COLSTRIP OPERATIONAL STUDY REPORT

SHUTDOWN OF COLSTRIP UNITS 1 & 2

2018

REGIONAL ELECTRIC TRANSMISSION PLANNING

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Executive Summary

Puget Sound Energy (PSE) has requested that NorthWestern Energy (NWE), the operator of the Colstrip Transmission System (CTS), conduct an Operational Study for the eventual shutdown of Colstrip units 1 and 2 (see Appendix 1). This study analyzed the potential impact that the shutdown could have on the Colstrip Transmission System after Colstrip Units 1 and 2 shut down. The results of this analysis conclude that the Colstrip Transmission System can support the 2200 MW of east to west transfer capability across Path 8 under a myriad of operating conditions, including the planned shutdown of Colstrip units 1 and 2.

NWE, working with the Colstrip Transmission Committee (CTC) (NorthWestern Energy, Puget Sound Energy, Inc., Avista Corporation, Portland General Electric Company, and PacifiCorp), developed the following study scope.

NWE performed post-transient power flow analysis, transient stability analysis, and short circuit analysis for the following three phases of the study:

Phase 1: Confirmation of 2200 MW Study

The purpose of this phase was to confirm that the CTS can handle 2200 MW East-to-West on Path 8 reliably. This study is tailored after NWE's Total Transfer Capability (TTC) study process, and establishes the capacity that can be moved across Path 8 which includes the 500 kV Colstrip system, along with the underlying transmission system, and interconnections to the Avista System. Since Path 8 is only capable of 2200 MW East-to-West under light load hours, only the following two cases were studied:

- 2018 Light Summer (18ls1ap)
- 2017-18 Light Winter (18lw2ap)

For each case, adjustments in the form of re-dispatching generation and/or adjusting phase shifting transformers (PSTs) were made to increase the westbound Path 8 flows, not to exceed 2200 MW. Colstrip units 1, 2, 3 and 4 were online for this study. Only PSTs on Paths 18, 80, and 83 were adjusted.

Phase 2: TTC Operational Study without Colstrip units 1 and 2

The intent of Phase 2 is to see if the CTS can handle the Path rating of 2200 MW reliably without Colstrip units 1 and 2. This study was performed the same as a Path Rating or TTC study would be performed under NERC Standard MOD-029. The base cases used for Phase 2 were:

- 2018 Light Summer (18ls1ap)
- 2017-18 Light Winter (18lw2ap)

For this study, adjustments in the form of re-dispatching generation and/or adjusting phase shifting transformers were made to increase the westbound Path 8 flows, not to exceed 2200 MW if achievable. Only PSTs on Paths 18, 80, and 83 were adjusted. Colstrip units 1 and 2, along with their associated station service power, were turned off.

Phase 3: 500 kV CTS study

PSE requested that NWE study the observable MW flows of the CTS (Colstrip to Townsend) only, without re-dispatching generation or adjusting PSTs while not exceeding system operating limits and path ratings on the interconnected systems. This study looked at varying operating conditions with and without Colstrip units 1 and 2. For all portions of Phase 3, the following cases were used:

- 2018 Heavy Summer
- 2018 Light Summer
- 2017-2018 Heavy Winter

For all cases, the PSTs were locked in their neutral tap positions.

For each of the cases listed above, the following 3 cases were created and analyzed:

- 3a - No changes made to the base cases
- 3b - Colstrip units 1 and 2 were turned off, along with their associated station service power, and generation was increased at Grand Coulee to make up for the lost power
- 3c - Colstrip units 1 and 2 were turned off, along with their associated station service power, and 610 MW of generic Type 4 wind generation on the Colstrip 230 kV bus was modeled and dispatched at 100%

Assumptions

The following assumptions were used for the base cases used for Colstrip Operational Study:

- Siemens PTI PSS®E software was used and included the Acceleration Trend Relay (ATR) simulation software
- All internal and external path limits were within their acceptable limits
- All in-service units at Colstrip will be set to output maximum generation

Post-Transient Power Flow Analysis

The post-transient power flow analysis was used to study the steady-state impacts to the system following a system contingency. The following assumptions were used:

- All manually operated voltage control devices were fixed to pre-contingency status
- PSTs were locked to pre-contingency tap position
- Automatically controlled Load Tap Changers and switched shunts were allowed to move
- Generators which manually control a high side remote bus were set to regulate the voltage at the terminal bus at pre-contingency voltage set point. Generators with automatically controlled remote regulation (i.e. LDC) were allowed to control the high side bus.
- Automatically controlled remedial action schemes (RAS), relay devices, and/or load shedding schemes were allowed to operate
- No lines were be allowed to be loaded over 100% of their emergency rating. If there was no emergency rating given to the line, lines were not be permitted to exceed 100% of their normal rating
- If automatic generation dropping occurred, system-wide generation was re-dispatched pro-rata to all generators within WECC
- TPL-001-WECC-CRT-3.1 Transmission System Planning Performance Criteria was used to determine system performance

Transient Stability Analysis

The transient stability analysis analyzed the dynamic impacts to the system during, and immediately following a system event. The following assumptions were used:

- Automatically controlled RAS, relay devices, and/or load shedding schemes were allowed to operate and were modeled appropriately
- A detailed ATR model was used
- A no-event 1 second simulation was ran prior to the event to show pre-contingency stability
- All machines in the WECC interconnection were monitored and were to remain in synchronism and relative rotor angles must not diverge

- TPL-001-WECC-CRT-3.1 Transmission System Planning Performance Criteria was used to determine system performance
- Impacts of tripping both Colstrip units 3 and 4 versus tripping either Colstrip Unit 3 or Colstrip unit 4 was studied for Phases 3b and 3c

Short Circuit Analysis

The short circuit analysis analyzed the fault current contributions as well as the X/R ratio of the transmission system around the CTS before and after the shutdown of Colstrip Units 1 and 2.

Contingencies

All Categories listed in NERC TPL-001-4 Table 1 were studied at the following locations:

- Colstrip
- Broadview
- Garrison
- Taft
- Hot Springs
- Bell
- Dworshak
- Grand Coulee
- Hatwai
- Lower Granite
- Hardin
- Crossover

P5 analysis was not performed as the system being studied has full redundant relaying. For P6 analysis (N-1-1), a base case was created after each P1.2 and 1.3 contingency was applied. Each P1.2 and P1.3 contingency was then applied to each one of these cases to provide the P6 results.

Phase 1: Confirmation of 2200 MW

The purpose of this phase was to confirm that the CTS can handle 2200 MW East-to-West on Path 8 reliably. This phase was tailored after NWE's TTC study process, and establishes the capacity that can be moved across Path 8, which includes the 500 kV Colstrip system, along with the underlying transmission system, and interconnections to the Avista System. Table 1 shows a summary of key path flows and the generation dispatch of the two cases studied.

Table 1: Phase 1 Dispatch Summary

	18ls1ap_p1	18lw2ap_p1
Colstrip Gross Total	2270 MW	2270 MW
Path 8	2200 MW	2200 MW
Path 18	56 MW	-140 MW
Path 80	-112 MW	-310 MW
Path 83	-242 MW	11 MW
Western Montana Hydro	1680 MW	1680 MW
NWE Control Area Load	1256 MW	1097 MW

A negative MW value indicates an import to NWE's transmission system.

Post-Transient Power Flow

The post-transient power flow analysis was performed after the transient stability analysis was performed in order to take into account RAS actions that will only occur in a transient stability simulation. The following is a summary and discussion of issues seen in the study.

Overloads

Colstrip – Broadview A or B 500 kV lines

Loss of one Colstrip – