APPENDIX I

NUCLEAR LEAVE BEHIND STUDY REPORT

Nuclear Leave Behind Study Report

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Transmission Planning
13 Nov, 2023

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Certification

I hereby certify that this 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

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11/13/2023
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Executive Summary

This analysis was performed to determine the steady state impacts and dynamic resources needed online as a result of retiring the Monticello Nuclear Generating Plant, Prairie Island Nuclear Generating Plant, and both the Monticello and Prairie Island Nuclear Generating Plants. Integrated System Planning (ISP) Transmission Planning engineers performed a study to evaluate the transmission system with the nuclear generation station retirements along with the planned Sherco coal generation replacement with Minnesota Energy Connection (MNEC) renewable generation and the AS King coal generation replacement with King Transmission Connection solar generation. Existing natural gas resources were turned on to replace the generation shortfalls based on the MISO dispatch of renewables in the model. This study is a reliability only look – system transfer capability and resource capacity analyses are out of the work scope of this study.

This study looks at the retirement of the nuclear generating stations without replacement of generation rights. The following Table M1-1 shows the retirement scenarios analyzed.

Table M1-1
Nuclear Generation Retired

Scenario Analyzed	Monticello Generation Retired (MW)	Prairie Island Generation Retired (MW)	Total Generation Retired (MW)
Monticello Retire	637	0	637
Prairie Island Retire	0	1150	1150
Monticello and Prairie Island Retire	637	1150	1778

The steady state analysis identified the retirement of the nuclear generation plants without replacement generation resulted in thermal overloads and voltage violations requiring system upgrades.

Based on the dynamic analysis results performed in this study, significant replacement generation is needed:

- Summer Peak Load Case, in addition to generation on in the base model, required all available gas generation on at Anson, Inver Grove, and Blue Lake (total 521 MW) as well as load reduction in the Twin Cities area.
    - Monticello Retire – 10% (537.37 MW)
    - Prairie Island Retire – 20% (1074.74 MW)
    - Monticello and Prairie Island Retire – 30% (1612.11 MW)
- Shoulder Load Average Wind Case, in addition to the generation on in the base model required additional combustion generation turned on.
    - Monticello Retire – High Bridge 7 and 9 (388MW), Riverside 7 and 9 (318 MW). Total generation addition of 706 MW.
    - Prairie Island Retire - High Bridge 7 and 9 (388MW), Riverside 7, 9, and 10 (476 MW), Blue Lake 7 and 8 (302 MW). Total generation addition of 1,166 MW.

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- Monticello and Prairie Island Retire – High Bridge 7, 8, and 9 (550 MW), Riverside 7, 9, and 10 (476 MW), Blue Lake 1-4, 7, and 8 (455MW), Inver Grove 1-6 (282 MW). Total generation addition of 1763 MW.

Scenarios Analyzed

2028 Summer Shoulder Average Wind, and Summer Peak scenarios are analyzed in this study. Renewables in the NSP system are modeled at seasonal generation levels; Solar at 50% for Summer Peak, 31% for Summer Shoulder Average Wind, Wind at 15.5% for Summer Peak, 27% for Summer Shoulder Average Wind.

NSP load information is shown in following Table M1-2.

Table M1-2
NSP Load Level

Year	Season	Load Level
2028	Summer Shoulder Average Wind	6,383 MW
2028	Summer Peak	9,064 MW

Steady State Simulation Results

Steady state analysis was performed on the base case, Monticello retire case, Prairie Island retire case, and both Monticello and Prairie Island retire case for both the Summer Peak and Summer Shoulder Average Wind case. Available NSP natural gas generation was turned on to reduce the number of unsolved contingencies. The number of unique facilities with new or increased >0.5% voltage violations and thermal violations beyond the preexisting violations in the base case and associated costs to mitigate them for each case are listed in Table M1-3.

Table M1-3
Voltage and Thermal Upgrades with cost for Steady State Violations

Transient Stability Simulation Results

Transient stability analysis was performed on the base case, Monticello retire case, Prairie Island retire case, and both Monticello and Prairie Island retire case for both the Summer Peak and

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Summer Shoulder Average Wind case. Available NSP natural gas generation was turned on to achieve stable dynamic response. If no additional NSP natural gas resources were available, load in the Twin Cities area was scaled down to achieve stable dynamic response.

Table M1-4
Generation and Load Adjustments with cost for Stable Dynamic Response

	Summer Peak			Summer Shoulder		
Scenario Analyzed	**Additional Generation On (MW/$)**	**Load Reduction (MW/$)**	**Total Cost ($)**	**Additional Generation On (MW)**	**Load Reduction (MW)**	**Total Cost ($)**

Without Twin Cities Load reduction for the summer peak case, and additional gas generation turned on in both summer peak and shoulder average wind case, generator rotor angles exceed +/- 300 degrees, which is indicative of the point where the generator would lose synchronization with the grid and trip offline. Example plots of Unstable and Stable Response are shown in Figure M1-1 and Figure M1-2.

