G523 Interconnection
Combined Feasibility/System Impact Study Report
550 MW Coal Generation
Marathon County, Wisconsin

MISO Queue #38503-02

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1. Summary

This report contains the combined Interconnection Feasibility/System Impact Study (ISIS) for the Generation Interconnection Request identified as MISO Project #G523, MISO Queue #38503-02. This study evaluates the impact of a 550MW coal-fired generating unit to be interconnected to the future Gardner Park 345kV substation in Marathon County, Wisconsin. The requested back-feed date for this project is November 1, 2010 and the requested in-service date is June 1, 2011. The customer is evaluating two alternative sites for the generating unit relative to the interconnecting substation – South site and North site. Preliminary bus configurations for Gardner Park 345kV and 115kV substations and the associated line termination changes were proposed by the customer for each site alternative. The one-line diagram for bus configurations corresponding to the two proposed alternatives for G523 interconnection are shown in Figure 1a (South site) and Figure 1b (North site).

This study identifies the steady state thermal violations, the breaker clearing time violations, and breaker duty violations. The identified violations are based on Linear Transfer and AC power flow analyses, angular stability simulations, and short circuit analysis respectively. The study also identifies the interconnection facilities and the necessary system upgrades, along with preliminary good faith cost estimates, that will eliminate any unacceptable system impacts and allow the generator to interconnect to the system as an Energy Resource (ER) or as a Network Resource (NR). For G523 to interconnect as either ER or NR, it is necessary to complete upgrades required to resolve injection limits. Injection limits are thermally overloaded facilities that either have a Distribution Factor (DF) of at least 20% in relation to real power injected at the generator Point of Interconnection (POI) and delivered to all of MISO, or they are direct outlets from the generator POI. Completing all identified system upgrades based on the ISIS, including a future Deliverability Study, to be performed by MISO, is necessary to qualify G523 as a NR.

1.1 Injection Limits

The study identified three (3) steady-state thermal violations for NERC Category A events and 22 steady-state thermal violations for NERC Category B events. Six (6) of these thermal violations meet the criteria for injection limits and will require mitigation for G523 to acquire ER status. The inclusion of three planned projects with an in-service date of Summer 2009 (see Table 3.1 in Section 3) in the study model resolved all injection limits, except one, which will require a new upgrade (see Table 3.2 in Section 3).

The maximum allowable generation without system upgrades was found to be 0 MW based on injection limits to the system. Inclusion of the three planned projects (that resolve the injection limits) increases the maximum allowable generation to 271 MW as shown in Table A.2 in Appendix A. Total plant output may still be limited to 0 MW when considering all identified thermal constraints.

1.2 Operation Restrictions

The study also identified 23 steady-state thermal violations for NERC Category C events (double contingencies) which require potential operation restrictions on G523. These operation restrictions were identified based on N-2 linear transfer analysis on the Summer 2011 model that included the three planned projects (see Table 3.1 in Section 3). A summary of the operation

restrictions on G523 under prior outage conditions is provided in Table B.1 in Appendix B. No additional operation restrictions were identified based on prior outage angular stability simulations.

1.3 Network Upgrades

Existing Network Upgrades Required Before G523 Operation (see Table 1.1)

Injection (Thermal Violation) Related
Prior to G523, there are no injection limiting elements due to thermal overloads once Weston G4 generator (MISO project G144) is in service along with associated network upgrades. However, the existing facility upgrade described in Table 1.1 is required to resolve Gardner Park – Rocky Run 345kV line as an injection limit for G523. This project is scheduled for completion in Y2006.

Angular Stability Related
There are no stability related problems prior to G523, once Weston G4 generator (MISO project G144) is in service along with associated system upgrades.

Breaker Duty Related
Prior to G523, the fault current interruption duty of four breakers at Weston 115kV station and one breaker at Sherman St. 115kV station is exceeded once Weston G4 generator (MISO project G144) is in service. ATC has scheduled upgrades for these five breakers by the end of 2007.

Network Upgrades Required Due to G523 Addition (see Table 1.2)

Upgrades to facilitate the G523 interconnection
Add a position for G523 interconnection within the Gardner Park 345kV substation -- requires installing two circuit breakers in a new bay. A new terminal may also have to be added for G523 Auxiliary Transformer. Table 1.2 describes this required network upgrade and provides a good faith cost estimate for them.

Injection Upgrades
The injection upgrades refer to those system upgrades that eliminate thermal violations of facilities in electrical proximity to G523, which are facilities that either have a Distribution Factor (DF) of at least 20% in relation to real power injected at the generator POI and delivered to all of MISO, or facilities that are direct outlets from the generator POI. The injection upgrades are required for both NR and ER services. The Gardner Park-Central Wisconsin 345kV line was the only injection upgrade identified in the power flow analysis, and is included in Table 1.2 along with its good faith cost estimate. Refer to Section 3.1.1 for more discussion on this subject and to Appendix A for detailed results.

Angular Stability Related
Adequate breaker clearing time margins for maintaining generator angular stability require the proposed North Site bus configuration for Gardner Park 345kV station for either G523 site

proposed. The following upgrades/reconfigurations are required to achieve adequate breaker clearing time margins for angular stability:

1) Gardner Park-Central Wisconsin 345kV line
2) Morgan-Central Wisconsin-Werner West 345kV line
3) Reconfiguration of Gardner Park 345kV substation to match proposed "North" site configuration

Table 1.2 describes these required network upgrades and provides a good faith cost estimate for them. Refer to Section 3.2 for more discussion on this subject and to Appendix C for detailed results.

Breaker Duty Related

Additional fault current in the system due to G523 generation does not cause any additional breakers to exceed their interruption duty. Therefore, no breaker upgrades are required for G523 provided the breaker upgrades identified for Weston G4 generator (MISO project G144) are completed. Refer to Section 3.3 for more discussion on this subject and to Appendix D for detailed results.

Network Resource (NR) Certification Related

MISO will be performing the generator deliverability study for this project. The required system upgrades to qualify G523 as an NR will be identified through the deliverability study at a later time.

1.4 Required Interconnection Facilities

New interconnection facilities will consist of facilities between the interconnection substation (Gardner Park 345kV) and the generator POI, which is the bus side of the disconnecting device on the high (345kV) side of the G523 GSU transformer. Note that the generator POI is also the point of change of ownership. Table 1.3 describes the required interconnection facilities and provides a good faith cost estimate for them.

Minimum permissible power factor at POI

For all system conditions, G523 will be required to operate within a power factor range from 0.90 lagging (delivering vars) to 0.95 leading (absorbing vars) at the POI. The G523 facility will also be required to maintain a minimum voltage of 1.02 pu at the POI for all system conditions, unless ATC system operations directs otherwise.

1.5 Further Study

The next step in the Generator Interconnection Request process is for the customer to decide if they want to proceed to a Facility Study. Additionally, MISO will complete a Deliverability Study for the proposed unit. A Facility Study will specify in more detail the time and cost of the equipment, engineering, procurement and construction of the system upgrades identified in this ISIS report.

Table 1.1– Existing Network Upgrades Required to be In Service before Operation of G523

Location	Facilities	Reason	Cost Estimate (Y2006)
Rocky Run 345kV Substation	Item#1 – Upgrade relaying at the Rocky Run 345kV end of line V-308 to match the relays at Gardner Park 345kV end – will result in 1600A or 956 MVA SN/SE facility rating.	Injection	$0.29 M

Table 1.2 – Required Network Upgrades due to the Addition of G523

Location	Facilities	Reason	Cost Estimate	Year Basis for Cost
Gardner Park 345kV Substation	Item#1 – Addition of terminal for G523 interconnection in 345kV Gardner Park substation (assumed no terminal is needed for G523 Aux Transformer). Includes two breakers, four disconnect switches, three CCVTs, two wave traps, associated buses and bus supports. Two new 345kV breakers for creating terminal in a new bay are required to have clearing time of 2 cycles or faster. The new breakers and relays are required to provide near-end primary clearing time of 4.5 cycles or faster.	Interconnection & Stability	$2.6 M	Y2005
	Item#2 – Reconfiguration of line terminations in Gardner Park substation to match the proposed North site bus configuration.	Stability	$13.0 M*	Y2005
	Item#3 – Construct Gardner Park – Central Wisconsin 345kV Line.	Injection & Stability	$131.5 M	Year of Occurrence
	Item#4 – Construct Morgan – Central Wisconsin – Werner West 345kV Line.	Injection & Stability	$132.3 M	Year of Occurrence

***** Significant overall cost savings could be realized if the existing design of lines (to be built for G144) incorporates the proposed line re-routings required for future (North site) bus configuration.

Table 1.3 – Required Interconnection Facilities for G523

Locations	Facilities	Cost Estimate (Y2005)
G523 South or North Site at Gardner Park/Weston	Item#1 –19/345kV Generation Step-Up Transformer (GSU), 19kV circuit-breaker and disconnect switch, and 345kV disconnect switch. These facilities are to be provided by the customer	N/A
Point of interconnection with G523 in Gardner Park 345kV substation	Item#2 –One 345kV circuit-breaker, two 345kV disconnect switches, one dead-end, three CCVTs, two wave traps, associated buses and bus supports. These facilities are to be provided by ATC	$1.5 M

Notes:

1. These facility interconnection requirements are not expected to vary irrespective of the location of G523 with respect to Gardner Park 345kV substation (South site or North site). Details of interconnection facilities will be finalized in the Facility Study.

