WEST TEXAS WIND FARMS
TRANSIENT STABILITY LIMITS
AT MAXIMUM POWER TRANSFERS

Version 1.0

Document Revisions

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The Electric Reliability Council of Texas (ERCOT) System Planning Transmission Services staff prepared this document. It is a transient stability screening report of the ERCOT transmission system, identifying system instabilities in angular separation, large voltage deviations and large frequency deviation when the electric system is tested with severe contingencies. Transmission system planning is a continuous process. Conclusions reached in this report can change with the addition (or elimination) of plans for new generation, transmission facilities, equipment, or loads.

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AUTHORS

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GLOSSARY

CSC	Commercially Significant Constraint, CSC zones group buses into larger regional areas
DWG	Dynamics Working Group, under ERCOT ROS
LaaR	Load acting as Resource, load set to trip automatically trip for underfrequency conditions
NERC	North America Electric Reliability Council
PV	Power versus Voltage relationship
PSSE	Siemens PTI Engineering Simulation Tool v.30, to perform dynamics studies

1. EXECUTIVE SUMMARY

The maximum stability limit for power export from West Texas will vary depending on the specific unit commitment and generation dispatch. For the ten unit commitment scenarios studied, the limit ranged from 3700 MW to 3400 MW as measured by the sum of power flows through all of the ties out of the West CSC zone. The limit on the ERCOT Operations West-to-North 345 kV interface defined by summing the power flowing on six 345 kV transmission lines (from Mesquite to Graham, from Sweetwater to Graham, from Morgan Creek to Graham, measured as entering Graham for these three flows, from Bowman to Graham, from Bowman to Jacksboro SS, measured as leaving Bowman for these two flows and from Red Creek to Comanche, measured as entering Comanche SS) ranged from 2950 MW to 2450 MW. Replacing non-wind generation with wind generation did not appear to have a large impact on the West Texas export stability limit. However, as more non-wind generating units were turned off, the negative impact on West Texas export stability limits became more significant.

The maximum amount of load shed due to the activation of LaaR relays in response to any of the tested contingencies at the stability limit exceeded 100 MW for several scenarios. Stability limits that allowed no more than 30 MW of load shed were generally lower for a particular scenario and ranged from 3650 MW to 3150 MW on all West CSC zone ties or 2950 MW to 2450 MW on the ERCOT Operations interface. Higher penetrations of wind generation generally led to a greater amount of load shedding in response to the tested disturbances (and more restrictive export limits when attempting to limit load shedding). Consideration should be given to limiting the amount of load shed when establishing a stability limit.

For all scenarios studied, the limiting contingency for stability was MB229_b1430 –

– resulting in excessive angular separation. However, for some of the scenarios other contingencies were more critical in restricting the amount of load shed following the disturbance.

In every case studied, there were contingencies that initiated wind generation trips due to wind farm voltage and/or frequency protection relays. The amount of generation tripped was generally on the order of several hundred MW. Simulation results indicate that the transmission system may be subject to excessive voltage levels when wind farms trip off.

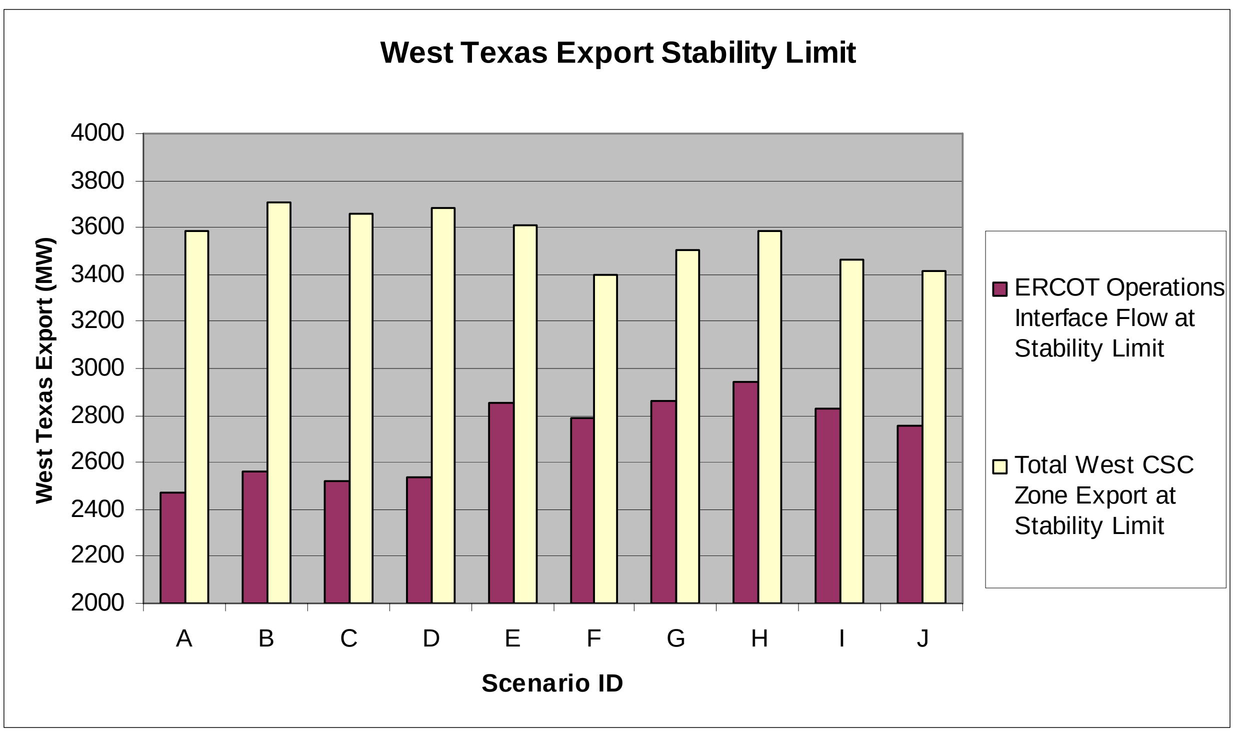
Stability limits have been reported in terms of net out flow from all West CSC zone ties and flow on the ERCOT Operations interface defined by the power flow in six 345 kV lines. An alternative interface described in Appendix II may be more appropriate for monitoring and enforcing stability limits related to West Texas exports. It is recommended that ERCOT Operations consider monitoring West-to-North transfers with this alternative interface instead of the 6-line interface currently being monitored.

Dynamic simulations were performed to assess transient stability response. A three-phase bus fault was simulated for 4 cycles (0.0667 seconds) on 345 kV buses and cleared by the removal of one or more elements followed by a dynamics simulation totaling 10 seconds. Faults at 138 kV buses were cleared after 5 cycles (0.08333 seconds). All study cases were derived from the 2006 Summer On-Peak ERCOT base case that was created by the ERCOT ROS' Dynamics Working Group for dynamic studies. A list of additional West Texas wind farms and associated transmission upgrades for 2007 were obtained from the ERCOT Regional Planning group and incorporated into the case in order to test higher levels of power export from West Texas.

Due to the nature of the study, a limit could not be found in a single run on a single case. The set of test disturbances was applied to base cases with increasing levels of export power from West Texas until an unstable result was achieved. Then, the maximum power transfer limit was found using an iterative approach until the difference in power transfer between a stable and unstable case was approximately 50 MW. Base cases with increasing levels of export power from West Texas were developed by reducing West Texas load, increasing West Texas wind generation (including adding expected future wind farms to the model) and decreasing remote generation (typically in the Houston or South CSC zones).

Summaries of the scenarios studied and stability limits based on both the overall West CSC zone export and the net flow on the ERCOT Operations 345 kV West-to-North interface flow are shown below. Note that limits based on the interface flow trend differently than limits based on overall West CSC zone export.

Scenario Description (Cumulative Scenario Modifications)	Total West CSC Zone Non-Wind Generation (MW)	Total West CSC Zone Wind Generation at Stability Limit (MW)	Total West CSC Zone Export at Stability Limit (MW)	ERCOT Operations Interface Flow at Stability Limit (MW)
A: Baseline case	3053	3279	3582	2469
B: +3 additional wind farm sites modeled online	3053	3411	3709	2565
C: +All Morgan Creek units off	2916	3490	3658	2519
D: +2 additional wind farm sites modeled online	2916	3521	3679	2541
E: +All Graham units at minimum MW output	2447	3968	3606	2850
F: +All Graham units off	2297	3896	3398	2791
G: +4 additional wind farm sites modeled online	2297	4008	3501	2864
H: +All TIE units minimum MW output	1833	4545	3583	2941
I: +One TIE combined cycle train off	1564	4674	3460	2833
J: +All TIE units off	1295	4887	3416	2754



2. INTRODUCTION

It is to the benefit of the ERCOT power system to know the power export limit from West Texas to the rest of ERCOT due to transient instability at high penetration levels of wind farm generation. This West Texas transient stability study includes wind farm dynamics and stress the ERCOT network for several wind power export levels, applying fault tests to uncover transient unstable conditions. This study builds upon results from previous studies.[1] Certain transmission upgrades and additional wind farms were added to the 2006 summer peak base case to simulate 2007 network conditions allowing higher levels of power export from West Texas.

2.1. Purpose

This study provides the maximum power export stability limit from the West Texas region to the rest of ERCOT for selected high levels of wind generation output. Wind farms were fully modeled for dynamic studies. The power exported from West Texas was increased until the network became unstable following selected fault tests.

