

Appendix C



Nobles Battery

**Economic Screening
Study 2025**

PREPARED BY:

Keith Parks

Manager, Data Science and Analytics

Randy Oye

Sr Market Operations and Transmission Analyst

Jason Standing

Director, ISP Transmission Planning

REVIEWED BY:

Jason Standing

Director, ISP Transmission Planning

DATE

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Contents

- 1. BACKGROUND AND SCOPE.....1
- 2. NEED1
- 3. CONCLUSIONS AND RECOMMENDED PLAN.....2
- 4. STUDY HISTORY AND PARTICIPANTS2
- 5. ECONOMIC STUDY ANALYSIS.....2
- 6. RELVANT CONCERNS7
 - 6.1 LOAD-SERVING ISSUES7
 - 6.2 CONSTRUCTABILITY AND SCHEDULE CONSIDERATIONS7
 - 6.3 OWNERSHIP.....7

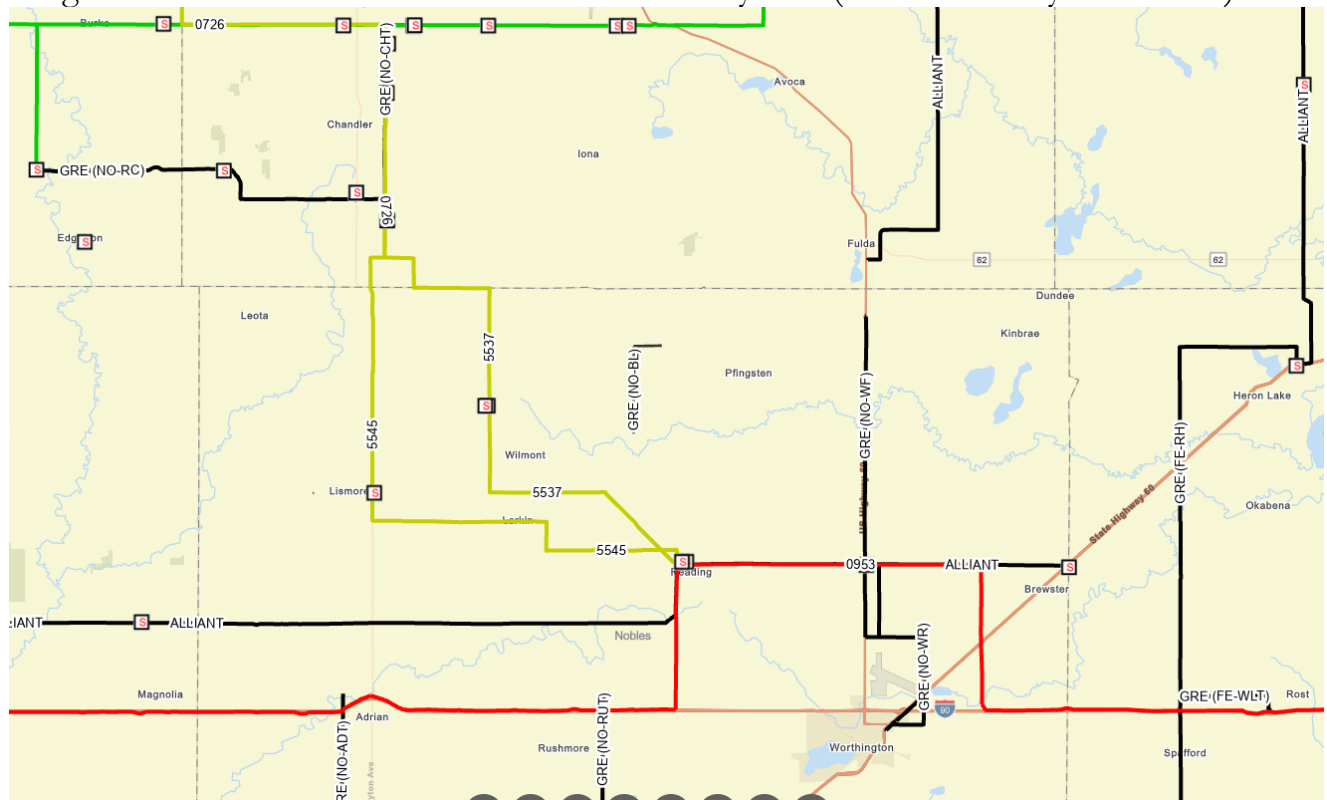
1. BACKGROUND AND SCOPE

This report examines the potential impacts of a battery energy storage system (BESS) near the Nobles County Substation in southwest Minnesota.

The Nobles County substation sits on a major 345 kV transmission line that connects wind generation zones in the west to load centers in eastern MISO. In recent years, significant renewable generation has been added in southwestern Minnesota, Iowa, and the Dakotas—sometimes exceeding the capacity of the existing transmission system to deliver all available energy to load centers. During these periods, the renewable generation must be reduced to avoid overloading the system, a process known as curtailment. This situation is typically caused by congestion, which occurs when there is insufficient transmission capacity to move low-cost generation to load centers.

Figure 1.1 below shows the location of the Nobles County Substation and surrounding area.

Figure 1.1: Southwest Minnesota Transmission System (Nobles County Substation)



2. NEED

This study was initiated in response to a request from the Minnesota Public Utilities Commission to analyze the potential benefits of installing a BESS at Nobles County Substation to help alleviate congestion. The primary concept is that during times of high wind generation and limited transmission capacity, the battery could be charged to store excess energy. That stored energy could then be discharged during periods of low wind to reduce congestion and improve system efficiency in the region.