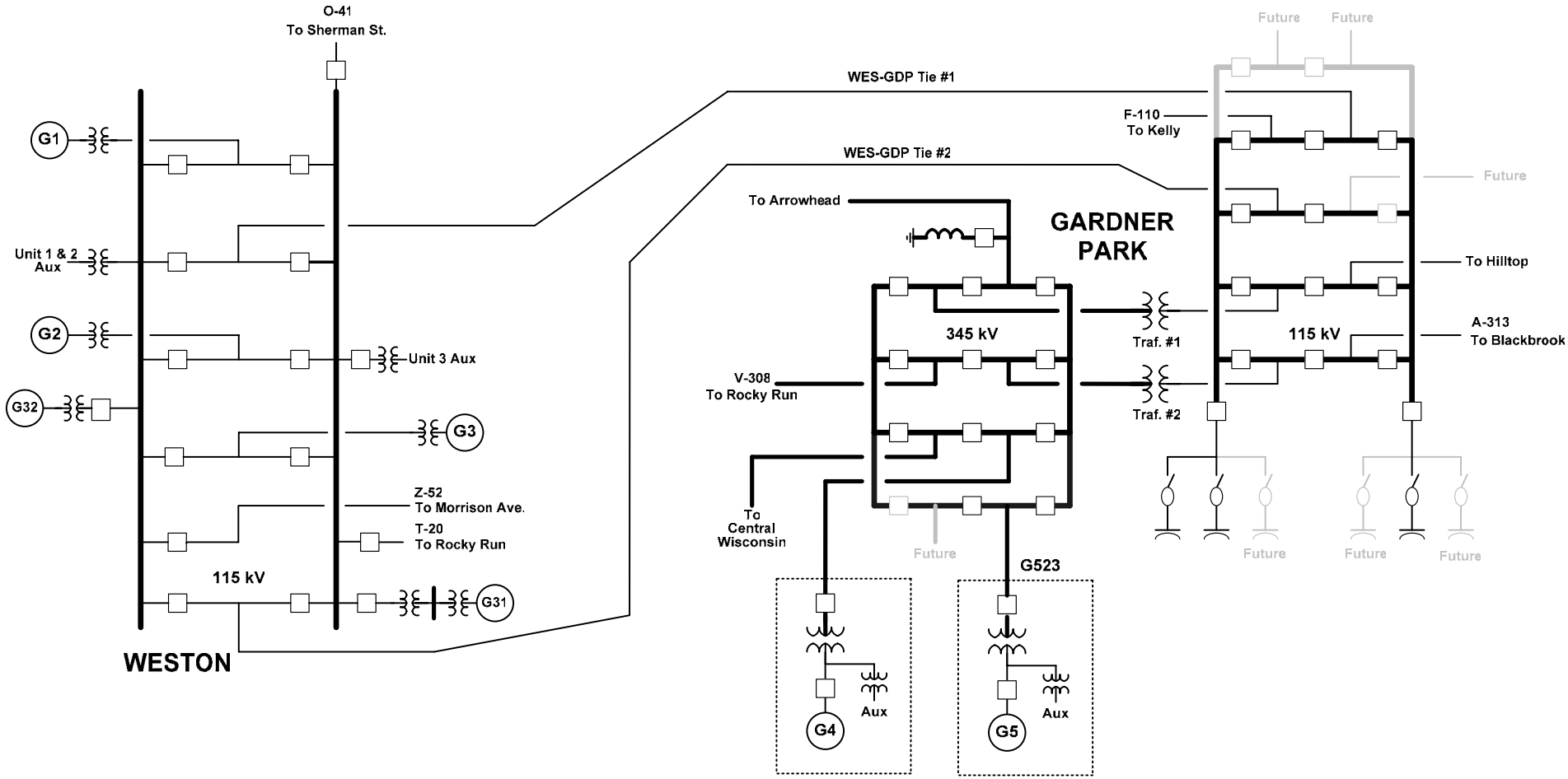

Figure 1a: One Line Diagram of G523 interconnected at Gardner Park substation — **South** site bus configuration ***(Rejected)***
See Figure 1b for **Required** configuration.

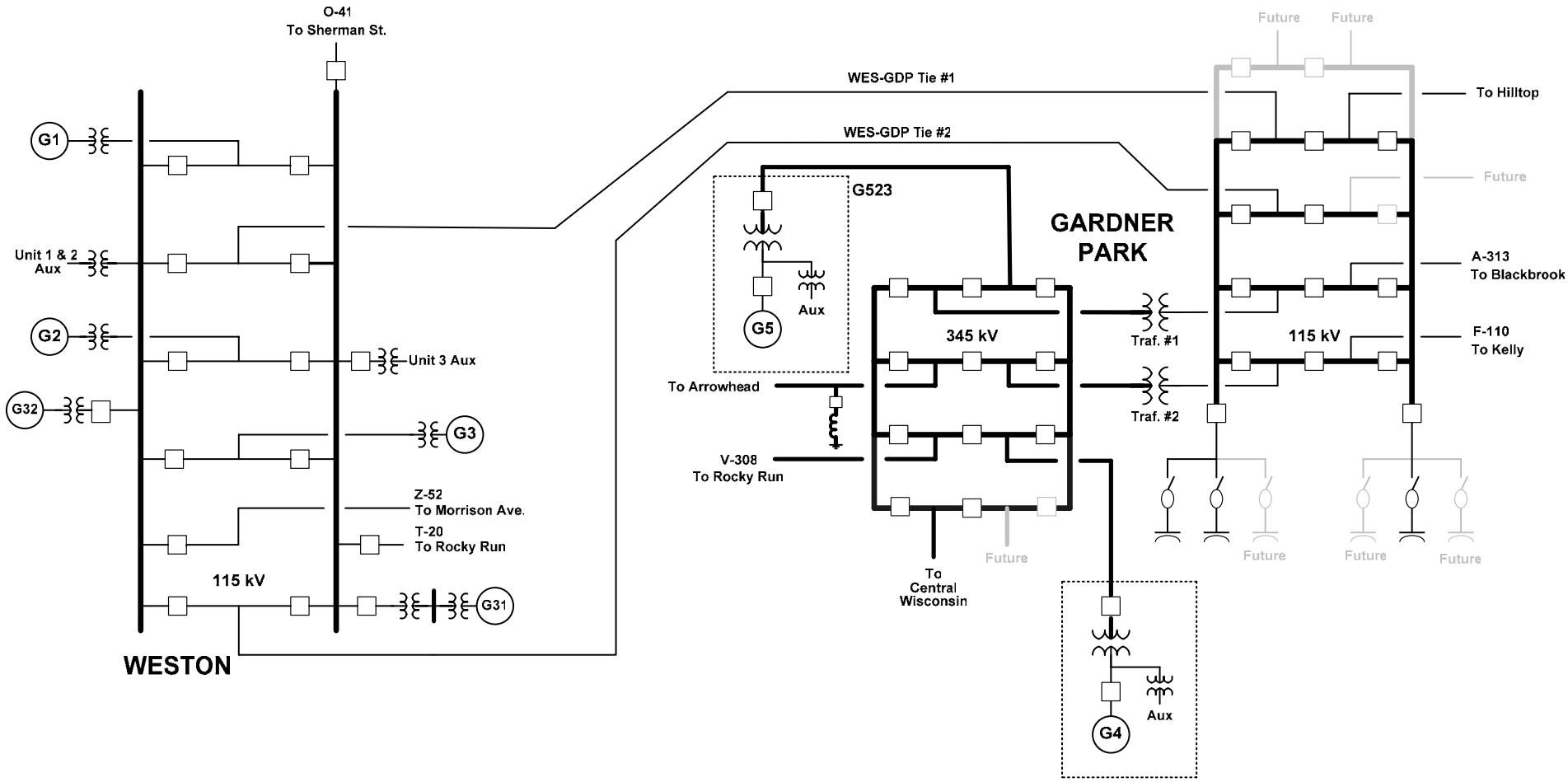

Figure 1b: One Line Diagram of G523 interconnected at Gardner Park substation — **North** site bus configuration
REQUIRED Configuration for either North or South site location for G523

2. Criteria, Methodology and Assumptions

2.1 Study Criteria

All relevant MISO-adopted NERC Reliability Criteria and the American Transmission Company ("ATC") contingency criteria are to be met for both the thermal and angular stability analysis. Details of the analysis criteria applied in this study can be found in the Appendix E.