2.2. Transient Stability Studies

Time domain dynamic simulation is a planning tool that allows analysis of the electric network response to major disturbances. Typical transient stability studies involve monitoring the dynamic response of the system following a disturbance in order to assess angular stability, voltage stability, frequency response and other transient or dynamic phenomena. These studies demand significantly more detailed system modeling data than steady-state power flow studies, typically take longer time to prepare and require more computer resources.

All network elements with a significant dynamic behavior during the disturbance under test are modeled with appropriate dynamic models to allow for pre-disturbance, on-disturbance and post-disturbance behavior response. Generators play an important role in maintaining the overall stability of the network since they help to sustain the power flow, the reactive power flow and the voltage profile; hence, their dynamic modeling and response to disturbance are extremely important. Load dynamics modeling will show the electric demand variations with voltage and frequency variations.

Voltage levels below 0.8 per unit could trigger the stalling of motor load leading to a fast voltage collapse scenario and may require additional study.

Frequency excursions below 59.7 for more than 20 cycles will activate the LaaR load shedding schemes. Frequency excursions below 59.3 for more than 20 cycles will activate the under-frequency load shedding schemes. The effects on the system when activated may require additional study.

In this study, dynamic models for wind farms in West Texas were utilized. For each dynamic run, a three-phase bus fault was simulated for 4 cycles (0.06667 seconds) at 345 kV buses or 5 cycles (0.0833 seconds) at 138 kV buses and cleared by the removal of one or more elements followed by a dynamics simulation totaling 10 seconds. Three criteria were used to assess the severity of the contingency test: angular separation, excessive bus voltage swing, and excessive bus frequency deviation. When the response of selected non-wind generating units does not comply with the transient stability criteria imposed in the study, the scenario is identified as unstable. Reliability criteria applicable in ERCOT are presented in Appendix V.

[1] See draft study reports: “WestTX_transferlimits_2006_report_v2.doc” dated September 2006 and “WestTX_WindFarms_transferlimits_2006_report_v3.doc” dated October 2006

3. STUDY DEVELOPMENT AND PROCESS

Transient stability simulations were performed on several dozen base cases derived from the 2006 Summer On-Peak ERCOT base case that was created for dynamic studies by the ERCOT ROS' Dynamics Working Group. Each base case represents a different power export scenario from West Texas to the rest of ERCOT. Accepted modeling and simulation techniques were used to conduct the study. The base cases prepared for the study include dynamic models for wind farms with updated voltage and frequency protection data from a 2006 ERCOT survey. A total of 56 disturbances were simulated for each base case so that the system response could be evaluated and a maximum power transfer level determined.

3.1. Base Case sets

The 2006 ERCOT summer peak case with dynamic wind farm models created by DWG for stability studies was customized further for this study. Transmission upgrades associated with West Texas wind farm development for 2007 were obtained from the ERCOT Regional Planning group and incorporated into the case. A list of additional wind farms for inclusion in the case was also provided. The export of power from West Texas was generally modeled by reducing load in the West CSC zone, increasing West Texas wind generation (including adding expected future wind farms to the model) and decreasing remote generation (typically in the Houston or South CSC zones). Ten unit commitment scenarios were analyzed. For each of these scenarios, a maximum power transfer level was determined by increasing wind output until simulations indicated an unstable system response. For each power transfer level studied, a base case was prepared and verified ready for dynamic simulation with a flat-start test. A summary of the analyzed scenarios is provided in the table below. A detailed listing of the West Texas generation dispatch for selected base cases is provided in Appendix III.

Scenario Description (Cumulative Scenario Modifications)	Total West CSC Zone Non-Wind Generation (MW)	Total West CSC Zone Load (MW)
A: Baseline case	3053	2329
B: +3 additional wind farm sites modeled online	3053	2329
C: +All Morgan Creek units off	2916	2329
D: +2 additional wind farm sites modeled online	2916	2329
E: +All Graham units at minimum MW output	2447	2329
F: +All Graham units off	2297	2329
G: +4 additional wind farm sites modeled online	2297	2329
H: +All TIE units minimum MW output	1833	2329
I: +One TIE combined cycle train off	1564	2329
J: +All TIE units off	1295	2329

3.2. Monitoring Elements

All machines in West Texas were monitored for deviations in machine angle, terminal voltage and power output. Two 345 kV buses, Graham and Moss, and two 138 kV buses, Rio Pecos and Permian Basin, were monitored for bus frequency and voltage deviations.

3.3. Load Models

Standard zip models, as used by the ERCOT's dynamics working group, were applied to the base cases.

3.4. Contingency sets

A selection process was used to determine the set of test disturbances utilized in dynamic simulation. An initial PV study for West Texas to North Texas power transfer identified those West Texas NERC category B and C contingencies that were most limiting due to voltage collapse or excessive low voltage conditions. A West Texas to North Texas power transfer transient stability study without wind farms identified those faults that were most limiting due to angular separation. The local utility stability expert recommended a few additional fault scenarios resulting in a final set of 56 test disturbances.

A PV study that modeled West Texas power transfers to the rest of ERCOT identified the most severe contingencies in each of the following sets:

NERC Category B Contingencies	
Single generator outage	Contingency set includes all West Texas Generators.
Single line outage	Contingency set includes all West Texas 345 kV & 138 kV lines.
NERC Category C Contingencies	
Single event multi-line outage	Contingency set includes the outage of multiple 345 kV and 138kV lines that are susceptible to a single failure (e.g. common supporting structures).
Single line and single generator	Selected single line (from the single line outage test) and a non-wind generator in West Texas
Single event multi-line and single generator	Selected single event multi-line (from the single event multi-line outage test) and a non-wind generator in West Texas

A transient stability study that modeled West Texas power transfers to the rest of ERCOT (without dynamic wind farm models) identified the most severe contingencies in each of the following sets:

NERC Category B Contingencies	
Single Line outage	Contingency set includes all West Texas 345 kV lines. A fault is applied at each end of the 345 kV line.
NERC Category C Contingencies	
Single Event Multi-Line outage	Contingency set includes the outage of multiple 345 kV and 138kV lines that are susceptible to a single failure (e.g. common supporting structures). A fault is applied at each 345 kV bus within the contingency definition.

A few more contingencies were added to the final set after consulting with the local utility stability expert (and DWG member) who is familiar with the West Texas maximum export issue. Event definitions for the test disturbances used in this study are listed in Appendix IV.

3.5. Study Limitations

This study is subject to the following issues that will limit its conclusions:

- Pre-existing conditions: Pre-existing conditions were not resolved prior to running this study. The base case may contain overloads, voltage violations and n-1 violations.
- Generation dispatch uncertainty: The base case is dispatched for minimum overloads on the ERCOT CSC interfaces, but there is no guarantee that such generation dispatch is the most severe to the region under study. Voltage collapse events may not be discovered when generation output are modeled with more reactive production and/or reserves than it would actually occur, resulting in not picking the corresponding contingency for the final stability runs.
- Load modeling uncertainty: Load types (large motor, small motor, discharge lamp and constant power) were assumed to be represented by standard ZIP models. Dynamic simulations did not include explicit dynamic models for motor load.
- Under-voltage violations: Depending on the composition in load types, low bus voltages could indicate the starting point for motor load stalling leading to fast voltage collapse.
- The effects of Special Protection Schemes (SPS) that take into account planned or controlled interruption of generators or transmission lines.
- The effects of protection relay (mis-) coordination resulting on cascading of uncontrolled successive loss of system elements triggered by the contingency under test.
- Breaker failure conditions of the relay protection system were not modeled.
- Load shedding, the planned removal from service of certain area loads (undervoltage and underfrequency load shedding schemes are not included in the model).
- Operational actions (curtailment of contracted firm power, etc.) as response to the disturbance event.

3.6. Study Process

The base cases with their corresponding dynamic data and 56 test disturbance definitions were processed as follows: run stability studies, one per disturbance, process the monitored data output and plot the parameters of interest, then visually assess if the base case remains stable after the disturbance.

For each test disturbance, a 3-phase (3φ) fault was applied lasting a period of four cycles (0.06667 seconds) at 345 kV buses or five cycles (0.08333 seconds) at 138 kV buses.

The fault was cleared by tripping (an) associated network element(s) connected to the bus:

Contingency	Fault cleared by
Single Line	Tripping single line. Fault is applied at each end of the line.
Single Event Multi-Line	Tripping all the lines that define the contingency. Fault is applied at each end of the lines.
Single Line and Generator	Tripping a single line together with a single non-wind generator in West Texas. Fault is applied at each end of the line.
Single Event Multi-Line and Generator	Tripping all the lines that define the contingency together with a single non-wind generator in West Texas. Fault is applied at each end of the lines.

The simulation continued without any other disturbance for a total of 10 seconds. Stability results were visually verified from plots of the monitored data. All machines in West Texas were monitored for deviations in machine angle, terminal voltage and power output. Two 345 kV buses, Graham and Moss, and two 138 kV buses, Rio Pecos and Permian Basin, were monitored for bus frequency and voltage deviations. The types of contingencies tested in this study are expected to result in angular separation, voltage drop or frequency deviations. However, it should be noted that contingencies that include a generator trip generally improve angle separation issues, but worsen voltage recovery issues.

