Xcel Energy

2010 TOT 7 Transfer Path
Transient Stability Study

Public Service Company of Colorado
Transmission Planning

November 22, 2010

Executive Summary

The TOT 7 transfer path is a transmission corridor located in north central Colorado that has been identified as being limited in its ability to deliver power to central Colorado load centers from the north. The TOT 7 transfer path is operated by Public Service Company of Colorado (PSCo) and jointly owned by PSCo and the Platte River Power Authority (PRPA). Thermal limits were developed by PRPA for the 2010 summer season. [1] Other possible limits may be due to voltage stability and transient stability. This study examined the potential for restrictive limitations to the TOT 7 transfer path due to transient stability. Voltage stability will be addressed in a separate study effort.

The studies were performed using two power flow models that were previously prepared by PRPA for use in a TOT 7 power flow study performed earlier in 2010. These cases were based on the WECC approved 10hs3bp.sav base case, as reviewed and updated for the WECC Rocky Mountain Region 2010 summer Operating Transfer Capability studies. One case represented the PRPA determined TOT 7 thermal power flow limit (484 MW) with system loads at 100% of 2010 summer peak levels and Colorado Big Thompson (CBT) generation at 0 MW. The other case represented the 890 MW TOT 7 path rating with area system loads at 64% of 2010 summer peak and CBT generation at 180 MW. These cases were modified to correct some area modeling issues. No-disturbance simulations were executed to verify modeling precision. NERC category B & C disturbances were modeled in the studies. Also, the disturbances were run with 3 cycles of fault time margin to examine the extent of the area transient stability margin.

The results from this study indicate that at the two thermal limit conditions tested, the TOT 7 transfer path is transiently stable with satisfactory damping characteristics for all modeled Category B & C disturbance scenarios and including a 3 cycle fault time margin. The transient voltage dip results from the study show that the system response on affected systems to the modeled disturbances is well within WECC transient voltage dip criteria. Also, the minimum transient frequency results indicate that the system will respond within the WECC criteria. Therefore, at the thermal TOT 7 flow limits tested,

---

[1] Two thermal limit operating points (peak load and light load) were developed with the 2010 summer case for use in the 2010 transient stability study. These thermal limits were slightly higher than the corresponding 2009 limits. The 2009 System Intact operating limits were used through the 2010 summer season because there were no material changes in system topology, facility ratings, generation, reactive devices, and loads.

transient stability does not impose an additional limit to MW flow across the TOT 7 transfer path beyond the established thermal limits.

Introduction

The TOT 7 transfer path is a transmission corridor located in north central Colorado that has been identified as being limited in its ability to deliver power to central Colorado load centers from the north. The TOT 7 transfer path is operated by Public Service Company of Colorado (PSCo) and jointly owned by PSCo and the Platte River Power Authority (PRPA). Thermal limits were developed by PRPA for the 2010 summer season. Other possible limits may be due to voltage stability and transient stability. This study examined the potential for restrictive limitations to the TOT 7 transfer path due to transient stability. Voltage stability will be addressed in a separate study effort.

Foothills Planning Group

The Foothills Planning Group consists of representatives from PRPA, PSCo, Tri-State Generation & Transmission, and Western Area Power Administration – Rocky Mountain Regional Office.

Study Scope

The study area for the transient stability study is the Foothills area and the surrounding system. The Foothills area consists of the transmission system in Colorado bounded by the Valmont and Henry Lake substations in the south to the Colorado/Wyoming border in the north, and from Estes Park in the west to Greeley in the east. A map of the Foothills area can be found in Appendix Section A.

The TOT 7 transfer path is a 230 kV transmission corridor in the Foothills area between Ault and Fort St. Vrain (FSV) substation and consists of three transmission lines:

- Ault-Windsor-FSV 230 kV line (metered at Ault)
- Weld-FSV 230 kV line (metered at Weld)
- Longs Peak-FSV 230 kV line (metered at FSV)

Study Performance Criteria

PSCo adheres to NERC Transmission Planning Standards and WECC Reliability Criteria for planning studies. Transient stability criteria require that all generating machines remain in synchronism and all generator rotor angle swings should be well damped. Also, transient voltage performance should meet the following criteria on affected systems:

- Following fault clearing for Category B contingencies, voltage may not dip more than 25% of the pre-fault voltage at load buses, more than 30% at non-load buses, or more than 20% for more than 20 cycles at load buses.