3. CONCLUSIONS AND RECOMMENDED PLAN

The study's economic analysis concluded that a 300 MW, 4-hour battery would have helped reduce curtailment in the region. This finding was based on a review of historical Locational Marginal Price (LMP) data from 2024 through first half of 2025 in the Nobles County Substation area. The analysis was purely economic, relying on historical price signals and assumed battery parameters.

4. STUDY HISTORY AND PARTICIPANTS

The study was performed by Xcel Energy's Integrated System Planning (ISP) Transmission Planning and Transmission Access groups, with input from Xcel Energy's Regulatory group. All study participants collaborated throughout the process and reached consensus on the study's findings.

5. ECONOMIC STUDY ANALYSIS

Xcel Energy Commercial Operations Department completed the first analysis using 2024 data (2025 is pending) for a 300 MW, 1200 MWh BESS interconnected to the Nobles County Substation that exclusively looked at the BESS impact on curtailment. The analysis only charged the BESS when curtailed energy was available. The next analysis, that is not yet complete, will look at charging the BESS based on LMP price differentials as opposed to just curtailed renewable energy. The BESS curtailment analysis showed less than optimal BESS charge/discharge cycles which could be made up by further utilizing the BESS using LMP cost differential opportunities.

The analysis shown on Tables 1 and 2 below utilized 2024 and 2025 historical 5-minute curtailment data for the Fenton, Prairie Rose, MinnDakota, Nobles, Moraine 2, and Zephyr project – which are the most curtailed Company projects and are all located in the area around Nobles. The analysis charged the BESS when any of the projects were being curtailed and discharged the BESS at varying positive LMP prices (Strike Price). The analysis calculated the Curtailment Savings, the % Curtailment Reduction, the Potential Revenue, and the number of BESS cycles for each Strike Price. The Potential Revenue calculation is provided for internal information since it ignores the impact of the BESS discharging on Real Time LMP prices and will likely be lower than actual.

For example, the analysis estimated that discharging the BESS at a \$5 strike price will save an estimated 240,257 MWh of curtailment, which is a 25% reduction from the 1,096,671 MW hours that would have occurred without the BESS. The BESS would have fully cycled 170 times during the year.

Table 1: 2024 Curtailment Analysis

Total Curtailment 2024 =1,096,671 MWh				
Strike Price \$	Curtailment Reduction MWh	% Curtailment Reduction	Revenue	BESS Cycles
1	249,803	23%	\$8,054,143	177
2	247,801	23%	\$8,049,978	175
3	245,441	22%	\$8,060,975	174
4	242,690	22%	\$8,080,247	172
5	240,257	22%	\$8,095,366	170
6	237,244	22%	\$8,104,469	168
7	235,373	21%	\$8,152,018	167
8	233,120	21%	\$8,195,820	165
9	230,771	21%	\$8,224,393	163
10	227,832	21%	\$8,276,642	161
11	224,811	20%	\$8,307,448	159
12	221,223	20%	\$8,335,897	157
13	217,134	20%	\$8,362,387	154
14	213,115	19%	\$8,405,768	151
15	208,389	19%	\$8,440,631	147
16	203,590	19%	\$8,497,595	144
17	198,271	18%	\$8,555,098	140
18	191,950	18%	\$8,652,923	136
19	184,111	17%	\$8,767,029	130
20	175,684	16%	\$8,758,565	124
21	166,437	15%	\$8,656,034	118
22	155,686	14%	\$8,472,791	110

23	147,150	13%	\$8,416,694	104
24	136,899	12%	\$8,185,184	97
25	129,435	12%	\$8,091,157	92
26	122,436	11%	\$7,982,759	87
27	116,318	11%	\$7,845,864	82
28	110,871	10%	\$7,727,236	78
29	106,731	10%	\$7,769,638	75
30	102,973	9%	\$7,715,669	73
31	99,115	9%	\$7,693,249	70
32	94,229	9%	\$7,609,208	66
33	91,145	8%	\$7,540,270	64
34	87,666	8%	\$7,466,936	61
35	84,144	8%	\$7,395,160	59
36	81,873	7%	\$7,347,112	57
37	79,632	7%	\$7,309,665	55
38	76,998	7%	\$7,227,454	54
39	74,444	7%	\$7,150,304	52
40	72,415	7%	\$7,079,704	50
41	70,600	6%	\$7,032,673	49
42	68,557	6%	\$6,950,144	48
43	67,264	6%	\$6,930,210	47
44	65,818	6%	\$6,896,044	46
45	64,054	6%	\$6,839,300	44
46	62,361	6%	\$6,803,511	43
47	60,923	6%	\$6,816,641	42
48	59,870	5%	\$6,786,817	41

49	58,820	5%	\$6,771,556	41
50	57,927	5%	\$6,742,171	40

Table 2: Partial 2025 Curtailment Analysis

Total Curtailment 1/1/2025 through 9/15/2025 = 532,889 MWh				
Strike Price \$	Curtailment Reduction MWh	% Curtailment Reduction	Revenue	BESS Cycles
1	145,814	27%	\$3,484,521	102
2	144,449	27%	\$3,537,593	101
3	142,515	27%	\$3,556,456	100
4	140,539	26%	\$3,593,981	99
5	139,042	26%	\$3,649,172	97
6	137,663	26%	\$3,666,881	97
7	136,434	26%	\$3,684,753	96
8	134,992	25%	\$3,701,629	95
9	133,683	25%	\$3,735,163	94
10	132,738	25%	\$3,752,851	93
11	131,696	25%	\$3,792,180	92
12	130,536	24%	\$3,811,985	91
13	129,495	24%	\$3,835,258	91
14	128,719	24%	\$3,886,125	90
15	127,352	24%	\$3,937,900	89
16	126,024	24%	\$3,973,889	88
17	124,254	23%	\$4,042,144	87
18	122,501	23%	\$4,091,753	86
19	121,182	23%	\$4,134,880	85