4. STUDY RESULTS

The maximum power export from West Texas to the rest of ERCOT that does not cause angular and/or voltage instability under the studied test disturbances was found to be 3709 MW as measured by the sum of power flows through all of the ties out of the West CSC zone (Scenario B). Alternatively, the power flow on selected lines can be monitored to determine a limit on that interface to serve as a proxy for the total export. The ERCOT Operations West-to-North 345 kV interface is defined by summing the power flowing on six 345 kV transmission lines (from Mesquite to Graham, from Sweetwater to Graham, from Morgan Creek to Graham, measured as entering Graham for these three flows, from Bowman to Graham, from Bowman to Jacksboro SS, measured as leaving Bowman for these two flows and from Red Creek to Comanche, measured as entering Comanche SS). A summary of stability results including the total West Texas export limit and this interface limit for each scenario is reported in Table 1a. The maximum amount of load tripped due to the activation of LaaR relays in response to any of the tested contingencies at the transfer limit is also reported in Table 1a. Note that for several scenarios, the amount of load shed exceeds 100 MW. It may be desirable to limit the amount of load shed due to the activation of LaaR relays. This could be accomplished by reducing the West Texas export level. A summary of export limits for each scenario while not allowing more than 30 MW of load shedding due to the activation of LaaR relays in response to any of the tested contingencies is provided in Table 1b. These results are presented graphically in Figure 1a and Figure 1b.

Development of the study scenarios generally involved increasing wind generation while decreasing non-wind generation in West Texas. The study results indicate that stability limits were typically more restrictive when non-wind generation was replaced with wind generation, especially when non-wind units were completely offline. For example, when Morgan Creek units were turned off, non-wind generation was reduced by 137 MW but a stability limit was reached when wind output was increased by only 79 MW. Steps that involved modeling more wind farm sites while keeping non-wind generation in West Texas constant typically resulted in higher export limits. A summary of non-wind output reductions and wind output increases associated with each scenario transition is provided in Table 2a and Table 2b. These results are presented graphically in Figure 2a and Figure 2b by plotting wind power output versus non-wind power output at the stability limit for each scenario.

Replacing non-wind generation with wind generation does not appear to have a large impact on the West Texas export stability limit if a sufficient number of non-wind units remain committed and online. However, as more non-wind generating units are turned off, the negative impact on West Texas export stability limits become more significant and stability limits become even more restrictive when enforcing a maximum level for allowable LaaR load shedding. As the amount of wind generation was increased, the system response to the tested contingencies generally resulted in greater amounts of LaaR load shedding. This is an expected result. Higher penetrations of wind generation would likely lead to greater amounts of wind generation tripped during a disturbance due to wind farm voltage and/or frequency protection relays. The remaining wind generation would not respond to the frequency excursion caused by the loss of wind generation. The system frequency response would depend on fewer conventional generators resulting in a slower frequency recovery and a greater likelihood that load shedding would be necessary to arrest the frequency decline and facilitate recovery.

The status of the Graham units has a significant impact on the ERCOT Operations interface flow. Because the Graham plant is located east of the interface it tends to reduce the interface flow when its units are online. When Graham units are at full output (Scenarios A through D), the stability limit on the interface is 200 to 400 MW less than when Graham units are at minimum output or offline (Scenarios E through J). In the step between Scenario D and E, the interface flow limit increases by approximately 300 MW while the overall West CSC zone export limit decreases by approximately 70 MW. Graham output is reduced by 469 MW which allows West Texas wind output to increase by 447 MW. This suggests that Graham units do contribute to west-to-north stability issues and that output from Graham may reduce the allowable output from other West Texas generators based on stability limits. This conclusion is also somewhat intuitive since the location of the critical contingency is east of Graham. Furthermore, Graham units are among the generators that experience excessive angular separation when the reported stability limits are exceeded. Thus, it appears reasonable that Graham output should be included with other West Texas output when identifying West Texas export limits. An alternate interface that would better incorporate Graham output is presented and discussed in Appendix II.

Table 1a: West Texas Export Stability Limits

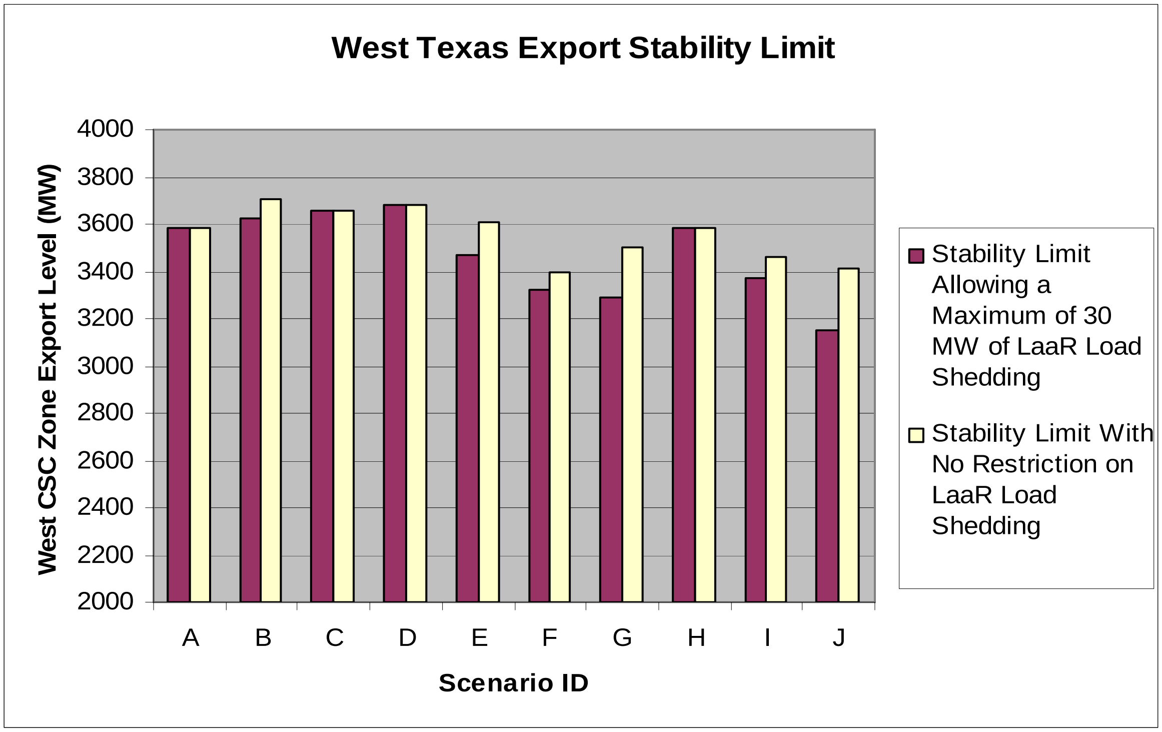
Scenario	West Generation (MW)		West Export Limit (MW)	West-to-North 345kV Interface Limit (MW)	LaaR Load Shed (MW)
	Non-Wind	Wind			
A	3053	3279	3582	2469	29
B	3053	3411	3709	2565	102
C	2916	3490	3658	2519	3
D	2916	3521	3679	2541	14
E	2447	3968	3606	2850	98
F	2297	3896	3398	2791	239
G	2297	4008	3501	2864	97
H	1833	4545	3583	2941	6
I	1564	4674	3460	2833	123
J	1295	4887	3416	2754	130

Table 1b: West Texas Export Stability Limits Allowing a Maximum of 30 MW of LaaR Load Shedding

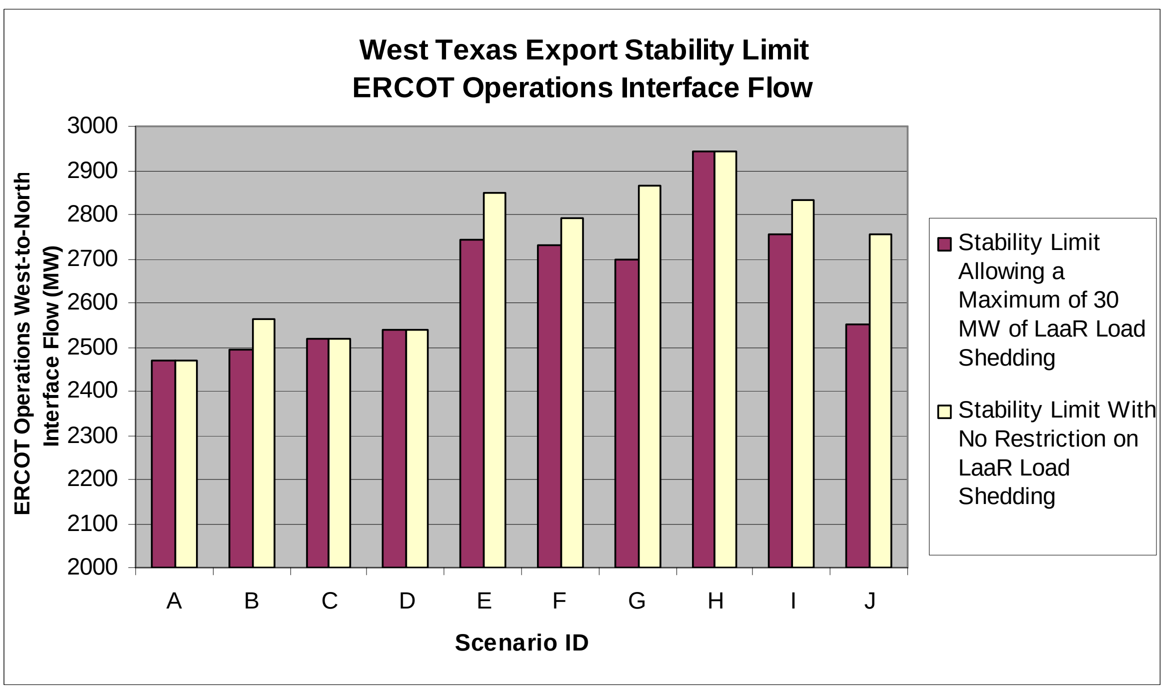
Scenario	West Generation (MW)		West Export Limit (MW)	West-to-North 345kV Interface Limit (MW)	LaaR Load Shed (MW)
	Non-Wind	Wind			
A	3053	3279	3582	2469	29
B	3053	3308	3622	2494	3
C	2916	3490	3658	2519	3
D	2916	3521	3679	2541	14
E	2447	3800	3470	2742	21
F	2297	3795	3323	2733	13
G	2297	3751	3288	2697	21
H	1833	4545	3583	2941	6
I	1564	4560	3368	2755	0
J	1295	4574	3151	2552	0