- Following fault clearing for Category C contingencies, voltage may not dip more than 30% of the pre-fault voltage at any bus or more than 20% for more than 40 cycles at load buses.

In addition, transient frequency performance should meet the following criteria on affected systems:

- Following fault clearing for Category B contingencies, frequency should not dip below 59.6 Hz for 6 cycles or more at a load bus.
- Following fault clearing for Category C contingencies, frequency should not dip below 59.0 Hz for 6 cycles or more at a load bus.

Note that load buses include generating unit auxiliary loads.

Modeling Assumptions

The transient stability studies were based on the WECC approved 10hs3bp.sav base case, as reviewed and updated for the WECC Rocky Mountain Region 2010 summer Operating Transfer Capability studies.

Load levels reflect 2010 heavy summer peak system conditions. This case was modified by PRPA to represent two different operating scenarios of interest as part of the thermal TOT 7 path limit studies:

1. 2010 summer peak load in the Foothills area with CBT generation at 0 MW and TOT 7 stressed to it's thermal limit at 484 MW (north to south), and
2. 2010 summer off-peak load (64% of peak) in the Foothills area and CBT generation at 180 MW with TOT 7 stressed to the 890 MW transfer rating of the transfer path.

These cases were used as a starting point for the TOT 7 transient stability studies.

The generation dispatch for Fort St. Vrain in the two cases was changed for the transient stability studies to reflect more realistic generation levels for this combination combined cycle and simple cycle plant. However, the total generation did not change. The generation dispatch for Rawhide in the two cases was not changed, except for minor changes due to dynamics initialization issues. Again, the total generation did not change. The following table provides the generation dispatch at the Fort St. Vrain and Rawhide plants in the two cases after redispatch and initialization changes:

Generating Unit	100 % Peak Load	64% Peak Load
Fort St. Vrain Unit 1	229 MW	261 MW
Fort St. Vrain Unit 2	87 MW	98 MW
Fort St. Vrain Unit 3	87 MW	98 MW
Fort St. Vrain Unit 4	87 MW	98 MW
Fort St. Vrain Unit 5	0 MW	0 MW
Fort St. Vrain Unit 6	0 MW	0 MW
Rawhide Unit 1	300 MW	300 MW
Rawhide Unit A	40 MW	15 MW
Rawhide Unit B	40 MW	Off
Rawhide Unit C	Off	Off
Rawhide Unit D	65 MW	65 MW
Rawhide Unit F	135 MW	135 MW

The Foothills area loads are in Zones 754 and most of Zone 706. In the 100% peak load case, the load in these zones was 1449.1 MW & 589.7 Mvar. The load in the 64% peak load case was 930.4 MW & 387.6 Mvar.

In the load flow cases, the Comanche Unit 3 model was adjusted to reflect updated modeling and test data. The generation output of Comanche Unit 3 was raised to the recently determined maximum of 842.6 MWgross (800 MWnet). This generation change was offset with generation at Fountain Valley and Manchief. Also, in the load flow case Rawhide Unit 1 Ra armature resistance was changed to reflect the recommended value in recent test data.

Because of dynamics initialization problems, small changes were made in each load flow case. In the 100% case, Rawhide Unit D output was lowered by 5 MW to 65 MW. This was offset by raising Rawhide Unit A 5 MW to 40 MW. Also, Comanche Units 1 & 2 were each lowered 10 MW to 340 MW. This was offset with generation at Manchief. In the 64% case, Rawhide Unit D was lowered 5 MW to 65 MW and Rawhide Unit A was raised 5 MW to 15 MW. Also, Comanche Units 1 & 2 were each lowered 10 MW to 340 MW. This was offset with generation at Manchief. In addition, WYGEN3 13.8 kV was lowered 5 MW to 95 MW. This was offset with generation at NSS_CT1 13.8 kV. Additional small changes were made in both cases to generators in PG&E.

Additional load flow case changes that were included were to restore the missing Midway-Daniels Park 230 kV line, insert the Daniels Park and Comanche 345 kV 40 Mvar reactors, and adjust the primary voltages of the Comanche Unit 1 & 2 GSU transformers.

The dynamics data that was used for the Fort St. Vrain units was the data that was included with the WECC distribution of the 10hs3bp.sav base case. However, the dynamics data for the Rawhide units was updated to reflect the results of testing that was performed in June and December of 2008. Updated Comanche Unit 3 dynamics data was also used. This data was based on testing performed Winter/Spring and June 2010.