20	119,687	22%	\$4,213,503	84
21	117,668	22%	\$4,247,274	82
22	113,899	21%	\$4,270,756	80
23	110,600	21%	\$4,275,322	77
24	107,664	20%	\$4,402,561	75
25	104,424	20%	\$4,636,353	73
26	101,395	19%	\$4,808,720	71
27	99,570	19%	\$4,950,556	70
28	97,582	18%	\$5,141,181	68
29	95,664	18%	\$5,289,539	67
30	93,046	17%	\$5,370,613	65
31	91,095	17%	\$5,449,989	64
32	88,869	17%	\$5,497,745	62
33	87,037	16%	\$5,560,721	61
34	85,602	16%	\$5,647,449	60
35	83,869	16%	\$5,776,823	58
36	82,504	15%	\$5,891,104	57
37	80,518	15%	\$5,917,244	56
38	78,099	15%	\$5,943,669	54
39	76,258	14%	\$5,992,234	53
40	74,440	14%	\$5,976,944	52
41	72,812	14%	\$6,035,602	51
42	70,976	13%	\$6,057,158	49
43	69,315	13%	\$6,081,398	48
44	67,492	13%	\$6,137,789	47
45	65,931	12%	\$6,188,591	46

46	64,671	12%	\$6,213,992	45
47	63,034	12%	\$6,151,905	44
48	61,736	12%	\$6,192,868	43
49	60,451	11%	\$6,200,548	42
50	59,353	11%	\$6,206,482	41

6. RELVANT CONCERNS

6.1 LOAD-SERVING ISSUES

No load serving issues were identified in this analysis.

6.2 CONSTRUCTABILITY AND SCHEDULE CONSIDERATIONS

No BESS has been identified in the previous or current MISO Interconnection Queue. The timing of a request for inclusion in the MISO Definitive Planning Process (DPP) will determine when a BESS can be interconnected and what associated may apply.

6.3 OWNERSHIP

It is currently unclear who would be responsible for owning the proposed BESS at the Nobles County Substation.

Appendix D

NOBLES GRID- FORMING BATTERY SCREENING SYSTEM IMPACT STUDY

TRANSMISSION PLANNING

PREPARED BY CHARLIE GERTEN

MODELED BY CHARLIE GERTEN

REVIEWED BY SAGE MAGRAS AND DEAN
SCHIRO

DATE 10/10/2025

VERSION 1.0

CONTENTS

Executive Summary 1

1.0 Introduction..... 2

 1.1 Background 2

 1.2 Scope of Study..... 2

 1.3 Purpose..... 3

2.0 Conclusion and Recommendations..... 3

3.0 Study History and Participants..... 3

 3.1 Need..... 3

4.0 Analysis 4

 4.1 NERC Criteria 4

 4.3 Dynamics Models..... 4

 4.4 Dynamic Modeling Assumptions..... 5

 4.5 Contingencies Modeled..... 5

 4.6 Options Evaluated 5

 4.8 Performance Evaluation Methods 6

5.0 Results of Detailed Analysis 7

 5.2 Dynamic Stability 7

 5.3 Constrained Interface Analysis 11

APPENDIX..... 12

EXECUTIVE SUMMARY

Xcel Energy Transmission Planning performed a screening System Impact Study (SIS) for an internal request to evaluate the voltage stability benefits of a future 300 MW battery storage generator (GI number S1085) to the local system around Nobles 115/345 kV station. The most recent operations guide (2021-S-017-N, effective Nov 2024) for the Southwest Minnesota wind region lists outages requiring local wind generation to be limited to maintain voltage stability. The guide describes operating conditions causing voltage instability if select groups of wind generators exceed a pre-determined MVA threshold. The operating conditions causing voltage instability are conservative, involving two pre-existing outages followed by a three-phase fault causing at least one other network outage; this is beyond the contingencies typically considered for compliance with TPL-001-5.

The SIS utilized 12 different Midcontinent Independent System Operator (MISO) MTEP25 Series Power flow models to study the transmission system around the Nobles 115/345 kV node. Different fault files were used to examine a variety of fault conditions described in Section 4.6.

This study builds off the previously completed EPRI study (“Grid forming inverter effectiveness study for Xcel Energy”) which had a similar goal of determining the dynamic voltage stability benefit of a grid-supporting inverter in the same area of the system. There are a few differences between this SIS and the EPRI study, including but not limited to:

- This SIS models the battery storage project as 300 MW (330 MVA) with grid-forming capabilities represented by REGFM_A1, which is a user-defined model aligning with WECC’s grid forming droop control model (REGFM_A1 was provided by TSAT).
- This SIS uses models for study years before and after major 345 kV circuits are implemented, such as Lyon County – Lakefield.
- This SIS uses alternative dispatches in which the battery storage project is importing power to compare against the same dispatch when the battery storage project is set to zero real power.

The results indicate that the grid-forming capabilities of the new battery storage project bring dynamic voltage stability benefits in high wind dispatches, raising the previously noted minimum constraint level, both when the battery storage project is fully importing power and when the project has no real power dispatch.