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Figure M1-1
2028SHAW Unstable Generator Angle Response

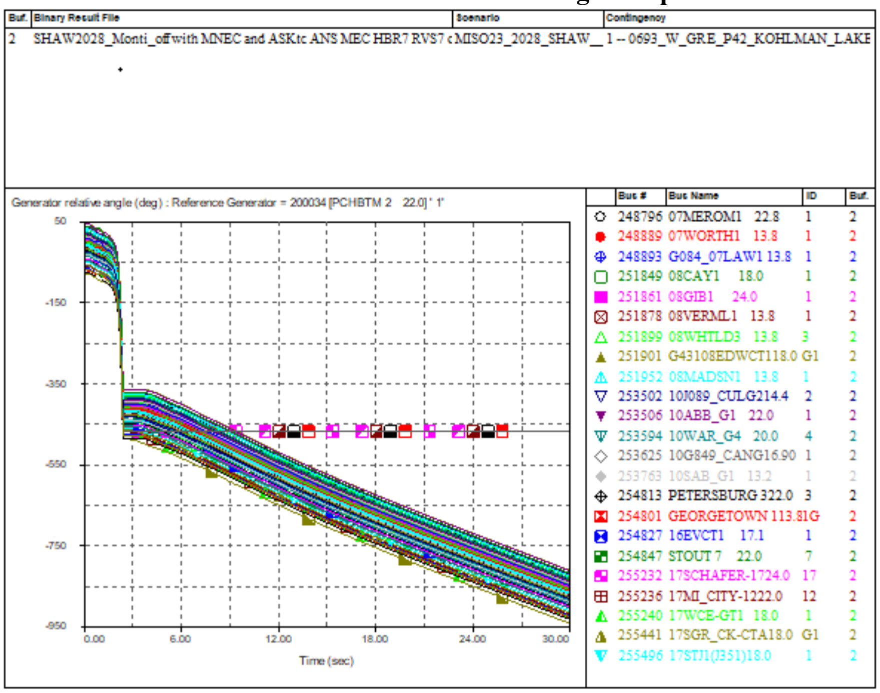

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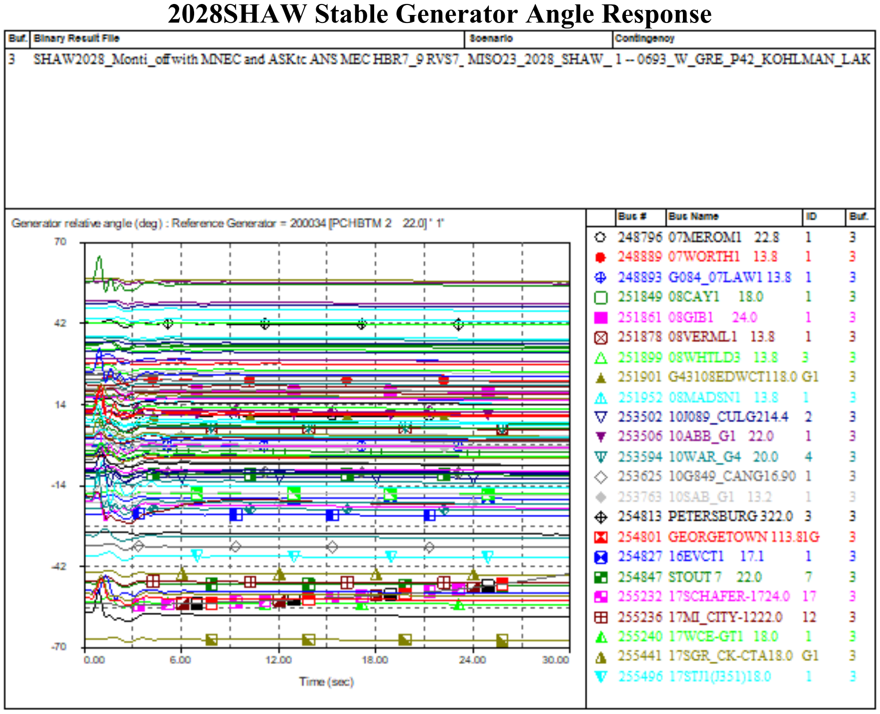
Figure M1-2
2028SHAW Stable Generator Angle Response



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Introduction

This analysis was performed to determine the steady state impacts and dynamic resources needed online as a result of separately retiring the Monticello Nuclear Generating Plant and the Prairie Island Nuclear Generating Plant. For further analysis, the retirements of both the Monticello and Prairie Island Nuclear Generating Plants simultaneously were included in the analysis. Additionally, Integrated System Planning (ISP) Transmission Planning engineers performed a study to evaluate the transmission system steady state with the nuclear generation station retirements along with the planned Sherco coal generation replacement with Minnesota Energy Connection (MNEC) renewable generation and the AS King coal generation replacement with King Transmission Connection solar generation. Existing natural gas resources were turned on to replace the generation shortfalls based on the MISO dispatch of renewables in the model. This study is a reliability only look – system transfer capability and resource capacity analyses are out of the work scope of this study.

Assumptions

This study is performed utilizing Siemens PSSE version 35.3.2 for steady state analysis and Powertech TSAT version 22.3.39 for dynamic analysis and based on the MISO Transmission Expansion Plan (MTEP) 2023 steady state models and dynamics package. MISO MTEP 2023 series, year 2028 models are selected as the starting models; no substantial load growth is assumed in this study. Sherco coal generation is replaced with Minnesota Energy Connection renewable generation at MISO renewable dispatch levels. AS King coal generation is replaced with King Transmission Connection solar generation at MISO solar dispatch levels.

Potential Limitations

Model

Sherco and King generation replacement locations and details are assumed based on the preliminary project scope, final project details may have minor differences.

Retirement of the nuclear generating stations were assumed to have no replacement generation installed. Load reduction where needed for stability was performed as a percent reduction across all loads in the Twin Cities area.

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1 Models and Assumptions

1.1.1 Models Utilized

Siemens PSSE version 35.3.2 for steady state analysis and Powertech TSAT version 22.3.39 for dynamic analysis and based on the MISO MTEP 2023 steady state models and dynamics package. MISO MTEP 2023 series, year 2028 models are selected as the starting models; no substantial load growth is assumed in this study.

1.1.2 Model Development

MTEP 2023, year 2028 Summer Peak (SUM) and 2028 Shoulder Average Wind (SHAW) models are selected as the starting models. Sherco coal generation is replaced with Minnesota Energy Connection renewable generation at MISO renewable dispatch levels. AS King coal generation is replaced with King Transmission Connection solar generation at MISO solar dispatch levels.

2028 Summer Shoulder Average Wind, and Summer Peak scenarios are analyzed in this study. Renewables in the NSP system are modeled at seasonal generation levels; Solar at 50% for Summer Peak and 31% for Summer Shoulder Average Wind; Wind at 15.5% for Summer Peak and 27% for Summer Shoulder Average Wind. NSP load information is shown in Table M1-5.

Table M1-5
NSP Load Level and Thermal Generation Level

Year	Season	Load Level
2028	Summer Shoulder Average Wind	6,383 MW
2028	Summer Peak	9,064 MW

1.1.3 Modeling Assumption

MTEP 2023, year 2028 Summer Peak (SUM) and 2028 Shoulder Average Wind (SHAW) models are selected as the starting models. Sherco coal generation is replaced with Minnesota Energy Connection renewable generation at MISO renewable dispatch levels. AS King coal generation is replaced with King Transmission Connection solar generation at MISO solar dispatch levels. Analysis is performed on cases with Monticello Nuclear Generating Plant retired, Prairie Island Nuclear Generating Plant retired, and both Monticello and Prairie Island Nuclear Generating Plants retired.

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2 Steady State Analysis

MISO MTEP 2023 Steady State 2033SUM and 2033SHAW models are used to conduct the steady state analysis. Steady analysis was performed on the base case, Monticello retire case, Prairie Island retire case, and both Monticello and Prairie Island retire case for both the Summer Peak and Summer Shoulder Average Wind case. Full N-1 and N-1-1 contingencies were run for LRZ 1.

Available NSP natural gas generation was turned on to reduce the number of unsolved contingencies. Robust solution in PSSE was used to allow for system adjustment of reactive devices and generation during contingency analysis to reduce the number of unsolved contingencies.

3 Stability Analysis

MISO MTEP 2023 Transient Dynamic package is used to conduct the transient stability analysis. Three phase faults with normal clearance time and single line to ground faults with a stuck breaker are tested for major 345 kV substations, transmission lines in Twin Cities and neighboring areas. Selected 345 kV bus voltages and transmission line power flow in Twin Cities and neighboring areas are monitored and plotted. The disturbances studied are listed in Table M1-6:

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Table M1-6
Disturbances Simulated in the Study

Name	Description
0693 redacted	
0857 redacted	
0860 redacted	
0865 redacted	
0866 redacted	
0867 redacted	
0868 redacted	
0879 redacted	
0890 redacted	
0891 redacted	
0892 redacted	
0893 redacted	
0896 redacted	
0898 redacted	
0920 redacted	
0922 redacted	
0927	

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Name	Description
0935 redacted	
0936 redacted	
0941 redacted	
0942 redacted	
0943 redacted	
0944 redacted	
0945 redacted	
2199 redacted	
2218 redacted	
2219 redacted	
2229 redacted	
2238 redacted	
2242 redacted	
2257 redacted	
2277 redacted	

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Available natural gas generation was turned on iteratively to achieve stability. Where insufficient natural gas generation was available to achieve stability, scalable load in the Twin Cities was reduced by a percentage of area load until stability was achieved.

- Summer Peak Load Case, in addition to generation on in the base model, required all available generation on at Anson, Inver Grove, and Blue Lake (total 521 MW) as well as load reduction in the Twin Cities area.
  - Monticello Retire – 10% (537.37 MW)
  - Prairie Island Retire – 20% (1,074.74 MW)
  - Monticello and Prairie Island Retire – 30% (1,612.11 MW)
- Shoulder Load Average Wind Case, in addition to the generation on in the base model required additional combustion generation turned on.
  - Monticello Retire – High Bridge 7 and 9 (388 MW), River Side 7 and 9 (318 MW). Total generation addition of 706 MW.
  - Prairie Island Retire - High Bridge 7 and 9 (388 MW), River Side 7, 9, and 10 (476 MW), Blue Lake 7 and 8 (302 MW). Total generation addition of 1,166 MW.
  - Monticello and Prairie Island Retire – High Bridge 7, 8, and 9 (550 MW), Riverside 7, 9, and 10 (476 MW), Blue Lake 1-4, 7, and 8 (455 MW), Inver Grove 1-6 (282 MW). Total generation addition of 1,763 MW.