The ERCOT Operations West-to-North 345 kV interface is defined by summing the power flowing on six 345 kV transmission lines: from Mesquite to Graham, from Sweetwater to Graham, from Morgan Creek to Graham, measured as entering Graham for these three flows, from Bowman to Graham, from Bowman to Jacksboro SS, measured as leaving Bowman for these two flows and from Red Creek to Comanche, measured as entering Comanche SS.

<u>Figure 1a:</u> West Texas Export Stability Limits



<u>Figure 1b:</u> ERCOT Operations West-to-North 345 kV Interface Flow at Stability Limits



The ERCOT Operations West-to-North 345 kV interface is defined by summing the power flowing on six 345 kV transmission lines: from Mesquite to Graham, from Sweetwater to Graham, from Morgan Creek to Graham, measured as entering Graham for these three flows, from Bowman to Graham, from Bowman to Jacksboro SS, measured as leaving Bowman for these two flows and from Red Creek to Comanche, measured as entering Comanche SS.

Table 2a: Impact of West Texas Generation Type on Stability Limits

Scenario Transition	Description	Non-Wind Generation Decrease (MW)	Wind Generation Increase (MW)
A to B	Wind Farm Sites Added	0	132
B to C	Morgan Creek Units Turned Off	137	79
C to D	Wind Farm Sites Added	0	31
D to E	Graham Reduced to Minimum	469	447
E to F	Graham Units Turned Off	150	-72
F to G	Wind Farm Sites Added	0	112
G to H	TIE Reduced to Minimum	464	537
H to I	One TIE Train Turned Off	269	129
I to J	All TIE Units Turned Off	269	213

Table 2b: Impact of West Texas Generation Type on Stability Limits Allowing a Maximum of 30 MW of LaaR Load Shedding

Scenario Transition	Description	Non-Wind Generation Decrease (MW)	Wind Generation Increase (MW)
A to B	Wind Farm Sites Added	0	29
B to C	Morgan Creek Units Turned Off	137	182
C to D	Wind Farm Sites Added	0	31
D to E	Graham Reduced to Minimum	469	279
E to F	Graham Units Turned Off	150	-5
F to G	Wind Farm Sites Added	0	-44
G to H	TIE Reduced to Minimum	464	794
H to I	One TIE Train Turned Off	269	15
I to J	All TIE Units Turned Off	269	14

Figure 2a: West Texas Generation at Stability Limits

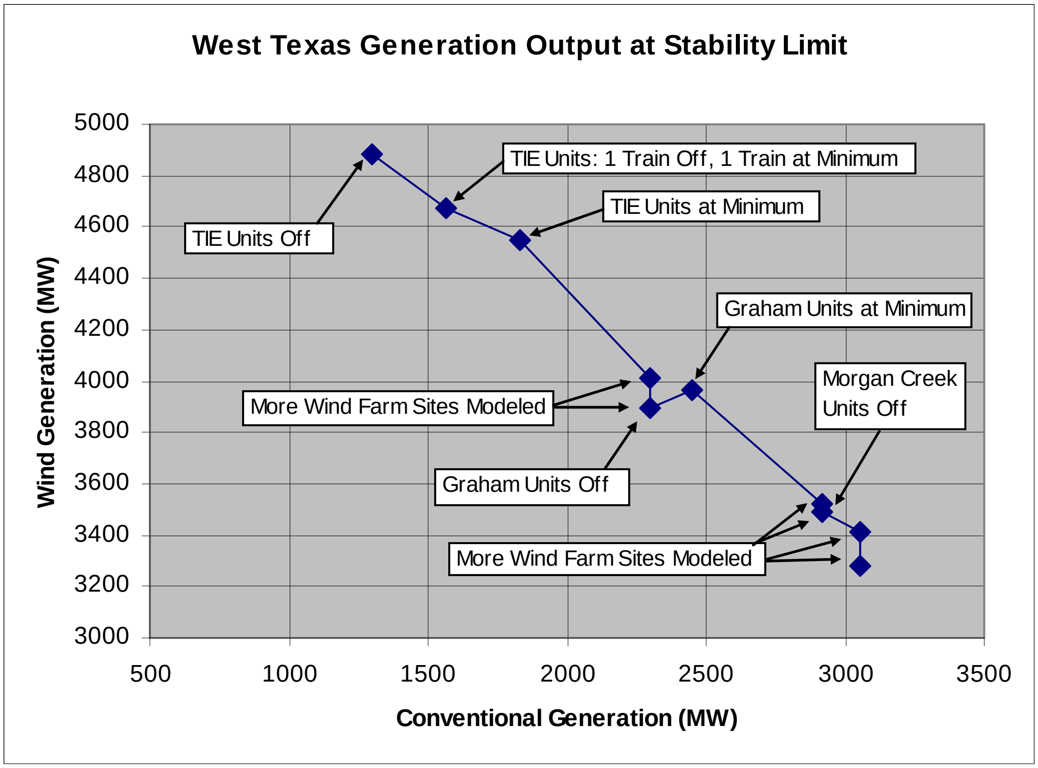
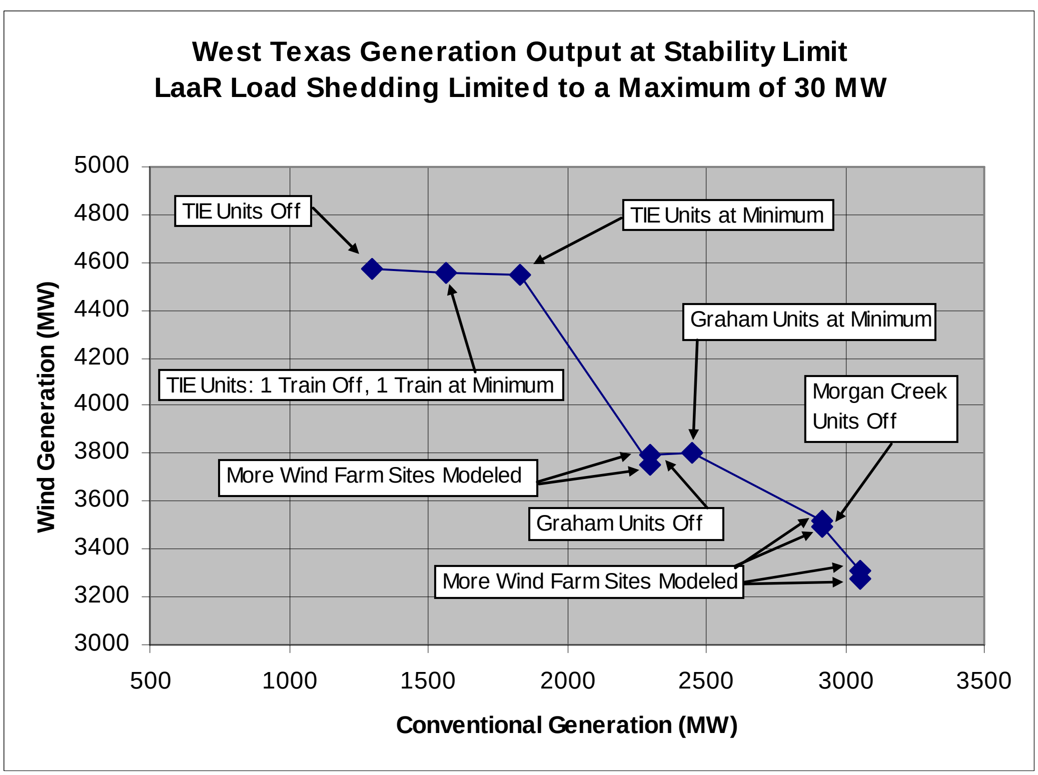


Figure 2b: West Texas Generation at Stability Limits Allowing a Maximum of 30 MW of LaaR Load Shedding – graphical representation



4.1. System Security

The criteria to determine the stability limit depends on how synchronous generating units in West Texas respond to the fault and resulting contingency outage. A case is considered unstable if simulation results indicate excessive angular separation (loss of synchronism with the rest of the system), excessive terminal voltage swing (voltage drop below 0.8 p.u. and without recovery to above 0.9 p.u. in the 10 second simulation) or excessive frequency swing (drop below 59.3 Hz. for more than 18 cycles).