1.0 INTRODUCTION

1.1 BACKGROUND

The request to evaluate the dynamic voltage stability capabilities of the upcoming Nobles battery storage project was completed by Xcel Energy's Transmission Planning department to determine the impacts to the overall transmission system and to determine whether wind generation constraints followed by operations would still be necessary. Figure 1 below shows a diagram of the previously mentioned stations and circuits.

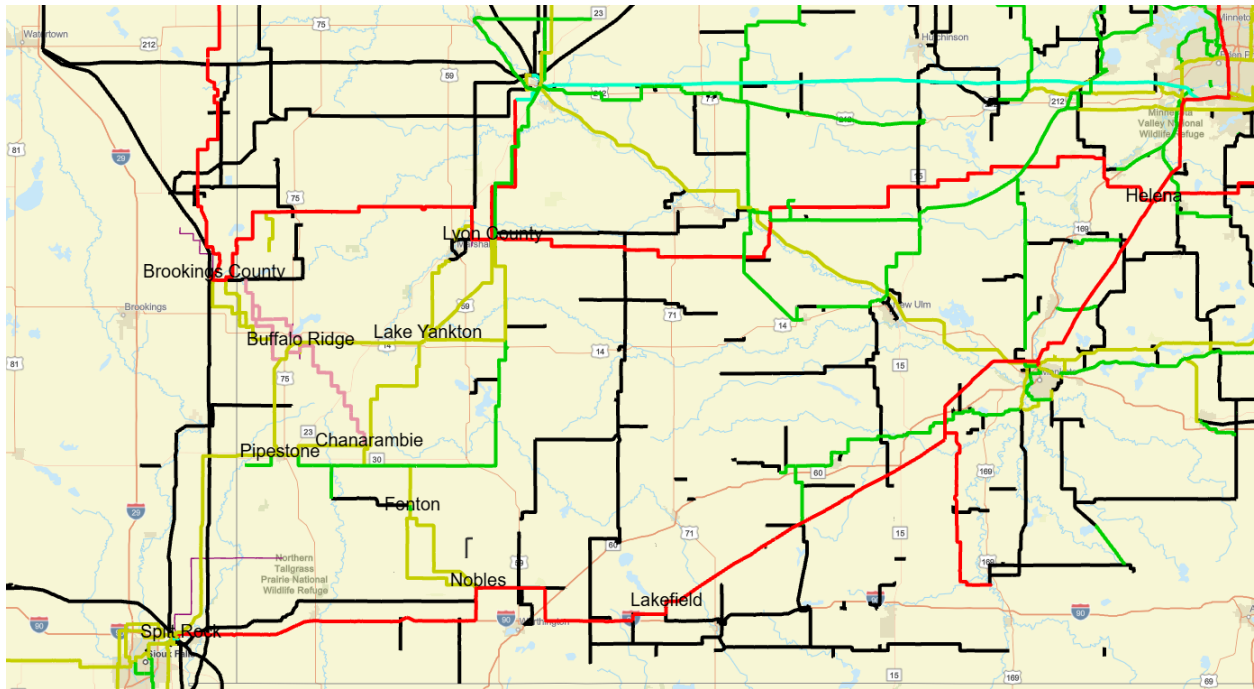


Figure 1: Area map showing existing station connections and surrounding circuits.

1.2 SCOPE OF STUDY

The scope of this screening study is to assess the dynamic voltage stability of buses around the Nobles 345 kV node before and after the proposed new Nobles Battery Storage Project and evaluate the benefits of grid-forming capabilities on the inverter. Adjusted generation to account for the changing generation levels of local wind around Nobles was assumed to come from the entire MISO market compensated by the slack bus of each model.

1.3 PURPOSE

The purpose of this study is to determine whether the new Nobles Battery Storage project will benefit the system by alleviating some of the need for previously noted wind generation constraints while meeting all system requirements. The most recent study by the internal operations group noting the dynamic voltage stability concerns and the listed elements needing constraint can be found in Section 5.3. All electrical solutions in this study require additional analysis to determine constructability of the project.

2.0 CONCLUSION AND RECOMMENDATIONS

This study determined that the proposed Nobles Battery Storage project will provide dynamic voltage stability benefits to the system in dispatches with high wind generation. These benefits are observed when utilizing a grid-forming inverter whether dispatched at zero real power output or full power import, although real power dispatch of the battery storage project will need to be managed to maximize the voltage stability benefits.

This study should be viewed as a screening study, as such, it should be replicated with greater detail when more information is known about the specific parameters of the inverter's grid-forming capabilities once the battery storage project system design is finalized and the inverter type has been selected. In addition, a more comprehensive review of the contingencies and faults used to determine generation constraints should be completed to increase alignment between transmission planning and operations.

3.0 STUDY HISTORY AND PARTICIPANTS

The results and content in this study were prepared by Xcel Energy's Transmission Planning department.

3.1 NEED

Xcel Energy Transmission Planning performed a system impact study to verify a previously identified operational constraint caused by contingencies in high wind generation dispatches leading to dynamic voltage instability in the buses around Nobles 115/345 kV. The proposed grid-forming inverter capabilities of the Nobles battery storage project is seen to alleviate at

least part of this operational constraint. Alleviating this operational constraint is beneficial because it allows more wind energy into the transmission system even outside of standard battery storage energy arbitrage operation. As the system continues to incorporate more inverter-based resources (IBRs), studies like this display financial value in providing a system service such as voltage stability. As alternative technologies are implemented to improve voltage stability, this study may serve as a reference as to how the minimum amount of deployed voltage stability projects can provide the maximum amount of benefit.