4 Analysis Results

In the steady state analysis, available NSP natural gas generation was turned on to reduce the number of unsolved contingencies. The number of unique facilities with new or increased >0.5% voltage violations and thermal violations beyond preexisting violations in the base case were

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identified. Associated costs assigned based on MISO Transmission Cost Estimation Guide For MTEP23[1] for rebuild of overloaded lines to larger conductor size and assuming 5 150MVAR statcoms, situated in the vicinity of the retired nuclear units would resolve the voltage violations observed. The cost breakdown of the associated upgrades is listed in Table M1-7:

Table M1-7
Voltage and Thermal Upgrades with cost for Steady State Violations

In the dynamic analysis, available NSP natural gas generation was iteratively turned on to achieve stability. Once all available NSP natural gas was turned on, Twin Cities load was scaled down to achieve stability. Generation additions and load reduction are summarized in Table M1-8:

Table M1-8
Generation and Load Adjustments for Stable Dynamic Response

	Summer Peak		Summer Shoulder	
Scenario Analyzed	**Additional Generation On (MW)**	**Load Reduction (MW)**	**Additional Generation On (MW)**	**Load Reduction (MW)**
Monticello Retire	**512**	**537.37**	**706**	**0**
Prairie Island Retire	**512**	**1074.74**	**1,166**	**0**
Monticello and Prairie Island Retire	**512**	**1612.11**	**1,763**	**0**

[1] MISO Transmission Cost Estimation Guide for MTEP23337433.pdf (misoenergy.org)

5 Analysis Results Discussion

For the steady state results, any line with thermal violations is assumed to need an upgrade. Transformers with thermal violations are assumed to be replaced with transformer sized to carry the contingency level flows. Voltage violations are assumed to need reactive support in the form of capacitors or reactors. MISO cost estimation values are used to determine the estimated cost of upgrades as summarized in Table M1-9.

Table M1-9
Steady State Upgrade Summary

	Summer Peak			Summer Shoulder		
	Line Upgrade (miles/cost $)	**Reactive Support (MVAR/cost $)**	**Total Cost ($)**	**Line Upgrade (miles/cost $)**	**Reactive Support (MVAR/cost $)**	**Total Cost ($)**
Monticello Retire						
Prairie Island Retire						
Monticello and Prairie Island Retire						

For the dynamic results, cost was applied to the natural gas units turned on to maintain system stability assuming gas price of [redacted]. Cost was also applied to load reduction to maintain system stability in the Summer Peak load case. Costs associated with dynamic stability are summarized in Table M1-10.

Table M1-10
Dynamic Generation and Load Adjustments Costs

	Summer Peak			Summer Shoulder		
Scenario Analyzed	**Additional Generation On (MW/$)**	**Load Reduction (MW/$)**	**Total Cost ($)**	**Additional Generation On (MW)**	**Load Reduction (MW)**	**Total Cost ($)**
Monticello Retire						
Prairie Island Retire						
Monticello and Prairie Island Retire						

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2028 Summer Peak Case:

Generator angular stability issues were identified at generation and load reduction levels below those indicated in Table 6 as indicated by generator angles exceeding +/- 300 degrees, which reflects the angle at which the generator would lose synchronization with the electric grid and trip offline. Indicative plot of angular instability is shown in Figure M1-3. Stable generator angle plot examples for each retirement scenario are shown in Figure M1-4, Figure M1-5, and Figure M1-6.

Figure M1-3
SUM28 Prairie Island and Monticello Retirement Angular Instability

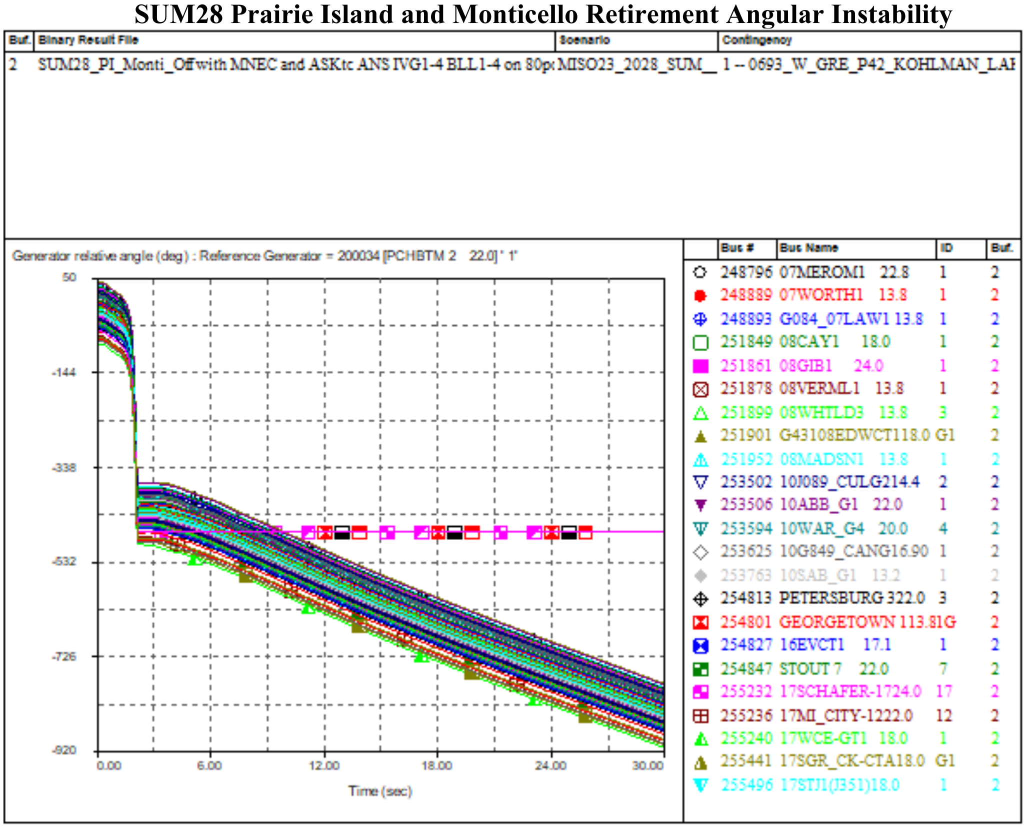

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Figure M1-4
SUM28 Monticello Retirement Angular Stability