The limiting contingency identified for every scenario in this study involves

resulting in excessive angular separation. Figures 3a and 3b show selected machine angle plots for simulation of this event at the stability limit and just beyond the stability limit under scenario B.

Figure 3a: Stable Response – Maximum Export Power Limit Scenario

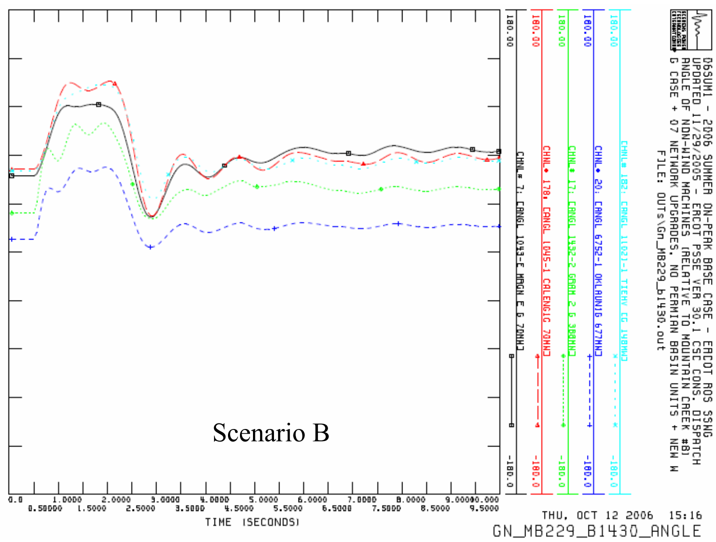
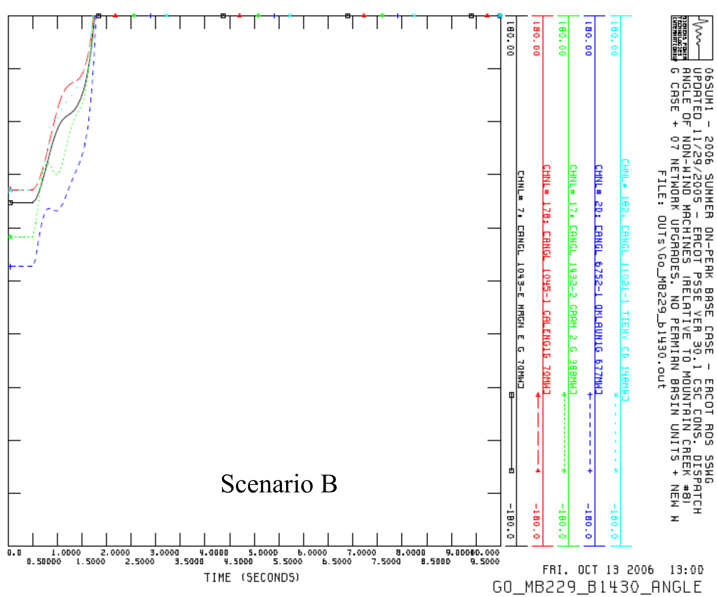


Figure 3b: Unstable Response – Additional 65 MW Export Power Out Of West Texas



4.2. Observations

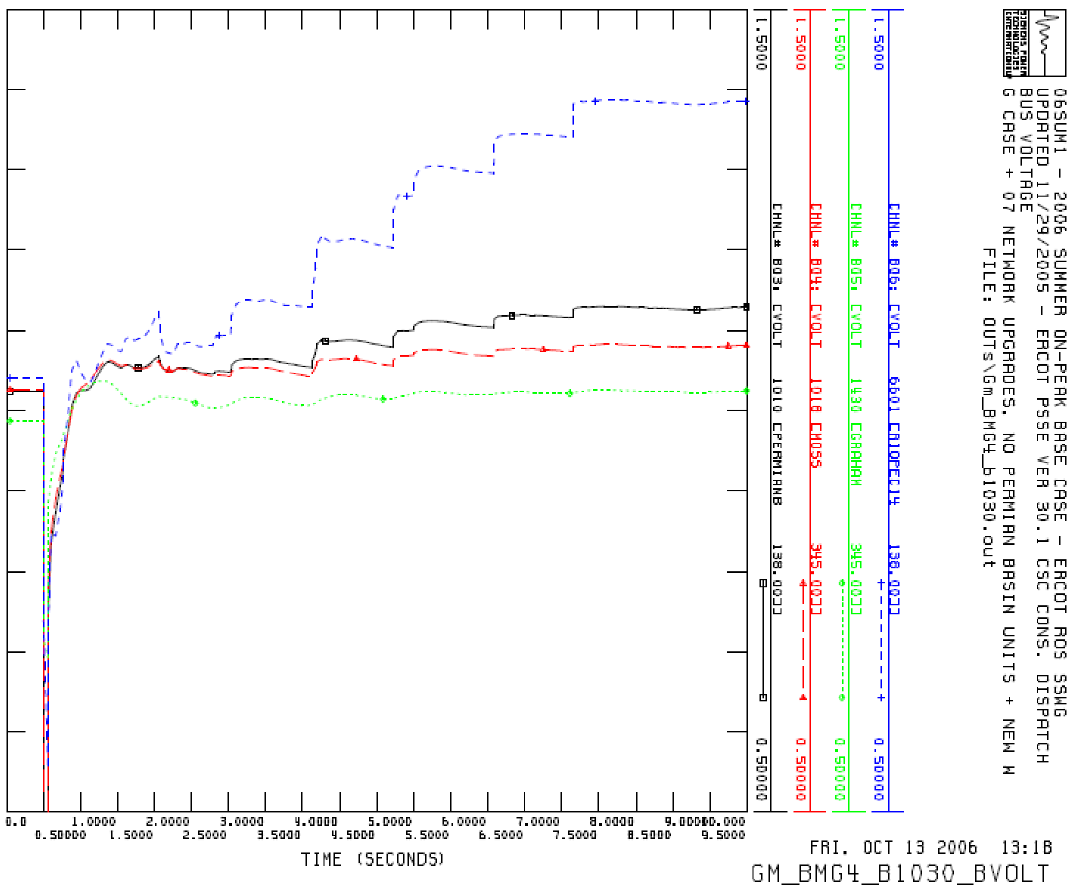
In every case studied, including cases where the West Texas export level was well below the stability limits found in this study, there were contingencies that initiated wind generation trips due to wind farm voltage and/or frequency protection relays. The amount of generation tripped was generally on the order of several hundred MW. Simulation results indicate that the transmission system may be subject to excessive voltage levels when wind farms trip off. An example of this is shown in Figure 4.

ERCOT LaaR relay data was also included in the simulations. Thus, information on LaaR activation for each contingency is available. The following table shows the amount of generation tripped and load shed on the ERCOT network for each contingency at the maximum stability limit and at the stability limit restricting LaaR load shedding to a maximum of 30 MW for scenario G. Contingencies that did not cause any generation tripping or LaaR activation are not listed in this table. Note that the most severe contingencies with respect to the amount of generation tripped and load shed were not always the same as the limiting stability contingency (which was MB229_b1430).

Contingency	Scenario G – at 30 MW LaaR Limit			Scenario G – at Stability Limit		
	Relay Tripping Events	Generation Tripped MW	Load Shed MW	Relay Tripping Events	Generation Tripped MW	Load Shed MW
SB81_b6601	77	571.96	0.00	77	645.68	0.00
SB81_b6632	58	551.07	0.00	77	713.07	0.00
SB525_b1028	59	600.57	0.00	59	608.07	0.00
SB526_b1029	59	600.57	0.00	59	608.07	0.00
MB227_b1028	10	128.63	0.00	59	608.07	0.00
MB227_b1030	35	404.95	13.96	118	1076.39	37.40
MB228_b1030	84	1010.07	0.00	97	1047.57	13.91
MB228_b1420	1	49.50	0.00	1	57.00	0.00
MB229_b1430	0	0.00	0.00	58	551.07	0.00
BMG3_b1028	59	600.57	0.00	78	770.07	0.00
BMG3_b1030	108	1038.89	19.77	128	1076.39	48.19
BMG4_b1028	78	762.57	0.00	78	770.07	0.00
BMG4_b1030	93	1116.81	0.00	90	1076.39	0.00
BMG7_b1029	59	600.57	0.00	78	770.07	0.00
BMG7_b1030	108	1038.89	19.77	128	1076.39	48.19
BMG8_b1029	78	762.57	0.00	78	770.07	0.00
BMG8_b1030	93	1116.81	0.00	90	1076.39	0.00
BMG11_b1030	110	1038.89	21.19	137	1076.39	96.89
BMG11_b1420	1	49.50	0.00	1	57.00	0.00
BMG12_b1030	90	1038.89	0.00	90	1076.39	0.00
BMG12_b1420	1	49.50	0.00	1	57.00	0.00
BMG15_b6601	77	645.68	0.00	77	645.68	0.00
BMG15_b6632	77	713.07	0.00	77	713.07	0.00
BMG16_b6601	77	498.21	0.00	77	498.21	0.00
BMG16_b6632	77	713.07	0.00	77	713.07	0.00

Figure 4: Selected Bus Voltages for Contingency BMG4_b1030 at Stability Limit Allowing a Maximum of 30 MW of Load Shedding due to the Activation of LaaR Relays, Scenario B

Step increases in voltage indicate the times when blocks of wind generation trip. Actual over voltages may not be this severe if reactive compensation trips off along with associated wind turbines or due to its own over voltage protection.