To check the precision of the dynamic models, no disturbance simulations were executed for both cases. These simulations represent a pre-contingency scenario with no system changes. All monitored quantities were flat with no stability problems noted.

Disturbance Analysis

The list of disturbances that were studied in the TOT 7 transient stability analysis can be found in Table 1 in Appendix Section B below. Category B and C disturbances were simulated at the Fort St. Vrain 230 kV and Rawhide 230 kV substations. The Category C disturbances included 3 phase faults involving two circuits on a multiple circuit tower. The contingencies that were evaluated were limited to those necessary to adequately assess the transient stability performance of the TOT 7 transfer path.

The analyses using three-phase faults with normal clearing assumed 5 cycle normal clearing time for 230 kV breakers. To demonstrate a reasonable amount of stability margin, 3 cycles were added to the total clearing time in each disturbance scenario.

To perform the assessment, for each contingency, plots of generator relative rotor angle were produced. Minimum transient bus voltage dips and minimum transient frequency dips for affected systems were also determined.

Study Results

The results indicate that at the TOT 7 thermal limits modeled, the system is transiently stable with satisfactory damping characteristics for all modeled Category B and C disturbances. Relative rotor angle plots of the units at Fort St. Vrain, Rawhide, Cherokee, Arapahoe, Ft. Lupton, Spindle, Valmont, RMEC, and Spruce can be found in Appendix Section D. The transient voltage dip and transient frequency dip results can be found in Appendix Section C below.

The transient voltage dip results show that the system response on affected systems to the modeled disturbances is well within WECC transient voltage dip criteria. The lowest voltage dip on an affected system in the 100% peak load case for Category B contingencies was to 91.40% at the DACONO 115.0 kV bus for disturbance scenario #102. The pre-disturbance voltage at this bus was 96.44%. Also, the lowest voltage dip for Category C contingencies was to 93.29% at the OWL_LOW 12.47 kV bus for disturbance scenario #311. The pre-disturbance voltage at this bus was 97.04%.

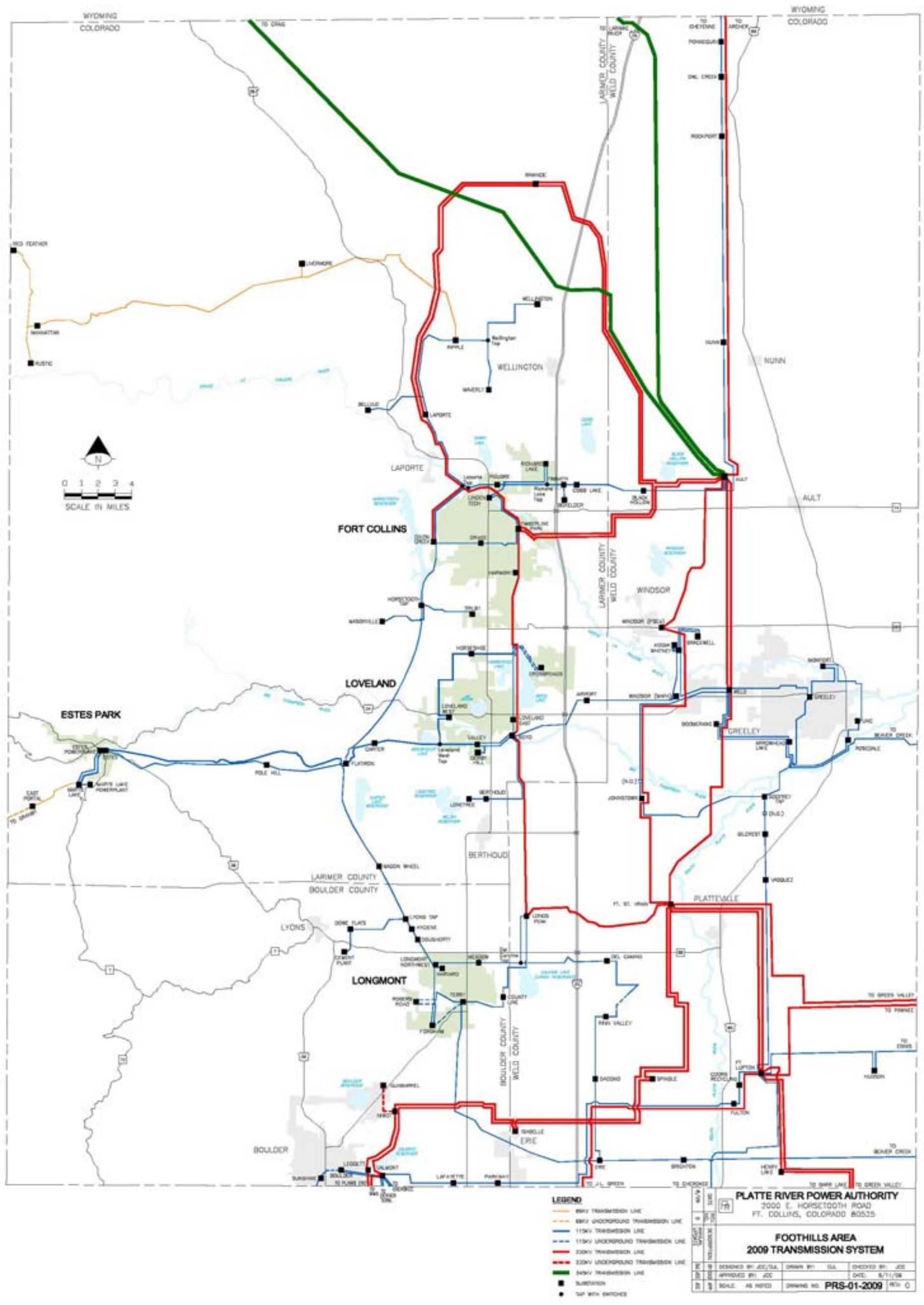
For the 64% peak load case, the lowest voltage dip on affected systems for Category B contingencies was to 94.51% at the VALMONT 230.0 kV bus for disturbance scenario #110. The pre-disturbance voltage at this bus was 95.74%. Also, the lowest voltage dip for Category C contingencies was to 94.14% at the VALMONT 230.0 kV bus for disturbance scenario #310. The pre-disturbance voltage at this bus was 95. 74%.