4.0 ANALYSIS

4.1 NERC CRITERIA

A selection of NERC Reliability Standard TPL-001-5 Category P1 through P7 contingencies in the localized area were analyzed at a high level. However, it was discovered that the contingencies utilized by the operations group to determine wind generation constraints were more severe than those defined by TPL-001-5. For example, N-1-1 contingencies classified as P6 and P7 were utilized as pre-existing outages, which were then followed by a fault and one to two post-fault outages. This gap between planning and operations should be addressed in the future so that onerous generation constraints are minimized, and unique steady-state and dynamic voltage violations are discovered prior to new projects' maturity.

The localized area refers to transmission facilities at voltages 115 kV and above in the system connected to Nobles 115/345 kV bus and up to 5 bus connections away in all directions.

4.3 DYNAMICS MODELS

The MISO MTEP 2025 model series was utilized in this study. For each model implemented, a base case and study case were developed. The base cases were the original models from MISO MTEP with the battery storage project modeled without dynamic grid support capabilities and the study cases included droop control grid-forming capabilities. The study cases represented the topographic changes to the transmission system over three years utilizing similar Summer Shoulder High Wind (SHHW) dispatches alternating local wind generation within each study year to reveal possible dynamic voltage stability issues. The study years utilized are 2030 and 2026.

The models implemented in this study are listed below.

- MISO25_2030_SHHW__TA.tst
- MISO25_2026_SHHW__TA.tst

The annual forecasted load data and system changes correspond with the data from the MISO MTEP development. Previously mentioned major 345 kV works in the region surrounding Nobles 115/345 kV node are implemented in every model with the exception of the 2026 study year which does not have Lakefield – Lyon County 345kV.

The In-Service Dates of the major 345kV works in the region are as follows:

- Hampton – Helena 345 kV 2nd Circuit, in-service 9/15/25
- Brookings County – Lyon County 345 kV 2nd Circuit, in-service 9/27/24
- Lakefield – Lyon County 345 kV Circuit, tentative in-service 2033

4.4 DYNAMIC MODELING ASSUMPTIONS

Dynamic voltage stability analysis was performed using the models listed above in Section 4.3. TSAT version 42.3.36 software was used to simulate and conduct the analysis.

4.5 CONTINGENCIES MODELED

A selection of NERC TPL-001-5 Categories P1 through P7 contingency files created for the MISO MTEP25 study years 2026, and 2030 were utilized as prior fault outages with one to two additional post-fault outages following NERC TPL-001-5 Categories P1-P6. The contingencies used for the analysis were taken from the Southwest Minnesota Wind Operating Guide, Appendix B. Specifically, the outages leading to constraint of the Fenton/Nobles County/Chanarambie (FENOCH) interface were utilized. To align with the focus of this study, the below short list of options involving network elements connected to the Nobles local network were recognized as being the worst-case contingencies for the FENOCH group.

4.6 OPTIONS EVALUATED

Option 1	No fault
Option 2	Prior outage of Pipestone-Split Rock 115 kV circuit, and Nobles County TR9. Three-phase bus fault on Nobles 345 kV followed by outages on Nobles-Split Rock and Nobles-Lakefield 345 kV circuits.

Option 3	Prior outage of Pipestone-Split Rock 115 kV circuit, and Nobles County TR9. Three-phase bus fault on Nobles 345 kV followed by and outage on Nobles-Lakefield 345 kV circuit.
Option 4	Prior outage of Pipestone-Split Rock 115 kV circuit, and Nobles-Split Rock 345 kV. Three-phase bus fault on Nobles 345 kV followed by an outage on Nobles-Lakefield 345 kV circuit and Nobles TR9.
Option 5	Prior outage of Pipestone-Split Rock 115 kV circuit, and Nobles-Split Rock 345 kV. Three-phase bus fault on Nobles 345kV followed by an outage on Nobles TR9.

4.8 PERFORMANCE EVALUATION METHODS

TSAT Version 24 was used, and bus voltages were monitored over a 5-second simulation, e.g. switching Option 2 shown in Figure 2. This is different than standard contingency files used in MTEP TSAT dynamic analysis for TPL compliance, but was chosen to standardize the switching and fault scenarios across a range of contingencies to aligns with the switching scenarios used to develop the Southwest Minnesota Wind Operating Guide. The focus of this study was on the change in performance caused solely by the grid-forming capabilities of the inverter. Future studies evaluating should use switching files that are based on the protection equipment for each network element, such as the standard MTEP contingencies.

The grid-forming capabilities of the inverter are deemed “beneficial” if the bus voltage results display an improved response to the fault and outages, such as returning to the pre-fault value at a faster rate or alleviating post-fault voltage oscillations.

```
/
Description Nobles Option 2
Simulation 5.000000 Seconds
Integration RK4
Plot 1 Steps
Report 999 Steps
Step Size 0.25 Cycles
/
Remove Line ;603013 ;603016 ;1
Remove Three Winding Transformer ;601034 ;603194 ;605664 ;9
At Time 0.1 Seconds
Three Phase Fault At Bus ;601034
After 5 Cycles
Remove Line ;601006 ;601034 ;1
Remove Line ;601034 ;631138 ;1
Clear Three Phase Fault
Nomore
/
END
```

Figure 2: Switching Option 2

5.0 RESULTS OF DETAILED ANALYSIS

5.2 DYNAMIC STABILITY

The below figures display the benefits of the grid-forming capabilities of the Nobles battery storage project for the study years 2026 and 2030. The below results capture the project operating at zero real power output as well as full import/charging (-300 MW). They were chosen from the complete results to cover a wide range of system conditions while not exceeding the project scope. These figures give a picture of the varied nature of the results under different system conditions and likely dispatches that the project may face, the Appendix should be referenced for the complete results, and it is recommended that an additional study be completed once the inverter has been selected and actual control parameters are being designed.