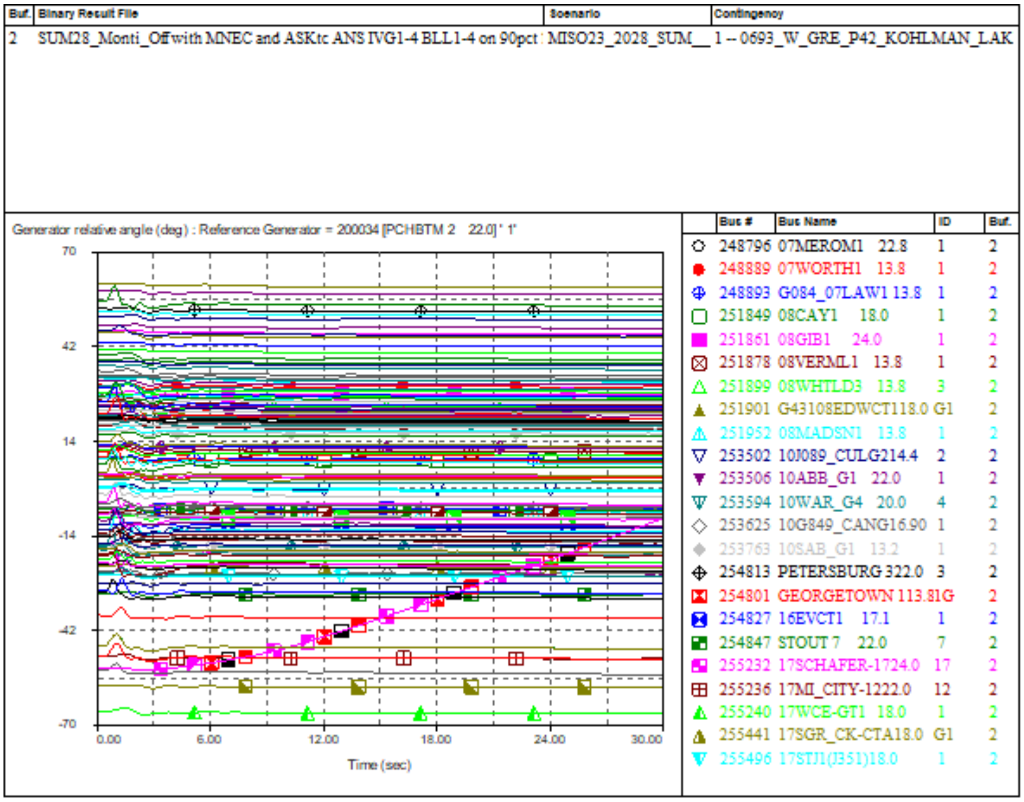

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Figure M1-5
SUM28 Prairie Island Retirement Angular Stability