2.2 Study Methodology

The results of this study are subject to change. The results of the study are based on data provided by the Generator and other ATC system information that was available at the time the study was performed, and the injection study does not guarantee deliverability to the MISO energy market. If there are any significant changes in the generator and controls data, in earlier queue Generator Interconnection Requests, in related Transmission Service Requests, or ATC transmission system development plans, then the results of this study may also change significantly. Therefore, this request is subject to restudy. The Generator is responsible for communicating any significant generation facility data changes in a timely fashion to MISO and ATC prior to commercial operation.

2.2.1 Competing Generation Requests

ATC determined in its sole judgment that two Generator Interconnection Requests with an earlier queue position will impact the G523 study results. G144 and G477 are considered competing requests for the interconnection of this generator and therefore included in each base case. G144 is a 550 MW coal fired generating facility located in Marathon County, WI. G477 is a 531 MW integrated gasification combined cycle generating facility located in Minnesota.

Public information related to Generator Interconnection Request queue can be found via the MISO web site at **http://oasis.midwestiso.org/documents/ATC/queue.html**.

2.2.2 Linear Transfer Analysis and A.C. Power Flow Analysis Methods

Thermal overloads were identified using linear transfer analysis and then verified with AC power flow solutions. The linear transfer analysis was used to evaluate the intact system, N-1 contingency, N-2 contingency and certain ATC multiple contingency conditions. The linear transfer analysis utilized adjusted MW ratings for facilities to account for reactive power flows and a 5% transmission reserve margin ("TRM"). All AC power flow solutions utilized actual facility ratings in MVA (i.e. 0% TRM) along with real and reactive power flows. However, the 5% TRM was factored in the computation of required MVA rating for the limiting elements.

The linear transfer analysis was performed using the Linear Transfer Analysis modules of the Managing and Utilizing System Transmission-6.03 (MUST, Version 6.03) program from Siemens Power Technologies, Inc (PTI). All AC power flow solutions were performed using the Power Flow module of the Power System Simulation/Engineering-29 (PSS/E, Version 29)

program from Siemens Power Technologies, Inc (PTI). These programs are accepted industry-wide for power flow analysis.

2.2.3 Base Cases

2.2.3.1 Power flow analysis

Base cases used in the thermal analysis for this study were developed based upon the ATC summer peak 2005 model and the July 2005 build of MISO seasonal cases of winter peak 2010/11 and the summer peak of 2011. Three base cases were developed to model the winter peak of 2010/11, a shoulder peak of 2011, and the summer peak of 2011. The ATC system was modified by updating all loads to the expected 2011 coincident peak value and including all proposed projects through 2007 and all planned projects through 2008 as listed in the ATC Ten Year Assessment. Consequently, all base cases include the Arrowhead-Gardner Park 345kV project that is expected to be in-service by end of Y2008. The MISO seasonal cases are accessible through the MISO Extranet. The 550 MW output of G523 was delivered to all on-line MISO generation for thermal analysis. For transfer sensitivity analysis, the 550 MW output of G523 was delivered equally between WPS and ALTE control areas (50% each).

Thermal analysis includes identifying limiting elements that incur thermal violations for an intact system and under N-1 contingencies by using linear transfer analysis and AC power flow analysis. For N-2 contingencies, thermal analysis includes evaluating thermal violations and prior outage operating restrictions based on linear transfer analysis only.

2.2.3.2 Angular Stability analysis

The 2011 light load base case used in the angular stability analysis for this study was developed based upon the 2005 ATC 50-percent peak load stability model. The 2005 stability model was modified by including all proposed projects through 2007 and all planned projects through 2008 as listed in the ATC Ten Year Assessment. All loads in the resulting model were updated to the expected 2011 coincident peak value based on EIA-411 forecast for Summer 2011 and additional generation was dispatched to supply the increased load plus losses. All constant loads at buses within ATC footprint were applied to the model and generation dispatch was accordingly changed, to obtain the 2011 ATC 50-percent peak load stability model. To convert this into G523 stability base case, all existing generators at Weston and the proposed G523 generator were dispatched at their full output in accordance with ATC generator interconnection stability study criteria. The resulting additional generation in WPS control area was delivered to ComEd (75%) and NSP (25%) control areas. To meet the minimum criteria for angular stability, it was necessary to enhance the G523 stability base case by adding all three planned ATC projects with in service date of Summer 2009 (see Table 3.1 in Section 3) to the model. For some transient angular stability simulations (i.e. faults in Gardner Park 115kV substation), the proposed ATC Cranberry-Conover Project[♦] with in service date of Summer 2010 was also added to the model to facilitate solution convergence in the simulations.

[♦] Construct Cranberry – Conover 115kV line. Rebuild/convert Conover – Plains 69kV line to 138kV. Construct 138kV bus at Conover and install 138/115kV and 138/69kV transformers. Construct 138kV bus at Iron Grove and install a 138/69kV transformer.

Angular stability analysis includes screening for stable operation at acceptable primary and delayed breaker clearing times for breaker failure contingency conditions, and acceptable primary breaker clearing times for prior outage conditions. These cases are typically the worst conditions for angular stability performance.

2.2.3.3 Deliverability analysis

Deliverability analysis, required for G523 to attain Network Resource status, was not performed in this study. It will be performed by MISO at a later date.

2.2.4 Generation Facility Modeling

The G523 generation was modeled at 550 MW of real power output while controlling the Gardner Park 345kV bus voltage to 1.02 pu for the power flow analysis, unless specified otherwise. For angular stability analysis for the 2011 light load conditions, the G523 generator was modeled at full 550 MW output but the Gardner Park 345kV bus voltage was controlled to 1.035 pu to ensure that G523 was operating at near unity power factor and not absorbing vars.

Construct 138kV bus at Aspen and install a 138/69kV transformer

3. Analysis Results

3.1 Power Flow Analysis Results

3.1.1 Results of Single Contingencies (N-1)

An injection study was performed by delivering 100% of the G523 output to the entire MISO footprint. This thermal analysis was performed on each seasonal base case and then on each base case plus the three Planned projects listed in Table 3.1. The injection study identified three (3) steady-state thermal violations due to G523 for NERC Category A events and 22 steady-state thermal violations due to G523 for NERC Category B events. Six (6) of these thermal violations are identified as injection limits. Results of the N-1 thermal analysis for the injection study can be found in Table A.1 in Appendix A.

Table 3.1: Additional Transmission Projects Affecting G523

Project Description	Expected In-Service Year	Project Status
Construct Gardner Park – Central Wisconsin 345kV line	2009	Planned
Construct Morgan – Werner West 345kV line	2009	Planned
String a new 138kV line from Clintonville to Werner West, primarily on the Morgan – Werner West 345kV line structures	2009	Planned

Notes:

1. All three Planned projects are included in the Summer 2011-2, Shoulder 2011-2, and Winter 2010/11-2 system models.

A transfer sensitivity study was performed on each of the three seasonal base cases by delivering 50% of the G523 output to WPS and 50% of the output to ALTE. The study found no thermal limits in addition to those found in the injection analysis and only a small change (~1%) in individual Distribution Factors (DFs) of each thermal limit. The two significant differences between the transfer sensitivity and injection analyses are:

1. Thermal overload of the Bain – Kenosha 138kV line for the outage of Pleasant Prairie – Zion 345kV line *does not* occur in the transfer sensitivity study. However, this facility does appear as a constraint for some Wisconsin generation in the publicly available deliverability results produced by the Midwest ISO. Public information related to the Generator Deliverability Test results can be found via the MISO web site at **http://www.midwestiso.org/plan_inter/gen_deliver_test_results.shtml**.
2. For base cases resulting after the inclusion of the three planned projects listed in Table 3.1, the DF of injection outlet Gardner Park – Rocky Run 345kV Line V-308 (for the outage of planned Gardner Park – Central Wisconsin 345kV Line) is reduced from 64.6% in the injection study to approximately 59% in the transfer sensitivity study.

Of the six (6) injection limits for G523 identified in Table A.1 in Appendix A, five (5) injection limits will get resolved when the three Planned projects listed in Table 3.1 are placed in service in Y2009. One injection limit, the Gardner Park – Rocky Run 345kV Line, will get resolved by a project authorized for completion in Y2006 that will result in an increased facility thermal rating

of 956 MVA SN/SE. Therefore, the solution identified for this injection limit in Table 3.2 is an existing transmission upgrade required to be in service before G523 interconnection.

Table 3.2: Existing Transmission Upgrades Required to Resolve G523 Injection N-1 Limits

Limiting Element	Solution
Gardner Park – Rocky Run 345kV Line V-308	Upgrade relaying at the Rocky Run 345kV end of line V-308 to match the relays at Gardner Park 345kV end – will result in 1600A (i.e. 956 MVA) SN/SE facility rating.

For each of the remaining non-injection limits identified in the N-1 analysis, a solution of limited scope is proposed in Table 3.3 (and in the footnotes of Table A.1 in Appendix A). These are not required upgrades for the G523 interconnection because the limits being resolved are not identified based on MISO deliverability study analysis. The potential solutions shown in Table 3.3 are supplied for informational purposes only and were developed in the following order:

1. If the line is not limited by the conductor rating, then replace the terminal equipment.
2. If the line is limited by the conductor rating, then increase phase conductor clearance to the maximum operating temperature of the conductor.
3. If the maximum operating temperature of the conductor does not resolve the limit, then a line reconductor or rebuild is proposed.