4.3. Conclusions

The maximum stability limit for power export from West Texas will vary depending on the specific unit commitment and generation dispatch. For the ten unit commitment scenarios studied, the limit ranged from 3700 MW to 3400 MW as measured by the sum of power flows through all of the ties out of the West CSC zone. The limit on the ERCOT Operations West-to-North 345 kV interface defined by summing the power flowing on six 345 kV transmission lines (from Mesquite to Graham, from Sweetwater to Graham, from Morgan Creek to Graham, measured as entering Graham for these three flows, from Bowman to Graham, from Bowman to Jacksboro SS, measured as leaving Bowman for these two flows and from Red Creek to Comanche, measured as entering Comanche SS) ranged from 2950 MW to 2450 MW. Replacing non-wind generation with wind generation did not appear to have a large impact on the West Texas export stability limit. However, as more non-wind generating units were turned off, the negative impact on West Texas export stability limits became more significant.

The maximum amount of load shed due to the activation of LaaR relays in response to any of the tested contingencies at the stability limit exceeded 100 MW for several scenarios. Stability limits that allowed no more than 30 MW of load shed were generally lower for a particular scenario and ranged from 3650 MW to 3150 MW on all West CSC zone ties or 2950 MW to 2450 MW on the ERCOT Operations interface. Higher penetrations of wind generation generally led to a greater amount of load shedding in response to the tested disturbances (and more restrictive export limits when attempting to limit load shedding). Consideration should be given to limiting the amount of load shed when establishing a stability limit.

For all scenarios studied, the limiting contingency for stability was MB229_b1430 –

– resulting in excessive angular separation. However, for some of the scenarios other contingencies were more critical in restricting the amount of load shed following the disturbance.

In every case studied, there were contingencies that initiated wind generation trips due to wind farm voltage and/or frequency protection relays. The amount of generation tripped was generally on the order of several hundred MW. Simulation results indicate that the transmission system may be subject to excessive voltage levels when wind farms trip off.

Stability limits have been reported in terms of net out flow from all West CSC zone ties and flow on the ERCOT Operations interface defined by the power flow in six 345 kV lines. An alternative interface described in Appendix II may be more appropriate for monitoring and enforcing stability limits related to West Texas exports. It is recommended that ERCOT Operations consider monitoring West-to-North transfers with this alternative interface instead of the 6-line interface currently being monitored.

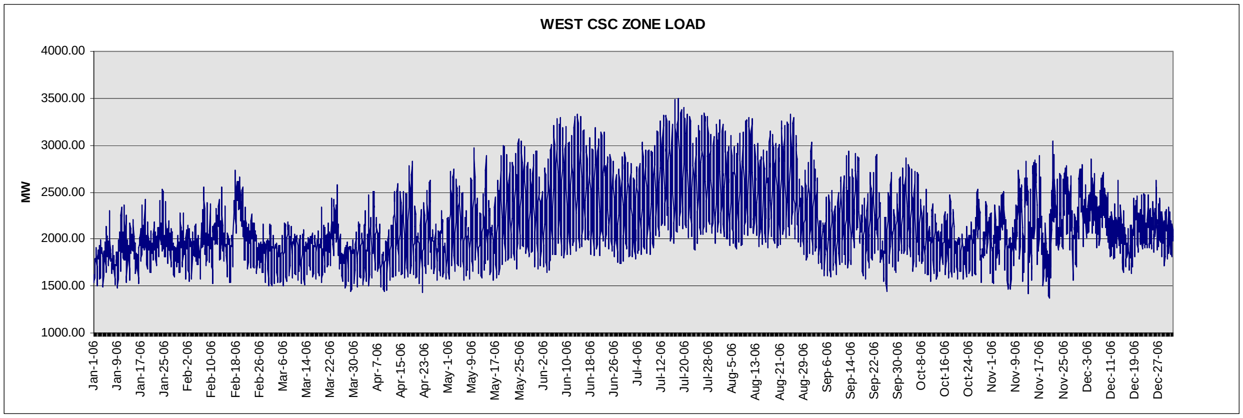
5. APPENDICES

- Appendix I Historical Operations Data
- Appendix II Alternative 345kV Interface
- Appendix III West Texas Generation Dispatch
- Appendix IV Test Disturbance Event Definitions
- Appendix V ERCOT Transmission System Standards

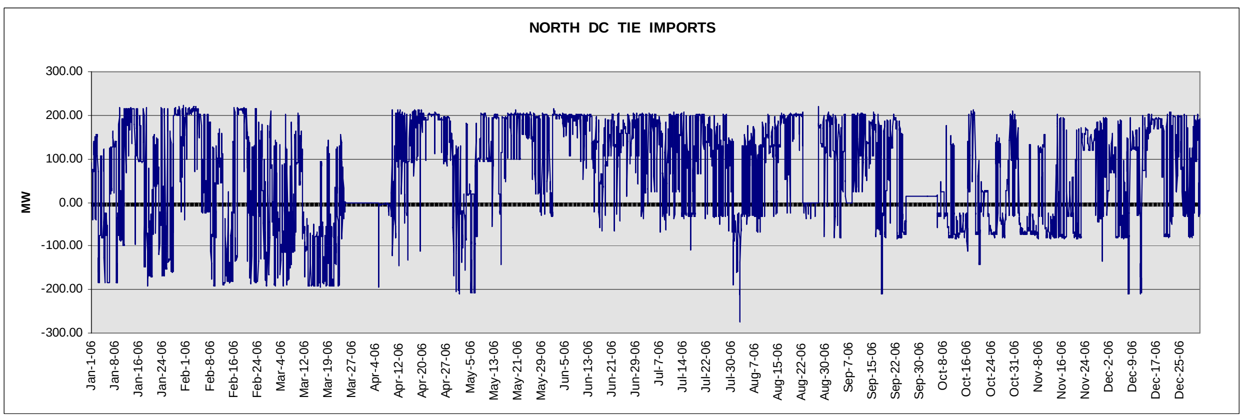
Appendix I Historical Operations Data

The 2006 trends below show that study assumptions made with respect to the generation dispatch, North DC tie import level and load level are reasonable. They also indicate that the ERCOT system has been operated securely with respect to West Texas export stability limits.

West CSC zone load varied in 2006 roughly between 1500 MW to 3500 MW. In this transient stability study, the West CSC zone lode was scaled down to 2329 MW to facilitate modeling of West Texas power exports.

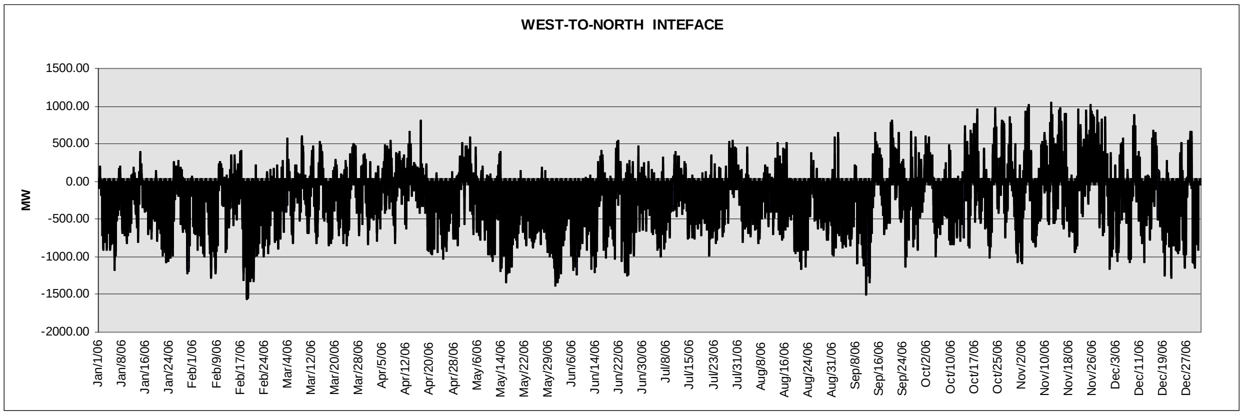


The North DC tie import power was not modified from its value (-25 MW) as dispatched on the 2006 summer on-peak case reviewed by ROS's DWG.