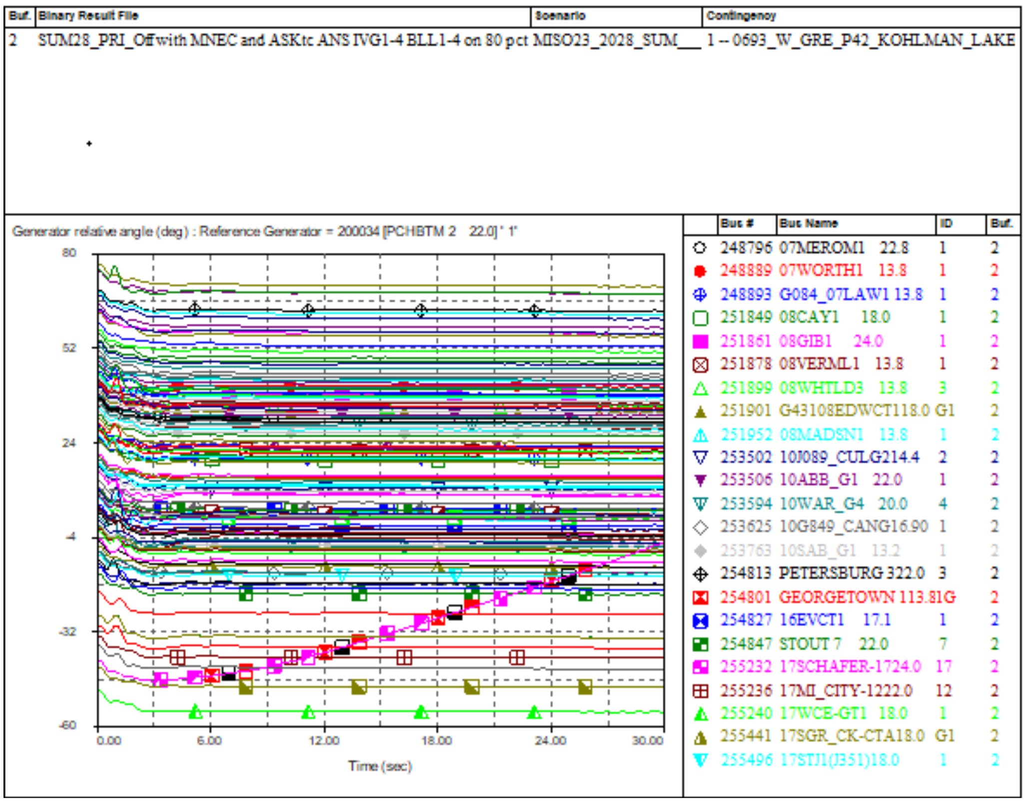

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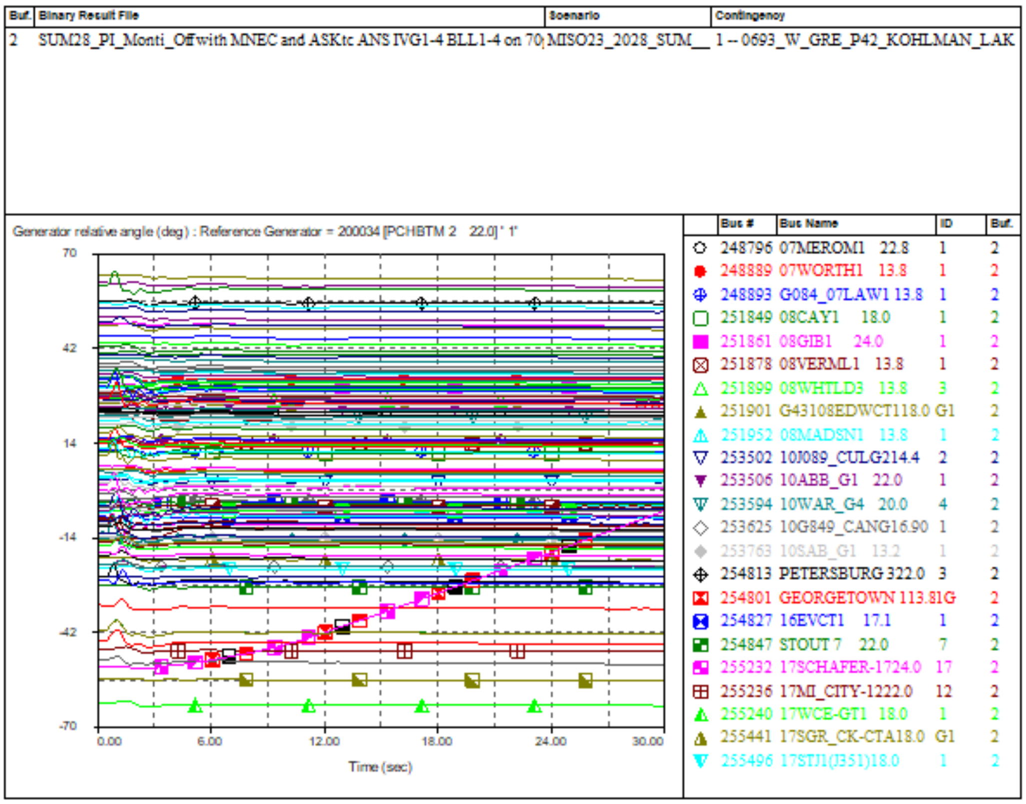
Figure M1-6
SUM28 Prairie Island and Monticello Retirement Angular Stability



Bus Voltage and Frequency were also montiored with no identified instability.

2028 Summer Shoulder Average Wind Case:

Generator angular stability issues were identified at generation levels below those indicated in Table 6 as indicated by generator angles exceeding +/- 300 degrees, which reflects the angle at which the generator would lose synchronization with the electric grid and trip offline. Indicative plot of angular instability is shown in Figure M1-7. Stable generator angle plot examples for each retirement scenario are shown in Figure M1-8, Figure M1-9, and Figure M1-10.

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Figure M1-7
SHAW28 Prairie Island and Monticello Retirement Angular Instability

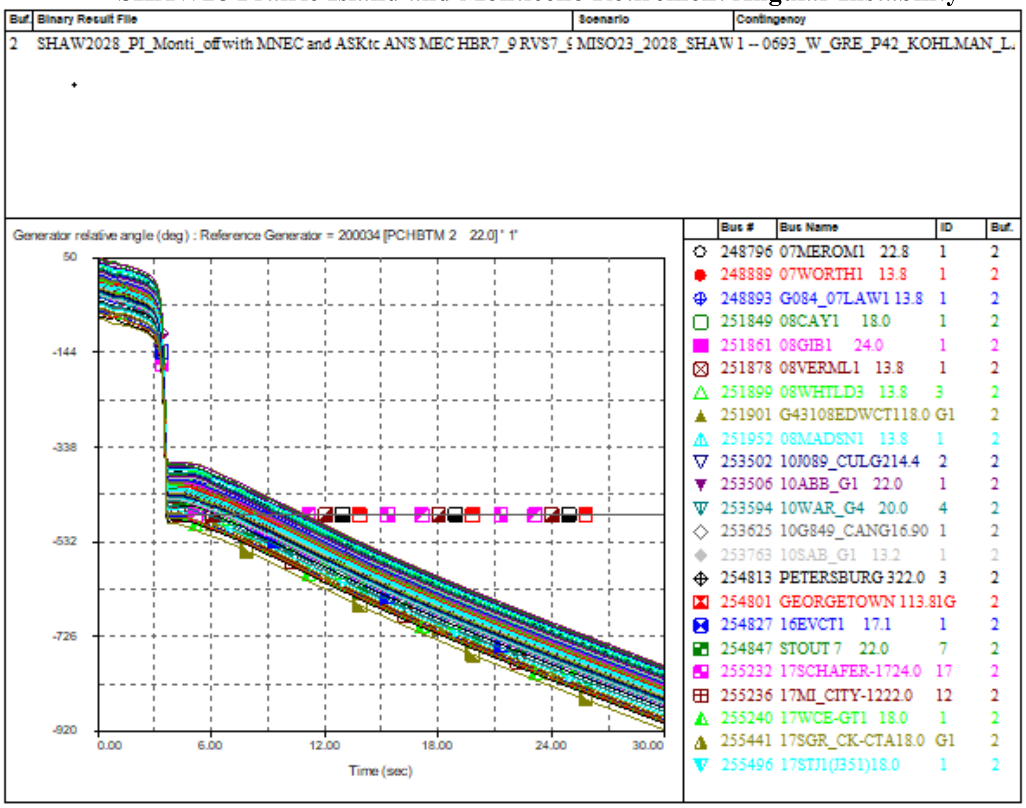

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Figure M1-8
SHAW28 Monticello Retirement Angular Stability

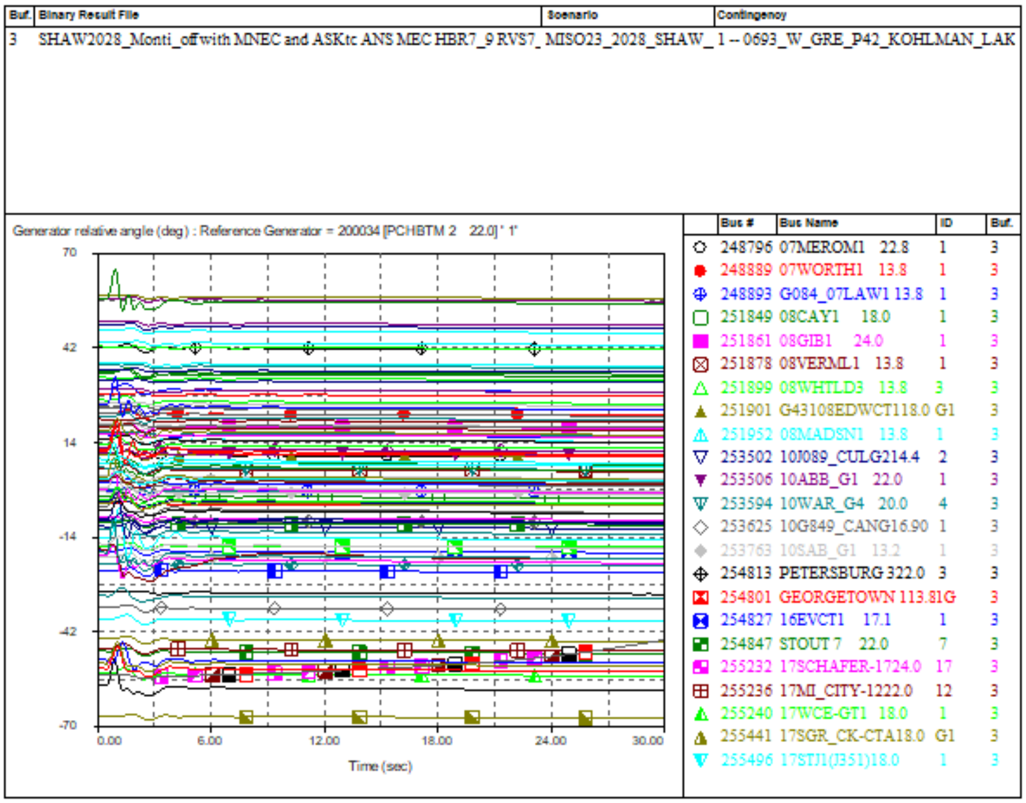

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Figure M1-9
SHAW28 Prairie Island Retirement Angular Stability