Table 3.3: Potential Transmission Projects to Resolve G523 Non-Injection N-1 Limits

Limiting Element	Potential Solution
Rocky Run – Plover 115kV Line S45	Two upgrades needed to obtain 268 MVA SE facility rating: (1) Replace jumpers at Plover 115kV substation; and (2) Increase the line conductor clearance to achieve a summer emergency operating temperature limit of 300º F.
Rocky Run – Whiting Ave. 115kV Line M91	Replace jumpers in Whiting Ave.115kV substation to obtain 328 MVA SE facility rating.
Bain – Kenosha 138kV Line 63151	Replace terminal equipment at the Kenosha 138kV substation
Washco – Stone Lake 161kV Line (DPC)	Increase the line conductor clearance to achieve a summer emergency operating temperature of 212º F to obtain 240 MW SE facility rating -- DPC plans to complete this project by Summer 2007.
Morgan – Falls 138kV Line 35351 and Falls – Pioneer 138kV Line 75541	Project to rebuild Morgan– Falls– Pioneer– Stiles line to double-circuit line has been completed. Associated project is underway to upgrade terminal equipment at Morgan, Falls and Pioneer substations to 2000A rating. Resulting SE, S/FE, WE facility ratings are expected to be higher than the thermal overloads seen by these facilities.
Plains 345/138kV Traf.	Since expected thermal loading equals the rating, no solution may be needed. Else, potential solution is the provisional ATC project to add a second transformer bank.

The viability of each potential solution in Table 3.3 was not assessed in this study. It may be possible that increasing the conductor clearance resolves the loading issue but is not physically or financially reasonable (e.g. the age and condition of the line structures may be an issue). Also, each solution is directly related to the individual constraint. It is possible that a separate plan may address all limits and offer secondary benefits such as relieving N-2 constraints. If the customer chooses to elect any of these upgrades in the Facility Study, then ATC will review the proposed solutions when preparing that report.

The maximum allowable real power output from G523 was determined by reducing G523 generation until all steady-state thermal violations due to G523 were resolved. Without any system upgrades, the maximum allowable output was identified as 0 MW due to injection limits. The maximum allowable outputs after the three Planned projects listed in Table 3.1 go in service were identified as:

271.4 MW in Summer 2011,
440.2 MW in Shoulder 2011, and
376.2 MW in Winter 2010-11.

Results of the maximum allowable output from G523 can be found in Table A.2 in Appendix A.

3.1.2 Results of Double Contingencies (N-2)

Thermal constraints were evaluated for NERC Category C events (N-2 contingencies) in the electrical proximity of G523. Thermal violations under a selected number of N-2 contingencies were evaluated using linear transfer analysis. The purpose of the N-2 analysis is (1) to reveal potential thermal violations under prior outage conditions, and (2) to identify potential operating restrictions to preempt these N-2 thermal violations. The N-2 analysis was performed only on the Summer 2011-2 model that includes the three Planned projects listed in Table 3.1.

The N-2 thermal violations are listed in Table A.3 in Appendix A. All limiting elements that were also identified in the N-1 thermal analysis were listed only for the most limiting double contingency. The required operating restrictions for the double contingencies are listed in Table B.1 in Appendix B. The restrictions are based on the most limiting element, which may be an element that was identified in the N-1 analysis. For this reason, Tables A.3 and B.1 may not appear to be developed from the same results.

The double contingency constraints are not required to be resolved for the generator to attain either Energy Resource or Network Resource status. All identified operating restrictions have been reviewed as solutions were developed for NERC Category A and B violations.

3.2 Angular Stability Analysis Results

The angular stability criteria used in this study requires that all machines modeled in the system must remain stable after a three-phase or single-phase to ground fault is cleared from any transmission element under the following scenarios:

1. Three-phase fault cleared in primary time with an otherwise intact system;
2. Three-phase fault cleared in primary clearing time with a prior outage of any other transmission element;
3. Three-phase fault cleared in delayed clearing time (i.e. breaker failure condition) with an otherwise intact system (wind turbines are exempt from the delayed clearing criterion, but must not adversely affect system angular stability performance);
4. Single Line to Ground (SLG) bus section fault cleared in primary clearing time with an otherwise intact system;
5. SLG internal breaker fault cleared in primary clearing time with an otherwise intact system.

In this ISIS study, potential angular stability problems were screened by studying the two scenarios that produce the most severe conditions for maintaining angular stability; that is, scenario #2 (prior outage) and scenario #3 (breaker failure). Results of the angular stability analysis are summarized in Tables C.1 and C.2 in Appendix C. Further, adequate damping of the local plant mode rotor angle oscillations was verified by running extended transient stability simulations (until 20 seconds) for selected prior outage and breaker failure cases. The two cases with smallest critical clearing time were selected from Tables C.1 and C.2 for verifying the absence of any local-plant swing mode and/or slow inter-area swing mode.

Based on the results obtained and engineering judgment, it is concluded that no unacceptable angular stability conditions will arise due to faults cleared in primary breaker clearing time with an otherwise intact system (that is, scenarios 1, 4 and 5 above).

3.2.1 Results of Delayed Clearing Contingencies

The breaker failure contingencies evaluated and the study results are summarized in Table C.1 in Appendix C.

The study identified no unacceptable angular stability performance after the addition of G523 for any of the studied delayed clearing contingencies, provided the Gardner Park 345kV substation bus configuration corresponds to what has been proposed for G523 North site option (see Figure 1b). With the proposed bus configuration for G523 South site option (Figure 1a), the computed Critical Clearing Time (CCT) has less than one cycle margin to the Maximum Expected Clearing Time (MECT) for two of the delayed clearing cases studied, thus not meeting the angular stability performance criteria in Section E.5 of Appendix 5.

Therefore, from an angular stability performance standpoint, the bus configuration for Gardner Park 345kV substation shown in Figure 1b is a requirement for the G523 interconnection.

3.2.2 Results of Prior Outage Primary Fault Contingencies

The prior outage contingencies evaluated and the study results are summarized in Table C.2 in Appendix C. The results obtained for these contingencies are not affected by the bus configuration assumed for Gardner Park substation (South or North site option).

The study identified no unacceptable stability performance after the addition of G523 for all the studied prior outage primary clearing contingencies, with one exception. For prior outage of the Gardner Park – Central Wisconsin 345kV Line, the computed CCT for clearing a fault on the Gardner Park – Rocky Run 345kV Line is 4.0 cycles, which is a 0.5 cycle margin to the MECT. This reduced stability margin occurs for the scenario when G523 is dispatched at full 550MW output with the prior outage. However, the operation restrictions identified in Table B.1 will preempt this operating scenario from occurring due to thermal limitations. As shown in Table B.1, the G523 output may have to be limited to 15 MW if the Gardner Park – Central Wisconsin 345kV Line is outaged. At this reduced output, the CCT increases to meet the one cycle stability margin criteria.

3.2.3 Results of Bus Section Fault and/or Internal Breaker Fault Contingencies

Two bus section fault/internal breaker fault contingencies were evaluated for Single-Line to Ground (SLG) fault at Weston 115kV substation East and West buses. The results are appended to the bottom of Table C.1 in Appendix C. The study identified no unacceptable stability performance for these types of faults.

3.3 Short-Circuit & Breaker Duty Analysis Results

Table D.1 and D.2 in Appendix D provide the maximum short-circuit duty seen at the Point of Interconnection (POI) and the corresponding Thevenin equivalent impedances for before and after G523 is interconnected.

The breaker duty analysis identified four breakers in Rocky Run 115kV station and one breaker in Sherman St. 115kV station that will exceed their interruption duty with the addition of G523. As shown in the results in Table D.3 in Appendix D, all five overdutied breakers were identified as pre-existing problems and do not need upgrading due to the addition of G523. While G523 does increase the margin by which the existing duty rating is exceeded for these breakers, their new duty rating requirement determined before the addition of G523 is not required to be altered with the addition of G523.