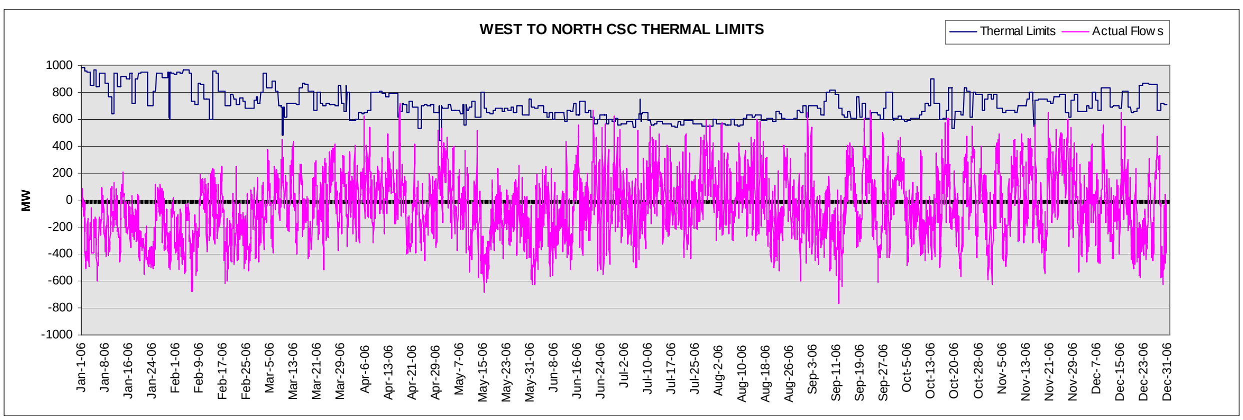


Trends for 2006 West Texas conventional generation power output are presented below.

Recently, ERCOT Operations began monitoring the West-to-North interface (six 345 kV lines as described earlier in this report) for a transient stability limit to match similar procedures implemented by TXU Electric Delivery at their Control Center. The 2006 trend of total flow measured at the interface shows only a few instances when its value reached 1000 MW or above. Study results indicate that the most restrictive transient stability limit as measured on this West-to-North interface is 2469 MW. Higher stability limits are found for certain dispatch patterns. For 2006 there was nearly 1400 MW of additional interface capacity before reaching the calculated West-to-North stability limit.



For reference, the trend of the calculated thermal limits and actual flow is shown below for the year 2006. ERCOT Operation monitors the flow on the two West-to-North CSC lines (thermal interface) against limits calculated roughly between 600 MW and 1000 MW. A direct comparison between the stability and thermal limits is not possible since they were calculated on different interfaces and different base cases.

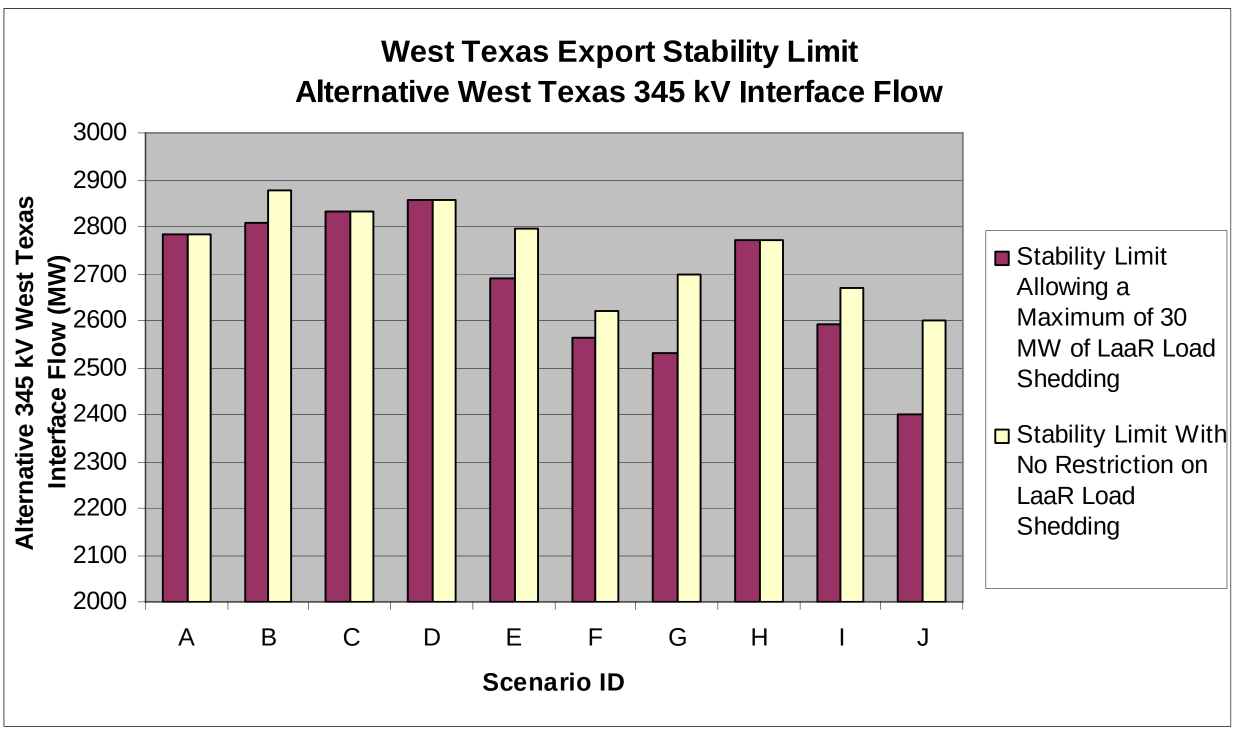


Appendix II Alternative 345 kV Interface

An alternative West Texas interface was defined by summing the power flowing on four 345 kV transmission lines (from Graham to Benbrook, from Graham to Parker, from Jacksboro SS to Willow Creek and from Red Creek to Comanche). This interface is located east of Graham and includes contributions from the Graham units in the determination of West Texas exports which appears to be appropriate based on the results of this study. A summary of stability limits on this interface limit for each scenario is reported below.

The stability limits on this interface correspond well with the stability limits calculated by summing the power flows through all of the ties out of the West CSC zone. Additionally, this interface incorporates the output of all West Texas generators that contribute to critical West-to-North transfers which may be limited by stability concerns. Thus, it is recommended that ERCOT Operations consider monitoring West-to-North transfers with this interface instead of the 6-line interface currently being monitored.

Scenario	Alternative West Texas 345 kV Interface Limit (MW)	Alternative West Texas 345 kV Interface Limit Allowing 30 MW Maximum LaaR Load Shedding (MW)
A	2783	2783
B	2877	2810
C	2833	2833
D	2856	2856
E	2795	2688
F	2620	2564
G	2697	2530
H	2772	2772
I	2668	2594
J	2599	2401



Appendix III West Texas Generation Dispatch

Bus #	Wind Farm Site Name	ID	Generation Output for Each Scenario at Stability Limit (MW)									
			A	B	C	D	E	F	G	H	I	J
6015	SWMESA	*	79.1	79.1	79.1	79.1	79.1	79.1	79.1	79.1	79.1	79.1
6019	ORIONNWP	*	77.9	77.9	77.9	77.9	77.9	77.9	77.9	77.9	77.9	77.9
6021	DESERTSKY1	*	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5	76.5
6633	WOODWARD1	*	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7
7387	DELAWARE	*	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0	57.0
7387	TWPP	*	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6	39.6
38331	WOODWARD2	*	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2	73.2
60001	DESERTSKY2	*	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5	85.5
60002	KINGMTNSW	*	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7
60004	KINGMTNNE	*	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4
60006	KINGMTNSE	*	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3	36.3
60021	KINGMTNNW	*	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7	73.7
1050	SWEETW	*	266.0	266.0	266.0	266.0	266.0	266.0	266.0	266.0	266.0	266.0
1063	BRAZOSWF	*	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8	140.8
1064	REDCANYON	*	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0	84.0
1343	TRENTWF	*	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5	142.5
1353	BIGSP	*	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8	28.8
60056	CALLAHAN	*	114.0	114.0	114.0	114.0	114.0	114.0	114.0	114.0	114.0	114.0
60059	BUFFALOGP1	*	120.6	120.6	120.6	120.6	120.6	120.6	120.6	120.6	120.6	120.6
60067	HORSEHOL1	*	222.0	222.0	222.0	222.0	222.0	222.0	222.0	222.0	222.0	222.0
60069	HORSGEN2	*	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0	115.0
6216	HORSEH3	*	187.5	134.9	187.5	187.5	187.5	187.5	187.5	187.5	187.5	187.5
6216	HORSEH4	*	225.0	161.8	225.0	225.0	225.0	225.0	225.0	225.0	225.0	225.0
60040	BUFGAP3	*	128.9	78.7	84.1	67.9	133.0	133.0	133.0	105.8	105.8	133.0
60061	BUFGAP2	*	220.7	106.9	106.9	220.7	211.4	211.4	206.7	148.7	218.4	232.3
1335	FORESTCRK	*	189.2	118.3	111.8	96.8	204.3	204.3	126.9	126.9	204.3	212.9
1435	MESQUITE	*	284.1	320.2	284.1	244.1	348.2	288.1	256.1	364.2	364.2	396.2
1030	CANNIBAL	*	0.0	142.0	142.0	71.8	136.0	82.2	73.3	133.1	133.1	148.0
6100	BEAVERCRK	*	0.0	171.0	171.0	88.2	178.2	178.2	178.2	142.2	178.2	178.2
6100	REDRIVER	*	0.0	134.0	134.0	69.1	139.6	139.6	139.6	114.2	139.6	139.6
1030	TRICOUNTY	*	0.0	0.0	0.0	94.1	74.5	94.1	74.5	186.2	186.2	172.5
6009	WATERVALD	*	0.0	0.0	0.0	112.1	87.2	109.6	94.6	236.6	174.3	219.1
1030	FUTUREWIND	*	0.0	0.0	0.0	0.0	0.0	0.0	57.0	139.5	139.5	105.0
1643	CLIPPER	*	0.0	0.0	0.0	0.0	0.0	0.0	24.8	24.8	24.8	68.3
6009	SILVERSTAR	*	0.0	0.0	0.0	0.0	0.0	0.0	135.0	255.0	255.0	285.0
6335	JACKSONMT	*	0.0	0.0	0.0	0.0	0.0	0.0	52.8	112.0	94.4	140.8
	Wind Generation Total:		3279	3411	3490	3521	3968	3896	4008	4545	4674	4887

* Aggregated generation from wind farms reported at transmission bus.