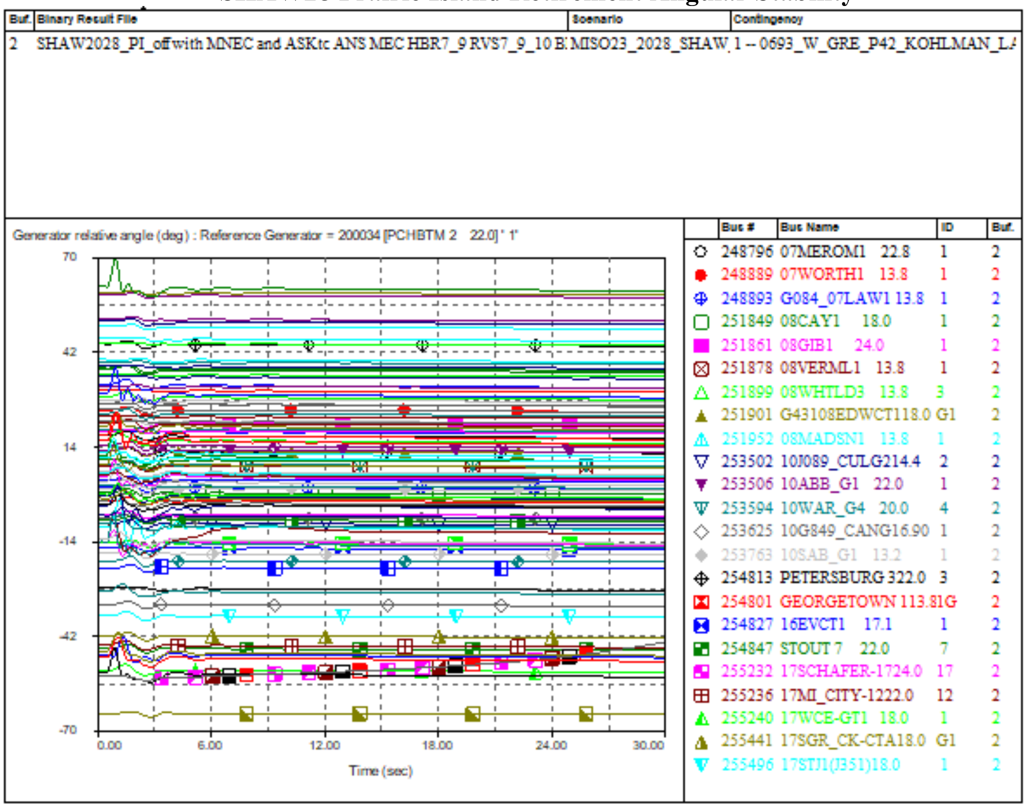

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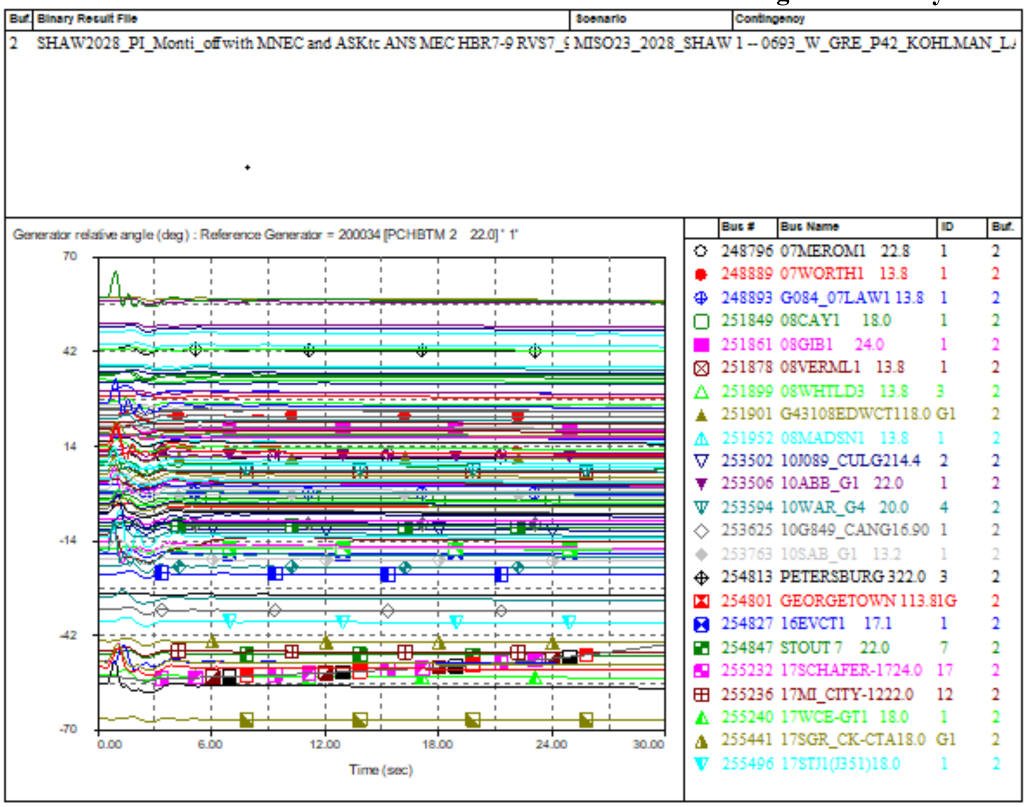
Figure M1-10
SHAW28 Prairie Island and Monticello Retirement Angular Stability



Bus Voltage and Frequency were also montiored with no identified instability.

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6 Observation

Based on the steady state results performed in this study, significant line upgrades and voltages support are needed to mitigate violations with their associated fixed costs as a result of the retirement of the nuclear units:

Table M1-11
Steady State Upgrade Cost Summary

	Summer Peak			Summer Shoulder		
	Line Upgrade (miles/cost $)	**Reactive Support (MVAR/cost $)**	**Total Cost ($)**	**Line Upgrade (miles/cost $)**	**Reactive Support (MVAR/cost $)**	**Total Cost ($)**
Monticello Retire						
Prairie Island Retire						
Monticello and Prairie Island Retire						

Based on the dynamic analysis results performed in this study, significant replacement generation is needed along with the associated annual costs of the generation:

- Summer Peak Load Case, added generation to achieve generator angular stability needed was 521 MW as well as load reduction in the Twin Cities area based on the nuclear generation being retired.
    - Monticello Retire – 10% (537.37 MW) Total Annual Cost [redacted].
    - Prairie Island Retire – 20% (1,074.74 MW) Total Annual Cost [redacted].
    - Monticello and Prairie Island Retire – 30% (1,612.11 MW) Total Annual Cost [redacted]
- Shoulder Load Average Wind Case, added generation to achieve generation angular stability based on the nuclear generation being retired.
    - Monticello Retire – Total generation addition of 706 MW Total Annual Cost [redacted]
    - Prairie Island Retire - Total generation addition of 1,166 MW Total Annual Cost [redacted]
    - Monticello and Prairie Island Retire - Total generation addition of 1,763 MW Total Annual Cost [redated]

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Appendix 1 – Steady State Analysis Thermal Overloads

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