Appendix A

Power Flow Analysis Results

Table A.1 – Identified Thermal Violations due to G523 Delivery to MISO for N-1 Contingencies

Limiting Element	Existing MVA Rating	Required MVA Rating^	Worst Contingency*	TDF (%)	Case Description	Injection Limit	Solution Planned for Limiting Element
		^includes provision for 5% TRM *there are many other contingencies that result in thermal overloads on each limiting element --- only the contingency that produces the worst overload is listed here					
Gardner Park – Kelly 115kV Line F-110	239	264.2	System Intact	4.6	Summer 2011-1[1]	No	Yes[4]
Gardner Park – Kelly 115kV Line F-110	336	362.3	Gardner Park – Rocky Run 345kV Line V-308	12.0	Summer 2011-1	No	Yes[4]
Kelly – Whitcomb 115kV Line J-36	121	132.5	System Intact	5.1	Summer 2011-1	No	Yes[4]
Kelly – Whitcomb 115kV Line J-36	165	228.0	Gardner Park – Rocky Run 345kV Line V-308	13.0	Summer 2011-1	No	Yes[4]
Whitcomb – Caroline 115kV Line J-36	120	168.6	Gardner Park – Rocky Run 345kV Line V-308	10.8	Summer 2011-1	No	Yes[4]
Caroline – Belle Plaine 115kV Line J-36	119	176.3	Gardner Park – Rocky Run 345kV Line V-308	12.1	Summer 2011-1	No	Yes[4]
Belle Plaine – Badger 115kV Line J-36	119	169.6	Gardner Park – Rocky Run 345kV Line V-308	12.1	Summer 2011-1	No	Yes[4]
Badger 115/138kV Traf.	147	169.7	Gardner Park – Rocky Run 345kV Line V-308	12.1	Summer 2011-1	No	Yes[4]
Sunnyvale – Sherman St. 115kV Line W-127	239	267.9	Gardner Park – Rocky Run 345kV Line V-308	16.4	Summer 2011-1	No	Yes[4]
Weston – Northpoint 115kV Line T-20	277	387.2	Gardner Park – Rocky Run 345kV Line V-308	26.1	Summer 2011-1	Yes	Yes[4]
Rocky Run – Northpoint 115kV Line T-20	244	357.0	Gardner Park – Rocky Run 345kV Line V-308	26.1	Summer 2011-1	Yes	Yes[4]
Gardner Park 345/115kV Traf. #1 and #2	500	521.1	Gardner Park – Rocky Run 345kV Line V-308	29.2	Summer 2011-1	Yes	Yes[4]
Stone Lake 345/161kV Traf.	300	306.3	Gardner Park – Rocky Run 345kV Line V-308	16.6	Summer 2011-1	No	Yes[4]
Hoover – Whiting Ave 115kV Line H-138	205	247.1	Rocky Run – Werner West 345kV Line L6831	11.9	Summer 2011-1	No	Yes[4]
Werner – Werner West 138kV Future Line	287	303.1	N. Appleton – Werner West 345kV Line L6831	24.5	Summer 2011-1	Yes	Yes[4]
Gardner Park – Rocky Run 345kV Line V-308	717	853	System Intact	64.2	Summer 2011-1	Yes	Yes[4]
Gardner Park – Rocky Run 345kV Line V-308	717	891	Gardner Park – Cntrl Wisc 345kV Future Line	64.5	Summer 2011-2[2]	Yes	Yes[5]
Plains 345/138kV Traf.	250	250	Morgan 345/138kV Traf.	3.0	Summer 2011-2	No	Yes[6]
Rocky Run – Plover 115kV Line S45	239	263[3]	Rocky Run – Whiting Ave. 115kV Line M91	4.3	Summer 2011-2	No	No[7]
Rocky Run – Whiting Ave. 115kV Line M91	277	290[3]	Rocky Run – Plover 115kV Line S45	4.8	Summer 2011-2	No	No[8]
Bain – Kenosha 138kV Line 63151	287	417[3]	Pleasant Prairie – Zion 345kV Line 2221	6.1	Summer 2011-2	No	No[9]
Washco – Stone Lake 161kV Line (DPC)	120	157[3]	Forbes – Chisholm 500kV Line (NSP)	3.8	Summer 2011-2	No	No[10]

Morgan – Falls 138kV Line 35351	380	398	Morgan – Plains 345kV Line	6.2	Shoulder 2011-2	No	Yes[11]
Falls – Pioneer 138kV Line 75541	382	391	Morgan – Plains 345kV Line	6.2	Shoulder 2011-2	No	Yes[11]
Morgan – Falls 138kV Line 35351	380	427	Morgan – Plains 345kV Line	6.2	Winter 2010/11-2	No	Yes[11]
Falls – Pioneer 138kV Line 75541	382	421	Morgan – Plains 345kV Line	6.2	Winter 2010/11-2	No	Yes[11]

Notes:

1. Summer 2011-1, Shoulder 2011-1, and Winter 2010/11-1 represent the expected summer peak of 2011, expected shoulder peak of 2011 and expected winter peak of 2010-2011, respectively. All three models include planned projects through 2008 and proposed projects through 2007.
2. Summer 2011-2 is obtained by augmenting the Summer 2011-1 model with the following three Planned projects having an expected in-service date prior to Summer 2009: (1) Clintonville – Werner West 138kV line, (2) Morgan – Central Wisconsin – Werner West 345kV line, (3) Gardner Park – Central Wisconsin 345kV line.
3. Required MVA rating is obtained using the thermal overload in Summer 2011-2 model. However, this contingent thermal overload occurs in both Summer 2011-1 and Summer 2011-2 models.
4. This limit is resolved after the three Planned projects Clintonville – Werner West 138kV line, Morgan – Central Wisconsin – Werner West 345kV line, and Gardner Park – Central Wisconsin 345kV line are included in the summer peak model. That is, the limit does not appear in the Summer 2011-2 model.
5. Thermal overload of Gardner Park – Rocky Run 345kV line V-308 for the outage of Gardner Park – Central Wisconsin 345kV future line is resolved by the planned Y2006 ATC project (no. F1340) to upgrade relays at the Rocky Run 345kV substation to match the relays at Gardner Park end. Removing the existing limiter will increase the facility rating to 1600A or 956 MVA, corresponding to the existing second limiting factor.
6. Plains 345/138kV transformer is reported only because its contingent loading is at 100% SN/SE/WE rating after providing for 5% TRM margin.
7. Thermal overload of the Rocky Run – Plover 115kV line for the outage of the Rocky Run – Whiting Ave. 115kV line can be resolved by two facility upgrades: (1) replacement of jumpers at Plover 115kV substation; and (2) increasing the line conductor clearance to achieve a summer emergency operating temperature limit of 300º F. The higher facility SE rating will be 268 MVA, which equals the SE rating of the second limiting factor (terminal equipment at each end). The feasibility of increasing the conductor clearance has not been evaluated. A reconductor or rebuild of this line may be required.
8. Thermal overload of the Rocky Run – Whiting Ave. 115kV line for the outage of the Rocky Run – Plover 115kV line can be resolved by changing the jumper conductors in Whiting Ave. substation. The higher facility SE rating will be 328 MVA, which equals the SE rating of the second limiting factor (line conductor SE rating).
9. Thermal overload of the Bain – Kenosha 138kV line for the outage of the Pleasant Prairie – Zion 345kV line can be resolved by replacement of terminal equipment at the Kenosha 138kV substation. However, this solution is not a planned or proposed ATC project.
10. DPC plans to uprate the Washco – Stone Lake 161kV Line to 240 MVA (corresponding to summer normal operating temperature of 212º F) by Spring 2007.
11. It is expected that the summer, shoulder and winter emergency ratings for these facilities will increase to SE=403MVA, S/FE=432MVA and WE=461MVA as a result of the Morgan– Falls– Pioneer– Stiles line rebuild to double-circuit line (project completed), and associated upgrade of terminal equipment at Morgan, Falls and Pioneer substations to 2000A rating (project underway).The new S/FE and WE ratings will likely be limited by the 795mcm, 26/7 Drake conductor rating on Morgan – Structure501 line-span, as well as the ratings calculated for the new jumper conductors at Falls and Pioneer substations.

Table A.2 – Maximum Allowable Generation[1] Before and After Planned System Upgrades

Limiting Element	G523 Maximum MW	Worst Contingency	Worst Season/Model Description
Gardner Park – Kelly 115kV Line F-110	0[2,3]	System Intact	Summer 2011-1
	550		Summer 2011-2[4]
Gardner Park – Rocky Run 345kV Line V-308	330.3[2,3]	System Intact	Summer 2011-1
	550		Summer 2011-2[4]
Gardner Park 345/115kV Traf. #1 and #2	440.4[2,3]	Gardner Park – Rocky Run 345kV Line V-308	Summer 2011-1
	550		Summer 2011-2[4]
Gardner Park – Rocky Run 345kV Line V-308	271.4	Gardner Park – Cntrl. Wisc. 345kV Future Line	Summer 2011-2[4]
Gardner Park – Rocky Run 345kV Line V-308	440.2	Gardner Park – Cntrl. Wisc. 345kV Future Line	Shoulder 2011-2[4]
Gardner Park – Rocky Run 345kV Line V-308	376.2	Gardner Park – Cntrl. Wisc. 345kV Future Line	Winter 2010/11-2[4]

Notes:

1. Based on thermal (linear transfer) analysis only, no angular stability limitations were discovered.
2. No restrictions on G523 output in Shoulder 2011-1 and Winter 2011-1 models.
3. After planned system upgrades (see note 4), the maximum allowable generation is no longer constrained to less than full output due to this limiting element-contingency pair.
4. Seasonal model obtained after including the following three Planned projects with an expected in-service date prior to Summer 2009: (1) Clintonville – Werner West 138kV line, (2) Morgan – Central Wisconsin – Werner West 345kV line, (3) Gardner Park – Central Wisconsin 345kV line.