Bus #	Conventional Generation	ID	Generation Output for Each Scenario at Stability Limit (MW)									
			A	B	C	D	E	F	G	H	I	J
344	MORSHEP	1	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
345	MORSHEP2	2	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0
719	WFEC 12G	1	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
719	WFEC 12G	2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
720	WFEC 34G	3	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
720	WFEC 34G	4	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2	19.2
1045	CALENG1G	1	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
1046	CALENG2G	2	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0	70.0
1047	CALENG3G	3	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0	68.0
1067	KM CT1	1	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7
1068	KM CT2	1	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7	36.7
1069	KM ST1	1	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0	17.0
1320	BSP 1	1	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
1416	SWTWTR1G	1	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0	29.0
1417	SWTWTR2G	2	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7	69.7
1418	SWTWTR3G	3	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
1419	SWTWTR4G	4	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
6096	NORTHDC7	1	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0	-25.0
6752	OKLAUN1G	1	676.7	676.7	676.7	676.7	676.7	676.7	676.7	676.7	676.7	676.7
1002	PBCT A G	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1003	PBCT B G	B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1004	PBCT C G	C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1005	PBCT D G	D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1006	PBCT E G	E	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1007	PB5 G	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1008	PB6 G	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1031	MRGN 6 G	MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1037	MORGAN5G	MB	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1039	MRGN A G	A	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1040	MRGN B G	B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1041	MRGN C G	C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1042	MRGN D G	D	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1043	MRGN E G	E	70.0	70.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1044	MRGN F G	F	67.7	67.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1432	GRAM 2 G	2	387.8	387.8	387.8	387.8	90.0	0.0	0.0	0.0	0.0	0.0
1433	GRAM 1 G	1	231.3	231.3	231.3	231.3	60.0	0.0	0.0	0.0	0.0	0.0
11020	TIEHV SG	1	214.0	214.0	214.0	214.0	214.0	214.0	214.0	63.0	0.0	0.0
11021	TIEHV CG	1	148.5	148.5	148.5	148.5	148.5	148.5	148.5	103.0	0.0	0.0
11022	TIEHV CG	1	136.0	136.0	136.0	136.0	136.0	136.0	136.0	103.0	0.0	0.0
11023	TIEHV CG	1	138.0	138.0	138.0	138.0	138.0	138.0	138.0	103.0	103.0	0.0
11024	TIEHV CG	1	150.5	150.5	150.5	150.5	150.5	150.5	150.5	103.0	103.0	0.0
11025	TIEHV SG	1	215.0	215.0	215.0	215.0	215.0	215.0	215.0	63.0	63.0	0.0
Conventional Generation Total:			3053	3053	2916	2916	2447	2297	2297	1833	1564	1295

Appendix IV Test Disturbance Event Definitions

SBxx contingencies are NERC Category B events. MBxx contingencies involve the loss of a double circuit transmission line and are NERC Category D events due to the application of a 3-phase fault. BMGxx contingencies are line (or common tower) plus unit contingencies that are Category C (or D for the common tower cases) though they may all be interpreted as NERC Category D events because the two outages were simulated simultaneously whereas Category C allows for manual system adjustments between the two events.

Contingency ID	Event Description
SB81_b6601	
SB81_b6632	
SB82_b787	
SB82_b1477	
SB525_b1028	
SB526_b1029	
MB227_b1028	
MB227_b1030	
MB228_b1030	
MB228_b1420	
MB228_b1430	
MB229_b1430	
BMG1_b1028	
BMG1_b1030	
BMG2_b1028	
BMG2_b1030	
BMG3_b1028	
BMG3_b1030	
BMG4_b1028	
BMG4_b1030	
BMG5_b1029	
BMG5_b1030	
BMG6_b1029	
BMG6_b1030	
BMG7_b1029	
BMG7_b1030	
BMG8_b1029	
BMG8_b1030	
BMG9_b1030	

Contingency ID	Event Description
BMG9_b1420	
BMG9_b1430	
BMG10_b1030	
BMG10_b1420	
BMG10_b1430	
BMG11_b1030	
BMG11_b1420	
BMG11_b1430	
BMG12_b1030	
BMG12_b1420	
BMG12_b1430	
BMG13_b6601	
BMG13_b6632	
BMG14_b6601	
BMG14_b6632	
BMG15_b6601	
BMG15_b6632	
BMG16_b6601	
BMG16_b6632	
BMG17_b787	
BMG17_b1477	
BMG18_b787	
BMG18_b1477	
BMG19_b787	
BMG19_b1477	
BMG20_b787	
BMG20_b1477	

Appendix V ERCOT Transmission Systems Standards — Normal and Contingency Conditions

Category	**Contingencies**	**System Limits or Impacts**					
	Initiating Event(s) and Contingency Component(s)	Components Out of Service	Thermal Limits	Voltage Limits	System Stable	Loss of Demand or Curtailed Firm Transfers	Cascading[c] Outages
A – No Contingencies	All Facilities in Service	None	Normal	Normal	Yes	No	No
B – Event resulting in the loss of a single component.	Single Line Ground (SLG) or 3-Phase (3Ø) Fault, with Normal Clearing: 1. Generator 2. Transmission Circuit 3. Transformer Loss of a Component without a Fault. Single Pole Block, Normal Clearing: 4. Single Pole (dc) Line	Single	Applicable Rating [a] (A/R)	A/R	Yes	No [b]	No
C – Event(s) resulting in the loss of two or more (multiple) components.	SLG Fault, with Normal Clearing: 1. Bus Section 2. Breaker (failure or internal fault) SLG or 3Ø Fault, with Normal Clearing, Manual System Adjustments, followed by another SLG or 3Ø Fault, with Normal Clearing: 3. Category B (B1, B2, B3, or B4) contingency, manual system adjustments, followed by another Category B contingency Bipolar Block, with Normal Clearing: 4. Bipolar (dc) Line Fault (non 3Ø), with Normal Clearing: 5. Double Circuit Towerline SLG Fault, with Delayed Clearing: 6. Generator 8. Transformer 7. Transmission Circuit 9. Bus Section	Multiple	A/R	A/R	Yes	Planned[d]	No

Footnotes

a) Applicable rating (A/R) refers to the applicable normal and emergency facility thermal rating or system voltage limit as determined and consistently applied by the system or facility owner.

b) Planned or controlled interruption of generators or electric supply to radial customers or some local network customers, connected to or supplied by the faulted component or by the affected area, may occur in certain areas without impacting the overall security of the interconnected transmission systems. To prepare for the next contingency, system adjustments are permitted, including curtailments of contracted firm (non-recallable reserved) electric power transfers.

c) Cascading is the uncontrolled successive loss of system elements triggered by an incident at any location. Cascading results in widespread service interruption, which cannot be restrained, from sequentially spreading beyond an area predetermined by appropriate studies.

d) Depending on system design and expected system impacts, the controlled interruption of electric supply to customers (load shedding), the planned removal from service of certain generators, or the curtailment of contracted firm (non-recallable reserved) electric power transfers may be necessary to maintain the overall security of the interconnected transmission systems.

Category	Contingencies	System Limits or Impacts
D e – Extreme event resulting in two or more (multiple) components removed or cascading out of service	3Ø Fault, with Delayed Clearing (stuck breaker or protection system failure): 1. Generator 3. Transformer 2. Transmission Circuit 4. Bus Section 3Ø Fault, with Normal Clearing: 5. Breaker (failure or internal fault) Other: 6. Loss of towerline with three or more circuits 7. All transmission lines on a common right-of way 8. Loss of a substation (one voltage level plus transformers) 9. Loss of a switching station (one voltage level plus transformers) 10. Loss of a all generating units at a station 11. Loss of a large load or major load center 12. Failure of a fully redundant special protection system (or remedial action scheme) to operate when required 13. Operation, partial operation, or misoperation of a fully redundant special protection system (or remedial action scheme) for an event or condition for which it was not intended to operate 14. Impact of severe power swings or oscillations from disturbances in another Regional Council.	Evaluate for risks and consequences. - May involve substantial loss of customer demand and generation in a widespread area or areas. - Portions or all of the interconnected systems may or may not achieve a new, stable operating point. - Evaluation of these events may require joint studies with neighboring systems. - Document measures or procedures to mitigate the extent and effects of such events. - Mitigation or elimination of the risks and consequences of these events shall be at the discretion of the entities responsible for the reliability of the interconnected transmission systems.

Footnotes

e) A number of extreme contingencies that are listed under Category D and judged to be critical by the transmission planning entity(ies) will be selected for evaluation. It is not expected that all possible facility outages under each listed contingency of Category D will be evaluated.

f) The “Table I. ERCOT Transmission Systems Standards” is taken from the ERCOT Operating Guides, OPG005_070104.doc, reformatted for this report.