Figure 3 displays the study year 2026 with local wind generation set to 72 percent capacity to align with the system wind dispatch level and the battery storage project set to zero real power output, then full import. The plots display the voltage performance without grid-forming capabilities (red) and with grid-forming capabilities (blue). The Nobles battery storage project is modeled as connected to Nobles 345 kV by a zero-impedance branch. The

buses selected are Nobles battery storage 1, Nobles 345 kV 601034, Pipestone 115 kV 603013, Chanarambie 115 kV 603180, Nobles 115 kV 603194, Fenton 115 kV 603195.

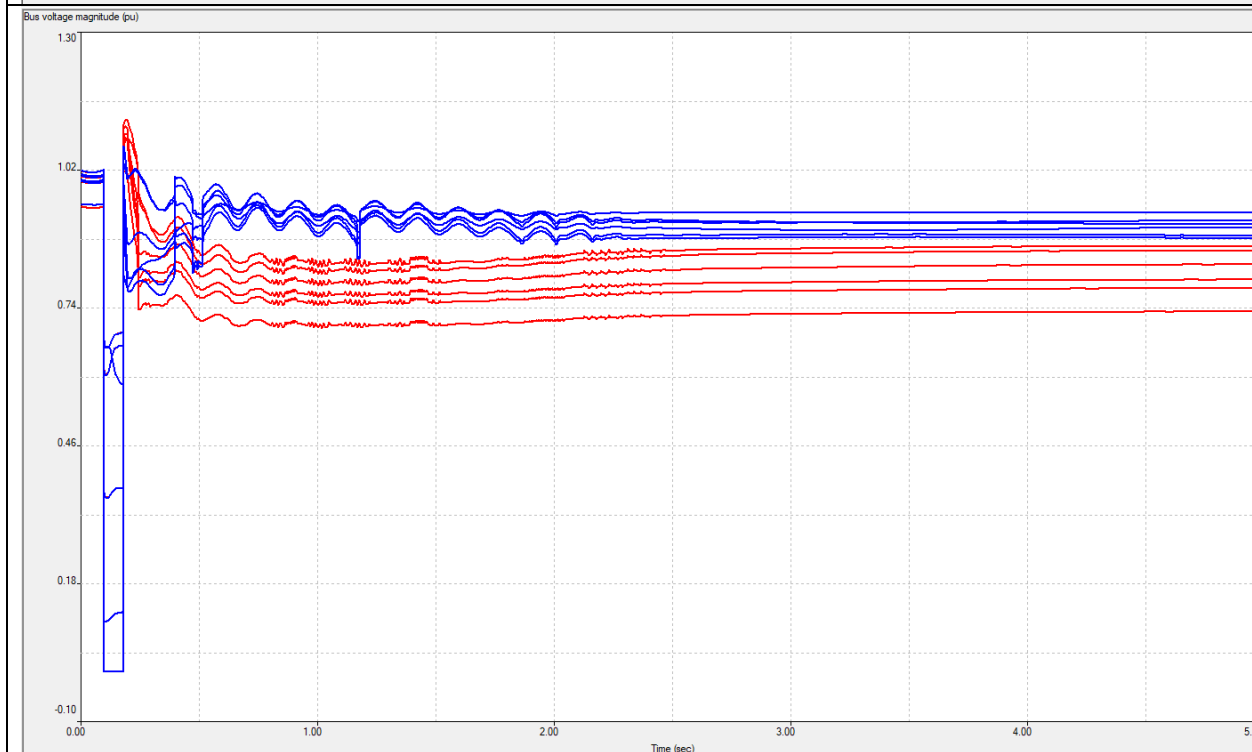
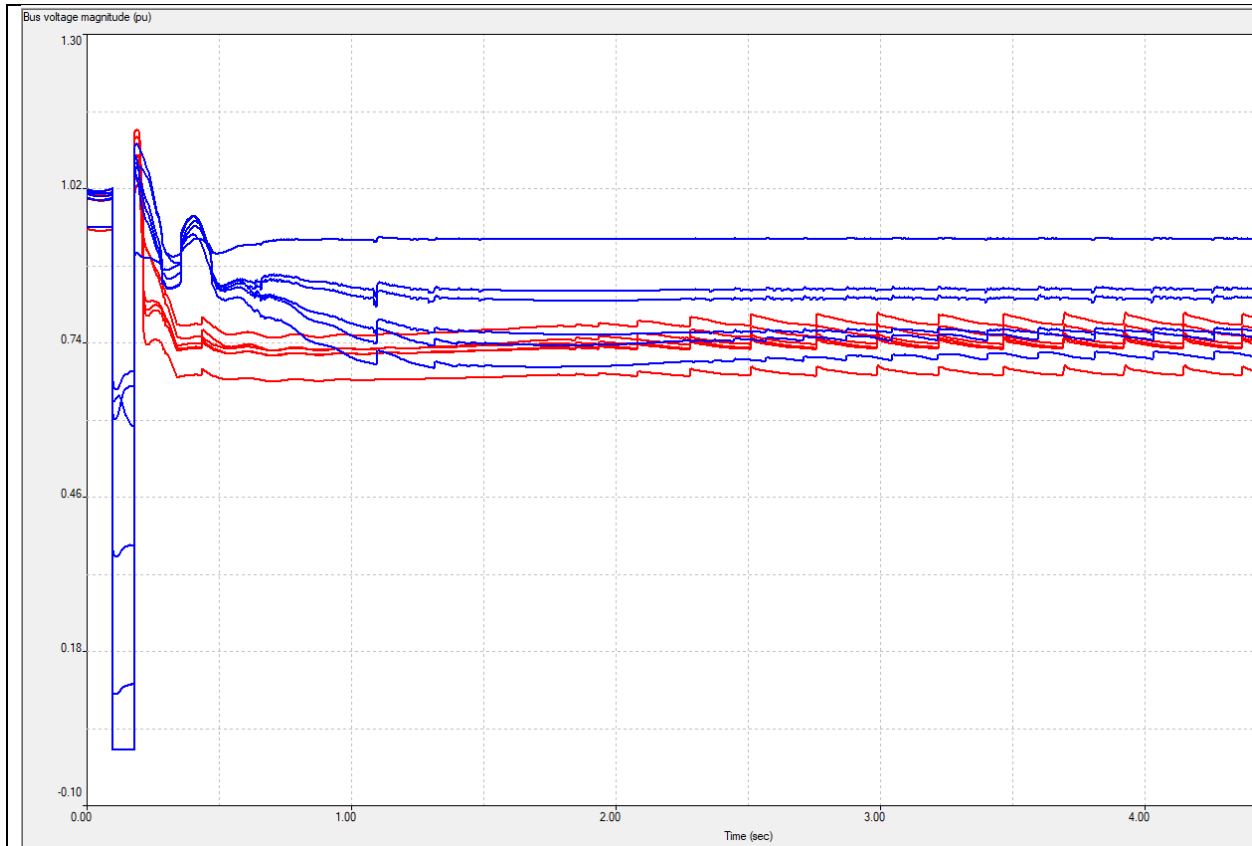
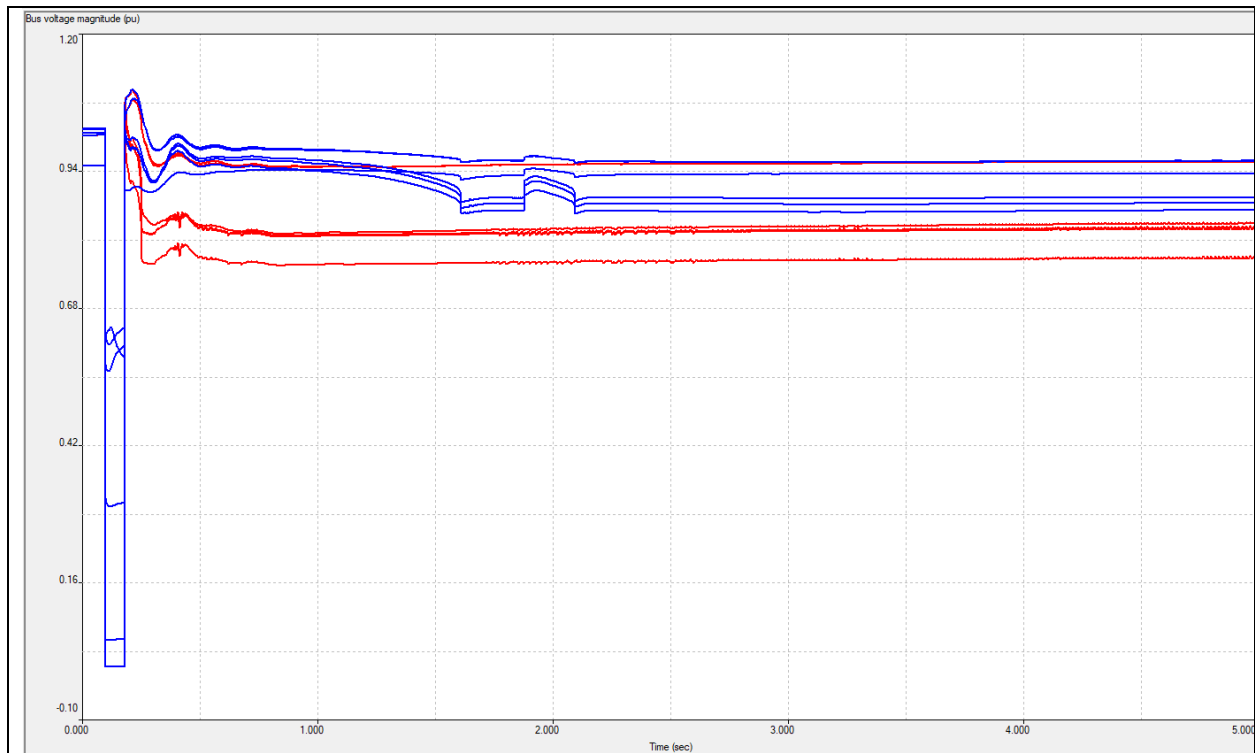


Figure 3: Results of the 2026 system model with the local wind at 72% capacity. The top panel is with the battery dispatched to zero real power and the bottom panel is set to -300 MW. Grid forming control using blue and standard operation shown in red. Switching option 2 utilized.