Table A.3 – Identified Thermal Violations due to G523 under N-2 Contingencies[1,5]

Limiting Element	Existing MVA Rating	Worst MW Loading	Worst Double Contingency	TDF (%)	Solution Planned for Limiting Element
Ellington – Casaloma 138kV Line 80331	216	248.5	N. Appleton – Apple Hills 138kV Line 6862 N. Appleton – Butte Des Mortes 138kV Line 6853	4.0	No
Weston – Northpoint 115kV Line T-20	277	379.4	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	25.9	No
Rocky Run – Northpoint 115kV Line T-20	244	345.1	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	25.9	No
Gardner Park – Kelly 115kV Line F-110	336	333.4	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	12.4	No
Kelly – Whitcomb 115kV Line J-36	165	207.4	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	13.5	No
Whitcomb – Caroline 115kV Line J-36	120	148.6	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	11.3	No
Caroline – Belle Plaine 115kV Line J-36	119	149.1	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	12.7	No
Belle Plaine – Badger 115kV Line J-36	119	142.9	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	12.7	No
Sunnyvale – Sherman St. 115kV Line W-127	239	254.6	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	16.3	No
Sunnyvale – Cassel 115kV Line S-71	244	237.7	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	16.3	No
Stone Lake 345/161kV Traf.	300	294.5	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	16.6	No
Washco – Stone Lake 161kV Line (DPC)	120	134.6	Gardner Park – Rocky Run 345kV Line V-308 Gardner Park – Cntrl Wisc 345kV Future Line	9.8	Yes[2]
Gardner Park – Rocky Run 345kV Line V-308	717	909.6	Arpin – Rocky Run 345kV Line Gardner Park – Cntrl Wisc 345kV Future Line	56.8	No
Hoover – Whiting Ave 115kV Line H-138	205	246.9	Rocky Run – Werner West 345kV Line L6831 Gardner Park – Cntrl Wisc 345kV Future Line	11.7	No

Limiting Element	Existing MVA Rating	Worst MW Loading	Worst Double Contingency	TDF (%)	Solution Planned for Limiting Element
Rocky Run – Whiting Ave. 115kV Line M91	277	316.6	Rocky Run – Werner West 345kV Line L6831 Gardner Park – Cntrl Wisc 345kV Future Line	10.4	No
Port Edward – Sand Lake 138kV Line X-11	155	157.5	Rocky Run – Werner West 345kV Line L6831 Gardner Park – Cntrl Wisc 345kV Future Line	10.6	No
Arpin – Sigel 138kV Line X-33		277.5	Rocky Run – Werner West 345kV Line L6831 Gardner Park – Cntrl Wisc 345kV Future Line	7.2	No
Werner West 345/138kV Traf.	500	513.0	Werner West – N. Appleton 345kV Line L6831 Morgan – Cntrl Wisc 345kV Future Line	28.7	No
Butte Des Mortes 138kV Bus Tie 1-2	287	280.7	Werner West 345/138kV Traf. N. Appleton – Fitzgerald 345kV Line Y311	4.6	No
Plains 345/138kV Traf.	250	251.8	Morgan 345/138kV Traf. Morgan – White Clay 138kV Line 26522	3.1	Yes[3]
Morgan – Falls 138kV Line 35351	380	377.1	Morgan – Plains 345kV Line 35321 Kewaunee 345/138kV Traf.	6.2	Yes[4]
Falls – Pioneer 138kV Line 75541	382	369.2	Morgan – Plains 345kV Line 35321 Kewaunee 345/138kV Traf.	6.2	Yes
Badger 115/138kV Traf.	147	142.9	Morgan – Plains 345kV Line 35321 N.Appleton – Mason St 138kV Line K-37	12.7	No

Notes:

1. N-2 linear transfer analysis performed using the Summer 2011-2 model that includes the following three planned projects having an expected in-service date of Summer 2009: (1) Clintonville – Werner West 138kV line, (2) Morgan – Central Wisconsin – Werner West 345kV line, (3) Gardner Park – Central Wisconsin 345kV line.
2. DPC plans to uprate the Washco – Stone Lake 161kV Line to 240 MW (corresponding to summer emergency operating temperature of 212º F) by Summer 2007.
3. ATC has a proposed project to install a second 345/138kV transformer bank at Plains.
4. It is expected that the emergency ratings for this facility will increase to SE=403MVA, S/FE=432MVA and WE=461MVA as a result of the Morgan– Falls– Pioneer– Stiles line rebuild to double-circuit line (project completed), and associated upgrade of terminal equipment at Morgan, Falls and Pioneer substations to 2000A rating (project underway). The new SE rating for Morgan-Falls line will likely be limited by the 795mcm, 26/7 Drake conductor rating on Morgan – Structure501 line-span.
5. Solutions to the N-2 limitations are not addressed unless specifically requested by the customer.

Appendix B

Summary of Operation Restrictions

Table B.1 – Summary of Identified Operating Restrictions on G523 due to Thermal Constraints[1,2]

Prior outage	Allowable MW Output	Worst Next Contingency	Most Limiting Element	MVA Rating	TDF %
N. Appleton – Apple Hills 138kV Line 6862	0	N. Appleton – Butte Des Mortes 138kV Line 6853	Ellington – Casaloma 138kV Line 80331	216	4.0
N. Appleton – Butte Des Mortes 138kV Line 6853	0	N. Appleton – Apple Hills 138kV Line 6862	Ellington – Casaloma 138kV Line 80331	216	4.0
Rocky Run – Werner West 345kV Line L6831	15.1	Gardner Park – Cntrl Wisc 345kV Future Line	Rocky Run – Whiting Ave. 115kV Line M91	277	10.4
Gardner Park – Cntrl Wisc 345kV Future Line	15.1	Rocky Run – Werner West 345kV Line L6831	Rocky Run – Whiting Ave. 115kV Line M91	277	10.4
Morgan 345/138kV Traf.	47.3	Morgan – White Clay 138kV Line 26522	Plains 345/138kV Traf.	250	3.1
Morgan – White Clay 138kV Line 26522	47.3	Morgan 345/138kV Traf.	Plains 345/138kV Traf.	250	3.1
Gardner Park – Rocky Run 345kV Line V-308	101.4	Gardner Park – Cntrl Wisc 345kV Future Line	Weston – Northpoint 115kV Line T-20	277	25.9
Arpin – Rocky Run 345kV Line	145.3	Gardner Park – Cntrl Wisc 345kV Future Line	Gardner Park – Rocky Run 345kV Line V-308	717	56.8
Morgan – Plains 345kV Line 35321	287.5	Kewaunee 345/138kV Traf.	Morgan – Falls 138kV Line 35351	380	6.2
Kewaunee 345/138kV Traf	287.5	Morgan – Plains 345kV Line 35321	Morgan – Falls 138kV Line 35351	380	6.2
Werner West – N. Appleton 345kV Line L6831	411.4	Morgan – Cntrl Wisc 345kV Future Line	Werner West 345/138kV Traf.	500	28.7
Morgan – Cntrl Wisc 345kV Future Line	411.4	Werner West – N. Appleton 345kV Line L6831	Werner West 345/138kV Traf.	500	28.7

Notes:

1. N-2 contingencies were analyzed by linear transfer analysis for the Summer 2011-2 model only.
2. No additional operating restrictions were identified based on angular stability analysis.

Appendix C

Angular Stability Analysis Results

Table C.1 Angular Stability Simulation Results for Breaker Failure Cases

Case Name (# denotes the primary and delayed clearing time)	**Faulted Element**	**Fault Location (Local / Remote)**	**Failed Circuit Breaker (CB)**	**Additional Element(s) Tripped to Clear Fault**	**Circuit Breaker Type**	**Acceptable Breaker Clearing Time (BCT) in cycles**	**Angular Stability at acceptable BCT**	**Critical Clearing Time (CCT)**
Gardner Park 345kV Switchyard – South site bus configuration								
BF_GDP-CWIS_#_S	Gardner Park – Central Wisconsin Line	Gardner Park end	Middle CB (1.5 CB bay)	Weston 4 GSU Tie	IPO	4.5/9.5	Stable	≥5.5/10.5
BF_GDP-STL_#_S	Gardner Park – Stone Lake Line	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #1	IPO	4.5/9.5	Stable	
BF_GDP-RRN_#_S	Gardner Park – Rocky Run Line (V-308)	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #2	IPO	4.5/9.5	Unstable at 3.5/9.5	4.0/9.0
BF_GDP-XG4_#_S	Weston 4 GSU Tie	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Central Wisconsin Line	IPO	4.5/9.5	Stable	≥5.5/10.5
BF_GDP-X1_#_S	Gardner Park 345/115kV Transformer #1	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Stone Lake Line	IPO	4.5/9.5	Stable	
BF_GDP-X2_#_S	Gardner Park 345/115kV Transformer #2	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Rocky Run Line (V-308)	IPO	4.5/9.5	Unstable	3.5/9.5
	Weston 5 GSU Tie	Gardner Park end	Middle CB (1.5 CB bay)	None(no other element terminated in this bay)	IPO	4.5/9.5	Trivial BF case -- not simulated	
Gardner Park 345kV Switchyard – North site bus configuration								
BF_GDPf-STL_#_N	Gardner Park – Stone Lake Line	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #2	IPO	4.5/9.5	Stable	
BF_GDP-STLf_#_N	Gardner Park – Stone Lake Line	Stone Lake end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #2	IPO	7.5/11.0	Stable	≥7.5/11.0
BF_GDPf-RRN_#_N	Gardner Park – Rocky Run Line (V-308)	Gardner Park end	Middle CB (1.5 CB bay)	Weston 4 GSU Tie	IPO	4.5/9.5	Stable	≥5.5/10.5
BF_GDP-RRNf_#_N	Gardner Park – Rocky Run Line (V-308)	Rocky Run end	Middle CB (1.5 CB bay)	Weston 4 GSU Tie	IPO	7.5/11.0	Stable	≥7.5/11.0
BF_GDP-X1_#_N	Gardner Park 345/115kV Transformer #1	Traf. High side 345kV	Middle CB (1.5 CB bay)	Weston 5 GSU Tie	IPO	4.5/9.5	Stable	≥5.5/10.5
BF_GDP-X2_#_N	Gardner Park 345/115kV Transformer #2	Traf. High side 345kV	Middle CB (1.5 CB bay)	Gardner Park – Stone Lake Line	IPO	4.5/9.5	Stable	
BF_GDP-XG4_#_N	Weston 4 GSU Tie	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Rocky Run Line (V-308)	IPO	4.5/9.5	Stable	≥5.5/10.5
BF_GDP-XG5_#_N	Weston 5 GSU Tie	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #1	IPO	4.5/9.5	Stable	≥5.5/10.5
	Gardner Park – Central Wisconsin Line	Gardner Park end	Middle CB (1.5 CB bay)	None(no other element terminated in this bay)	IPO	4.5/9.5		
Gardner Park 115kV Switchyard – South site bus configuration								
BF_GDP-HLTP_#_N	Gardner Park – Hilltop Line	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #1	3-pole Operation	4.5/9.5	Stable	< 5.5/10.5

Case Name (# denotes the primary and delayed clearing time)	Faulted Element	Fault Location (Local / Remote)	Failed Circuit Breaker (CB)	Additional Element(s) Tripped to Clear Fault	Circuit Breaker Type	Acceptable Breaker Clearing Time (BCT) in cycles	Angular Stability at acceptable BCT	Critical Clearing Time (CCT)
BF_GDP-KLY_#_N	Gardner Park – Kelly Line (F-110)	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Weston Tie #1 (UGDP-61)	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_GDP-X1L_#_N	Gardner Park 345/115kV Transformer #1	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Hilltop Line	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_GDP-WES1_#_N	Gardner Park – Weston Tie #1 (UGDP-61)	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Kelly Line (F-110)	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_GDP-BBK_#_S	Gardner Park – Blackbrook Line (A-313)	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #2	3-pole Operation	4.5/9.5	Stable	< 5.5/10.5
BF_GDP-X2L_#_S	Gardner Park 345/115kV Transformer #2	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Blackbrook Line (A-313)	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
	Gardner Park – Weston Tie #2 (UGDP-71)	Gardner Park end	Middle CB (1.5 CB bay)	None(no other element terminated in this bay)	3-pole Operation	4.5/9.5		
Gardner Park 115kV Switchyard – North site bus configuration								
BF_GDP-BBK_#_N	Gardner Park – Blackbrook Line (A-313)	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #1	3-pole Operation	4.5/9.5	Stable	< 5.5/10.5
BF_GDP-HLTP_#_N	Gardner Park – Hilltop Line	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Weston Tie #1 (UGDP-61)	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_GDP-KLY_#_N	Gardner Park – Kelly Line (F-110)	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park 345/115kV Transformer #2	3-pole Operation	4.5/9.5	Stable	< 5.5/10.5
BF_GDP-X1L_#_N	Gardner Park 345/115kV Transformer #1	Traf. Low side 115kV	Middle CB (1.5 CB bay)	Gardner Park – Blackbrook Line (A-313)	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_GDP-WES1_#_N	Gardner Park – Weston Tie #1 (UGDP-61)	Gardner Park end	Middle CB (1.5 CB bay)	Gardner Park – Hilltop Line	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_GDP-X2L_#_N	Gardner Park 345/115kV Transformer #2	Traf. Low side 115kV	Middle CB (1.5 CB bay)	Gardner Park – Kelly Line (F-110)	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
	Gardner Park – Weston Tie #2 (UGDP-71)	Gardner Park end	Middle CB (1.5 CB bay)	None(no other element terminated in this bay)	3-pole Operation	4.5/9.5		
Weston 115kV Switchyard(bus configuration same for both South & North sites)								
BF_WES-GDP_#_West	Weston – Gardner Park Tie (#1 or #2)	Weston end	CB to West Bus	Z-52 (to Morrison Ave) and G32 GSU	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_WES-GDP_#_East	Weston – Gardner Park Tie (#1 or #2)	Weston end	CB to East Bus	O-41 (to Sherman St.), T-20 (to Rocky Run) and 115/46 kV Traf.	3-pole Operation	4.5/9.5	Stable	< 5.5/10.5
BF_WESf-SHMN_#	Weston – Sherman St. Line (O-41)	Weston end	CB for O-41	T-20 (to Rocky Run) and 115/46 kV Traf.	3-pole Operation	4.5/9.5	Stable	< 5.5/10.5
BF_WES-SHMNf_#	Weston – Sherman St. Line (O-41)	Sherman St end	CB for O-41	T-20 (to Rocky Run) and 115/46 kV Traf.	3-pole Operation	6.0/23.5	Stable	≥ 6.0/23.5
BF_WESf-RRN_#	Weston – Rocky Run Line (T-20)	Weston end	CB for T-20	O-41 (to Sherman St.) and 115/46 kV Traf.	3-pole Operation	4.5/9.5	Stable	< 5.5/10.5

Case Name (# denotes the primary and delayed clearing time)	**Faulted Element**	**Fault Location (Local / Remote)**	**Failed Circuit Breaker (CB)**	**Additional Element(s) Tripped to Clear Fault**	**Circuit Breaker Type**	**Acceptable Breaker Clearing Time (BCT) in cycles**	**Angular Stability at acceptable BCT**	**Critical Clearing Time (CCT)**
BF_WES-RRNf_#	Weston – Rocky Run Line (T-20)	Rocky Run end	CB for T-20	O-41 (to Sherman St.) and 115/46 kV Traf.	3-pole Operation	6.0/23.5	Stable	≥ 6.0/23.5
BF_WESf-MRSN_#	Weston – Morrison Ave. Line (Z-52)	Weston end	CB for Z-52	G32 GSU	3-pole Operation	4.5/9.5	Stable	≥ 5.5/10.5
BF_WES-MRSNf_#	Weston – Morrison Ave. Line (Z-52)	Morrison Ave. end	CB for Z-52	G32 GSU	3-pole Operation	6.0/23.5	Stable	≥ 6.0/23.5
	Weston East Bus	SLG fault at Weston bus	GP Tie CB to East Bus	GP Tie, O-41 (to Sherman St.), T-20 (to Rocky Run) and 115/46 kV Traf.	3-pole Operation	4.5/9.75	Stable	
	Weston West Bus	SLG fault at Weston bus	GP Tie CB to West Bus	GP Tie,G32 GSU andZ-52 (to Morrison Ave)	3-pole Operation	4.5/9.75	Stable	

Table C.2 Angular Stability Simulation Results for Prior Outage Cases

Case Name (# denotes the primary clearing time)	**Prior Outage Element**	**Faulted Element**	**Acceptable Breaker Clearing Time (BCT) in cycles**	**Angular Stability at acceptable BCT**	**Critical Clearing Time (CCT)**
Gardner Park 345kV Switchyard – South or North site bus configuration					
GDP-CWISout-RRNtrip_#	Gardner Park – Central Wisconsin Line	Gardner Park – Rocky Run Line (V-308)	4.5	Unstable	**4.0**
GDP-CWISout-STLtrip_#	Gardner Park – Central Wisconsin Line	Gardner Park – Stone Lake Line	4.5	Stable	≥ 7.5
GDP-CWISout-XFMRtrip_#	Gardner Park – Central Wisconsin Line	Gardner Park 345/115kV Transformer (#1 or #2)	4.5	Stable	≥ 8.5
GDP-RRNout-CWIStrip_#	Gardner Park – Rocky Run Line (V-308)	Gardner Park – Central Wisconsin Line	4.5	Stable	**4.5**
GDP-RRNout-STLtrip_#	Gardner Park – Rocky Run Line (V-308)	Gardner Park – Stone Lake Line	4.5	Stable	≥ 6.5
GDP-RRNout-XFMRtrip_#	Gardner Park – Rocky Run Line (V-308)	Gardner Park 345/115kV Transformer (#1 or #2)	4.5	Stable	≥ 8.5
GDP-STLout-CWIStrip_#	Gardner Park – Stone Lake Line	Gardner Park – Central Wisconsin Line	4.5	Stable	≥ 7.5
GDP-STLout-RRNtrip_#	Gardner Park – Stone Lake Line	Gardner Park – Rocky Run Line (V-308)	4.5	Stable	≥ 7.5
GDP-STLout-XFMRtrip_#	Gardner Park – Stone Lake Line	Gardner Park 345/115kV Transformer (#1 or #2)	4.5	Stable	≥ 8.5
GDP-XFMRout-CWIStrip_#	Gardner Park 345/115kV Transformer (#1 or #2)	Gardner Park – Central Wisconsin Line	4.5	Stable	≥ 7.5
GDP-XFMRout-RRNtrip_#	Gardner Park 345/115kV Transformer (#1 or #2)	Gardner Park – Rocky Run Line (V-308)	4.5	Stable	≥ 7.5
GDP-XFMRout-STLtrip_#	Gardner Park 345/115kV Transformer (#1 or #2)	Gardner Park – Stone Lake Line	4.5	Stable	≥ 7.5
GDP-XFMRout-XHItrip_#	Gardner Park 345/115kV Transformer (#1 or #2)	Other Gardner Park 345/115kV Transformer (#2 or #1)	4.5	Stable	≥ 7.5
RRN-WWout-CWIStrip_#	Rocky Run – Werner West Line	Gardner Park – Central Wisconsin Line	4.5	Stable	≥ 5.5
RRN-WWout-RRNtrip_#	Rocky Run – Werner West Line	Gardner Park – Rocky Run Line (V-308)	4.5	Stable	≥ 5.5
CWIS-MGNout-RRNtrip_#	Central Wisconsin – Morgan Line	Gardner Park – Rocky Run Line (V-308)	4.5	Stable	≥ 5.5

Case Name (# denotes the primary clearing time)	**Prior Outage Element**	**Faulted Element**	**Acceptable Breaker Clearing Time (BCT) in cycles**	**Angular Stability at acceptable BCT**	**Critical Clearing Time (CCT)**
Gardner Park 115kV Switchyard					
GDP-RRNout-XFMRtrip_#	Gardner Park – Rocky Run 345kV Line (V-308)	Gardner Park 345/115kV Transformer #1	4.5	Stable	≥ 6.5
GDP-RRNout-KLYtrip_#	Gardner Park – Rocky Run 345kV Line (V-308)	Gardner Park – Kelly Line (F-110)	4.5	Stable	≥ 6.5
GDP-RRNout-HLTPtrip_#	Gardner Park – Rocky Run 345kV Line (V-308)	Gardner Park – Hilltop Line	4.5	Stable	≥ 6.5
GDP-RRNout-BBKtrip_#	Gardner Park – Rocky Run 345kV Line (V-308)	Gardner Park – Blackbrook Line (A-313)	4.5	Stable	≥ 6.5
GDP-XFMRout-XLOtrip_#	Gardner Park 345/115kV Transformer (#1 or #2)	Other Gardner Park 345/115kV Transformer (#2 or #1)	4.5	Stable	≥ 7.5
Weston 115kV Switchyard					
GDP-RRNout-T20trip_#	Gardner Park – Rocky Run 345kV Line (V-308)	Weston – Rocky Run 115kV Line (T-20)	4.5	Stable	≥ 6.5
WES-RRNout-SHMNtrip_#	Weston – Rocky Run 115kV Line (T-20)	Weston – Sherman St. Line (O-41)	4.5	Stable	≥ 6.5
WES-RRNout-MRSNtrip_#	Weston – Rocky Run 115kV Line (T-20)	Weston – Morrison Ave. Line (Z-52)	4.5	Stable	≥ 6.5
WES-GDP1out-GDPTie2trip_#	Weston – Gardner Park Tie #2 (UGDP-71)	Weston – Gardner Park Tie #1 (UGDP-61)	4.5	Stable	≥ 6.5

Appendix D

Short Circuit / Breaker Duty Analysis Results

Table D.1 – Maximum Fault Duty at the G523 Point of Interconnection in Intact System

*Fault Duty **Before** G523*		*Fault Duty **After** G523*	
Single-phase	*Three-phase*	*Single-phase*	*Three-phase*
14.65 *kA*	13.78 *kA*	20.48 *kA*	16.69 *kA*

Table D.2 – Thevenin Equivalent Impedances in Ohms at the G523 Point of Interconnection in Intact System

	Pos Seq.	**Neg. Seq.**	**Zero Seq.**
Before	1.04982 + j14.4137	1.31982 + j14.4090	1.06035 + j11.8188
After	0.78959 + 11.9064	1.07856 + 11.9009	0.38483 + j5.28221

Table D.3 – Fault Duty Margins for Breakers Before and After G523 Interconnection

Station	**Breaker Name**	**Rating (kA)**	*Margin **Before** G523*		*Margin **After** G523*	
			Single-phase	***Three-phase***	***Single-phase***	***Three-phase***
Weston 115	B-0098---1151	**24**	– 17.0%	3.1%	– 20.6%	– 0.2%
Weston 115	B-0108---T-20	**24**	– 12.1%	7.8%	– 15.3%	4.9%
Weston 115	B-0105---166	**24**	– 7.2%	11.3%	– 10.0%	8.65%
Weston 115	B-0134---266	**24**	– 5.4%	12.2%	– 8.2%	9.6%
Shrmn St 115	B-0046---W-127	**16.7**	17.4%	– 4.1%	14.6%	– 9.4%

Appendix E

Study Criteria

Study Criteria

E.1 Contingencies

For stability analysis, a set of branches in the vicinity of the generator/power plant of concern is selected as contingencies, based on engineering judgment. Fault analysis is performed for the following six categories of contingency conditions:

1. Three-phase fault cleared in primary time with an otherwise intact system.
2. Three-phase fault cleared in delayed clearing time (i.e. breaker failure conditions) with an otherwise intact system.
3. Three-phase fault cleared in primary clearing time with a pre-existing outage of any other transmission element.
4. Single Line Ground (SLG) bus section fault cleared in primary clearing time with an otherwise intact system.
5. SLG internal breaker fault cleared in primary clearing time with an otherwise intact system.
6. SLG fault of double circuits on common tower cleared in primary time with an otherwise intact system.

For power flow analysis, contingencies include:

1. N-1 contingencies – all lines and transformers operated at 69kV and above in the following control areas/zones: ATC Planning Zones 1-5 and ties to those zones, and all branches of voltage level 69kV and above in the Dairyland Power Cooperative, Northern States Power Control Area, Commonwealth Edison, and Alliant West control areas.
2. Selected N-2 and multiple contingencies that ATC has determined to be significant.

E.2 Monitored Elements

E.2.1 Intact System, N-1, N-2, and Special Multiple Contingency Evaluation Using Linear Transfer Analysis Method

All load carrying elements operated at 69kV and above in the following control areas/zones were studied:ATC Planning Zones 1-5 and ties to those zones, and all branches of voltage level 69kV and above in the Dairyland Power Cooperative, Northern States Power Control Area, Commonwealth Edison, and Alliant West control areas.

A Transmission Reliability Margin (TRM) of 5% was applied to MVA ratings of all monitored elements. Thermal violations are reported based upon the TRM adjustment of MVA ratings.

E.3 Thermal Loading Criteria

E.3.1 Injection Violations

Generation injection violations include 1) thermal violations of the transmission elements that connect the Generator to the rest of the transmission network (outlet congestion); 2) thermal violations of the transmission elements that have TDF ≥ 20% anywhere in the studied system.

E.3.2 Operation Restriction Calculation

$$\text{Allowable Generation Output} = \frac{\text{Equipment Rating} - [\text{Line Flow} - (\text{Generation Output} * \text{TDF})]}{\text{TDF}}$$

E.4 Steady State Voltage Criteria

E.4.1 Intact System, N-1 and Special Multiple Contingency Evaluation Using ACCC

Under intact system conditions, the voltage magnitude of all transmission system buses with a decrease of 0.01 pu due to the Generator must not be lower than 0.95 pu. Under contingency conditions, the voltage magnitude of all transmission system buses with a decrease of 0.01 pu due to the Generator must not be lower than 0.90 pu.

E.4.2 N-2 Contingency Evaluation

Power flow solutions must converge for a selected number of N-2 contingencies in the electrical proximity of the studied Generator. Divergence of a power flow solution indicates potential voltage collapse.

E.5 Angular Stability Criteria

Critical Clearing Time (CCT) is a period relative to the start of a fault, within which all generators in the system remain stable (synchronized). CCT is obtained from simulation. Maximum Expected Clearing Time (MECT) determines a period of time that is needed to clear a fault using the existing system facilities. MECT is dictated by the existing system facilities. In any contingency, if the computed CCT is less than the MECT plus a margin determined by ATC (1.0 cycle in this study), it is considered an unstable situation and is unacceptable. Otherwise, it is considered acceptable stability performance.

In the context of angular stability analysis, voltages of all transmission system buses must recover to at least 70% of the nominal system voltage immediately after fault removal and 80% of the nominal system voltage within 0.5 second after fault removal.