV	1059	2543	3478
Sweetwater 115 kV	2753	3482	3655
Devils Lake East 115 kV	3950	4581	4683
Ramsey 115 kV	3953	4581	4682

Single line-to-ground fault currents were not evaluated as part of this analysis due to the complexity of deriving their values through PSS/E's short circuit tool. However, fault currents during single line to ground events are generally less than 3 phase fault currents and therefore should not be a concern as compared to the fault currents noted in Table 5.10.1.

The new 115 kV breakers at Langdon and Hensel, along with one breaker at Drayton and the breaker at Devils Lake East, have an interrupting capability of 40 kA. The existing breaker at Hensel and the three remaining breakers at Drayton have only 23 kA interrupting capability. A comparison of the fault currents to the capability of the new and existing breakers at the local substations indicates that there is adequate interrupting capability following the addition of the new generation.

5.11 Ellendale Thermal Analysis

A sensitivity thermal analysis was performed on the Summer Off-peak condition to determine how the Langdon generation project may interact with other near-term prior queued projects (G132) from a thermal standpoint. As was identified in the G132 interconnection study, the intent of this analysis was to determine if the Langdon generation project had an impact on the loading issues identified in the Ellendale area. Two new contingencies were performed as part of this analysis and are listed in Table 5.11.1.

Table 5.11.1 – Ellendale Thermal Analysis

		Loading, MVA		
Outage	Monitored	Existing System	Langdon-Hensel 115 kV line	Langdon 160 MW Langdon-Hensel
Ellendale-Oakes	Ellendale TX	143.3 (139%)	143.6 (139%)	141.8 (137%)
& Oakes-Forman	Elndale-Abrdeen	133.5 (162%)	133.9 (162%)	132.1 (160%)
Center-Jamestown	Ellendale-G132	323.2 (138%)	322.8 (137%)	319.4 (136%)
	Ellendale-Oakes	256.7 (109%)	256.4 (109%)	253.5 (107%)

This table shows that the Langdon generation project has a negligible impact to the system by unloading previously identified overloaded facilities in the Ellendale area. This is the expected result given the significant electrical distance between the Langdon and Ellendale generation projects.

6.0 Conclusions

The study results presented in this report demonstrate that the proposed addition of the 159 MW Langdon wind farm in conjunction with the proposed Langdon-Hensel 115 kV line will result in adequate transmission interconnection and outlet capability to satisfy relevant MAPP/NERC system performance standards with respect to steady-state, dynamic, and constrained interface (flowgate) impacts. The output of the wind farm will be delivered to Minnkota Power Cooperative (99 MW) and Otter Tail Power Company (60 MW).

Due to the Langdon-Hensel 115 kV line addition, excessive post-contingent loading of the existing 84 MVA Ramsey 230/115 kV transformer is possible during periods of low Langdon generation output during winter peak load conditions. The Langdon-Hensel 115 kV line addition creates a parallel path for the outage of the Ramsey-Prairie 230 kV line; this makes it possible for the loading on the Ramsey 230/115 kV transformer to exceed its emergency rating of 125% of its continuous rating. Operation of the Langdon generation alleviates this loading. To address the post-contingent loading during periods of low or zero Langdon generation, it is proposed that the short-term solution be implementation of a special protection scheme (SPS) which involves tripping the Devils Lake East 115 kV breaker thereby opening the parallel 115 kV path between Ramsey and Drayton. This scheme will result in a separation between Langdon (Sweetwater) and the Devils Lake area resulting in less load having to be carried from the Ramsey transformer while still maintaining reliable service to loads served from the Drayton 230 kV source. This scheme is only intended to operate if the actual post-contingent loading on the Ramsey transformer exceeds permissible loading criteria.

The long-term solution will be identified as part of a load-serving study for the Devils Lake area recently initiated by the local load-serving entities. Currently, several options are being evaluated through the load serving study, including replacement of the existing or the addition of a second Ramsey 230/115 kV transformer. This project will coordinate with that study to ensure that an acceptable long-term solution is implemented for both load serving needs and generation outlet needs.

Generation reduction schemes will be required at Langdon to disconnect a portion of the 159 MW generation addition (approximately 40 MW) for certain local 115 kV line outages. This generator reduction requirement stems from voltage stability considerations at the Langdon 115 kV bus for outage of the Langdon-Hensel 115 kV line or the Hensel-Drayton 115 kV line (with Hanks Corners generation addition). Following the proposed 115 kV line upgrades, voltage stability is more limiting than thermal (line or transformer overload) considerations.

To accommodate the Langdon 159 MW generation addition, the thermal ratings of the local 115 kV lines will need to be increased. The Langdon-Sweetwater-Devils Lake 115 kV line will have its continuous rating increased from 69 MVA to 130 MVA, while the Hensel-Drayton 115 kV line will have its continuous rating increased from 72 MVA to 129 MVA. If an earlier-queued generation project on the MISO interconnection queue at Hanks Corner (MISO Project G651 on 69 kV system between Hensel and Langdon) proceeds, a reduction scheme will then be required for the Hensel-Drayton 115 kV outage as well as the Langdon-Hensel 115 kV line outage to reduce Langdon generation to within the voltage stability limit of 120 MW.

During Summer Off-peak, high transfer conditions with both NDEX and MHEX at their maximum simultaneous transfer limits (2080 MW and 2175 MW respectively), both the Dorsey-Forbes 500 kV line and the Forbes – Chisago Co 500 kV line are loaded beyond their 1732 MVA ratings during system intact conditions. These line overloads are not unique to this project and are not considered an interconnection related upgrade and therefore will only be addressed if they would happen to appear during the transmission service approval process for this project.

During the stability analysis, it was observed that with the Langdon 159 MW generation addition, the voltage on the Wahpeton 115 kV bus violated the 0.80 pu voltage criteria during the "NMZ" disturbance. This issue is not a concern for this project since subsequent analysis has shown that reducing the flow on the Forbes–Chisago 500 kV line to respect the 1765 MVA flowgate limit does not result in this violation during a NMZ disturbance.