The transient frequency dip results show that the system response on affected systems to the modeled disturbances is well within WECC transient frequency dip criteria. For the 100% peak load case, the lowest frequency dip for Category B contingencies was to 59.81 Hz at the RAWHIDE 24.00 kV bus for disturbance scenarios #102, 104, & 105. Also, the lowest frequency dip for Category C contingencies was to 59.81 Hz at the RAWHIDEB 13.80 kV bus for disturbance scenario #301.

For the 64% peak load case, the lowest frequency dip on affected systems for Category B contingencies was to 59.78 Hz at the RAWHIDE 24.00 kV bus for disturbance scenario #101-106. Also, the lowest frequency dip for Category C contingencies was to 59.79 Hz at the RAWHIDE 24.00 kV bus for disturbance scenarios #300-301.

Appendix

A. Foothills Area Diagram



B. Transient Stability Study Fault Scenarios

Table 1
Listing of Transient Stability Study Contingency Scenarios

Disturbance Scenario #	Fault Type	Fault Location	Tripped Facilities
100	3ph	Ft St Vrain 230 kV	FSV – Weld 230 kV
101	3ph	Ft St Vrain 230 kV	FSV – Ault 230 kV
102	3ph	Ft St Vrain 230 kV	FSV – Longs Peak 230 kV
103	3ph	Ft St Vrain 230 kV	FSV – Isabelle 230 kV
104	3ph	Ft St Vrain 230 kV	FSV – Spindle 230 kV
105	3ph	Ft St Vrain 230 kV	FSV – Ft Lupton 230 kV #1
106	3ph	Ft St Vrain 230 kV	FSV – Green Valley 230 kV
110	3ph	Rawhide 230 kV	Rawhide – Ault 230 kV
111	3ph	Rawhide 230 kV	Rawhide – Timberline 230 kV
112	3ph	Rawhide 230 kV	Raw – Dixon Ck/Timb 230 kV
113	3ph	Rawhide 230 kV	Rawhide – Laporte 230 kV
300	3ph	Ft St Vrain 230 kV	FSV – Isabelle 230 kV FSV – Spindle 230 kV
301	3ph	Ft St Vrain 230 kV	FSV – Ft Lupton 230 kV #1 FSV – Ft Lupton 230 kV #2
310	3ph	Rawhide 230 kV	Rawhide – Ault 230 kV Rawhide – Timberline 230 kV
311	3ph	Rawhide 230 kV	Raw – Dixon Ck/Timb 230 kV Rawhide – Laporte 230 kV