Figure 4 displays the study year 2030 with local wind generation set to 72 percent capacity to align with the system wind dispatch level and the battery storage project set to zero real power output, then full import. The plots show results without grid-forming capabilities (red) and with grid-forming capabilities (blue). The Nobles battery storage project is modeled as connected to Nobles 345 kV by a zero-impedance branch. The buses selected are Nobles battery storage 1, Nobles 345 kV 601034, Pipestone 115 kV 603013, Chanarambie 115 kV 603180, Nobles 115 kV 603194, Fenton 115 kV 603195.



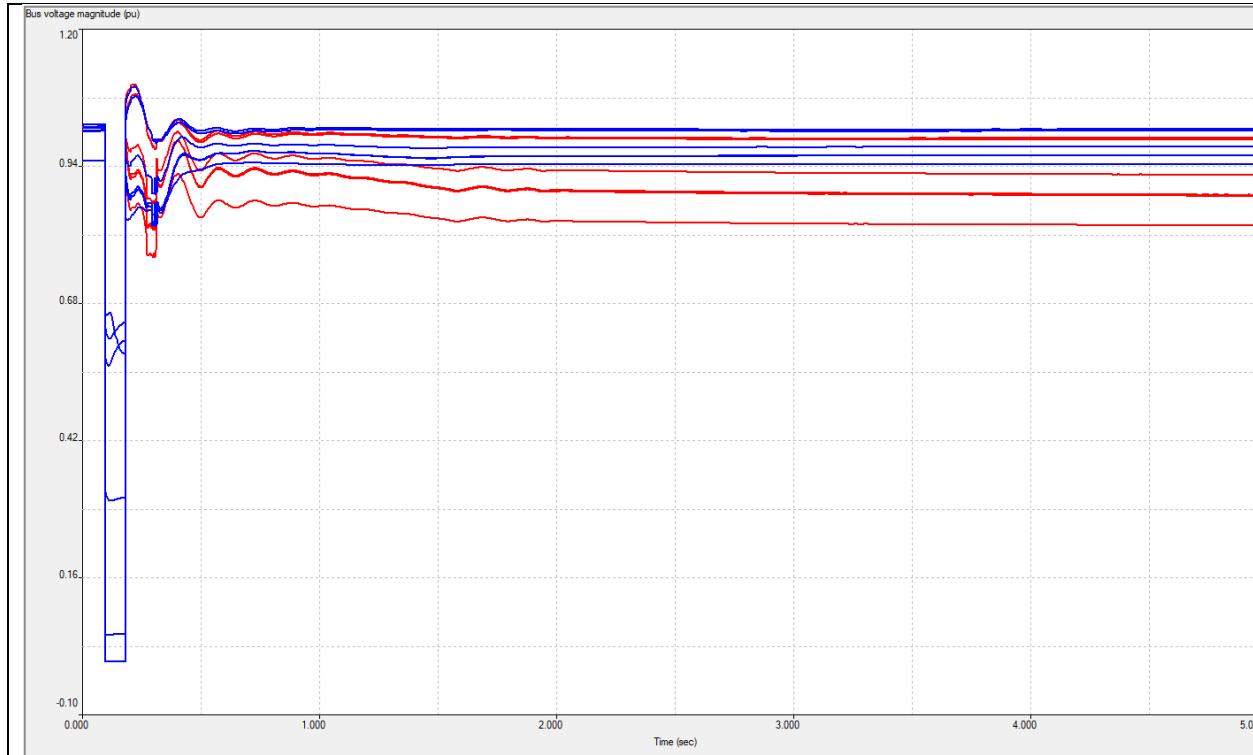


Figure 4: Results of the 2030 system model with the local wind at 72% capacity. The top panel is with the battery dispatched to zero real power and the bottom panel is set to -300 MW. Grid forming control using blue and standard operation shown in red. Switching option 2 utilized.

From the above figures, it is observed that the grid-forming capabilities of the battery storage project result in bus voltages recovering closer to their pre-fault values compared to the results without the grid-forming capability. This impact is more pronounced on the Nobles 345 kV, Nobles 115 kV, and Fenton 115 kV buses. In the 2026 and 2030 cases, reduced post-fault bus voltage oscillations are also observed. Notably, the local wind generation dispatch level influences the results. If the battery storage project is dispatched to full import/charging and grid-forming capability enabled, voltage instability will persist if the local wind generation is dispatched to 100% capacity. However, the cases examined in this study suggest grid-forming capabilities at the Nobles battery could reduce the amount of curtailed wind by pushing the point of voltage instability higher than if no grid-forming capabilities are used. The ultimate changes in wind output constraints will not be available until the grid-forming system is fully designed and a complete operations-focused study has been completed.

5.3 CONSTRAINED INTERFACE ANALYSIS

Complete constrained interface analysis will need to be completed in the future to update the Southwest Minnesota Wind Operating Guide. The scope of this study focused on the interfaces found in Section 2.1.1 of the Southwest Minnesota Wind Operating Guide. Specifically, those that were impacted by the Nobles battery storage project such as “FENOCH” which includes the below elements:

- Chanarambie-Ellsborough-Lake Yankton 115 kV line
- Chanarambie-Pipestone 115 kV line
- Nobles County 345/115 kV TR9
- Nobles County 345/115 kV TR10
- Fenton 115/69 kV TR5

The subgroup of local wind generators altered in each scenario of this study were selected because of their impact to FENOCH and the other interfaces listed in Section 2.1.1. By filtering the selected buses to those found in each interface and comparing against each scenario, the impact of the Nobles battery storage project was examined. This provides value by displaying how deep into the network the benefits of the grid forming capabilities are realized.

APPENDIX

Full TSAT output results (available upon request)

Full project documentation (available upon request)