C. Transient Stability Study Results

Table 2
Transient Stability Study Results with 3 Cycles Fault Time Margin
Foothills Area Load = 100% of Summer Peak
CBT Generation @ 0 MW
TOT 7 Transfer Path @ Thermal Flow Limit

Disturbance Scenario #	Stability	Transient Voltage Dip In Affected Systems		Minimum Transient Frequency In Affected Systems		
		Bus	Minimum Voltage Dip pu	Bus	Minimum Frequency Hz	Time at or Below WECC Limit sec.
100	Stable	OWL_LOW 12.47	0.9427	RAWHIDE 24.00	59.82	0
101	Stable	OWL_LOW 12.47	0.9463	RAWHIDE 24.00	59.82	0
102	Stable	DACONO 115.00	0.9140	RAWHIDE 24.00	59.81	0
103	Stable	OWL_LOW 12.47	0.9500	RAWHIDE 24.00	59.82	0
104	Stable	OWL_LOW 12.47	0.9473	RAWHIDE 24.00	59.81	0
105	Stable	OWL_LOW 12.47	0.9489	RAWHIDE 24.00	59.81	0
106	Stable	OWL_LOW 12.47	0.9474	RAWHIDE 24.00	59.82	0
110	Stable	OWL_LOW 12.47	0.9521	VALMONT6 13.80	59.90	0
111	Stable	OWL_LOW 12.47	0.9508	VALMONT6 13.80	59.90	0
112	Stable	OWL_LOW 12.47	0.9480	VALMONT6 13.80	59.90	0
113	Stable	OWL_LOW 12.47	0.9491	VALMONT6 13.80	59.90	0
300	Stable	OWL_LOW 12.47	0.9487	RAWHIDE 24.00	59.82	0
301	Stable	OWL_LOW 12.47	0.9500	RAWHIDEB 13.80	59.81	0
310	Stable	BERTHOUD 115.00	0.9461	AULT 115.00	59.89	0
311	Stable	OWL_LOW 12.47	0.9329	VALMONT6 13.80	59.90	0

Xcel Energy

Table 3
Transient Stability Study Results with 3 Cycles Fault Time Margin
Foothills Area Load = 64% of Summer Peak
CBT Generation @ 180 MW
TOT 7 Transfer Path @ 890 MW Rated Flow

Disturbance Scenario #	Stability	Transient Voltage Dip In Affected Systems		Minimum Transient Frequency In Affected Systems		
		Bus	Minimum Voltage Dip pu	Bus	Minimum Frequency Hz	Time at or Below WECC Limit sec.
100	Stable	JLGREEN 230.00	0.9572	RAWHIDE 24.00	59.78	0
101	Stable	JLGREEN 230.00	0.9578	RAWHIDE 24.00	59.78	0
102	Stable	JLGREEN 230.00	0.9579	RAWHIDE 24.00	59.78	0
103	Stable	JLGREEN 230.00	0.9546	RAWHIDE 24.00	59.78	0
104	Stable	JLGREEN 230.00	0.9538	RAWHIDE 24.00	59.78	0
105	Stable	JLGREEN 230.00	0.9569	RAWHIDE 24.00	59.78	0
106	Stable	JLGREEN 230.00	0.9568	RAWHIDE 24.00	59.78	0
110	Stable	VALMONT 230.00	0.9451	AULT 115.00	59.90	0
111	Stable	VALMONT 230.00	0.9455	QF_BCP2T 13.80	59.90	0
112	Stable	VALMONT 230.00	0.9453	QF_BCP2T 13.80	59.90	0
113	Stable	VALMONT 230.00	0.9458	QF_BCP2T 13.80	59.90	0
300	Stable	JLGREEN 230.00	0.9455	RAWHIDE 24.00	59.79	0
301	Stable	JLGREEN 230.00	0.9531	RAWHIDE 24.00	59.79	0
310	Stable	VALMONT 230.00	0.9414	AULT 115.00	59.89	0
311	Stable	VALMONT 230.00	0.9445	QF_BCP2T 13.80	59.91	0

D. Transient Stability Study Plots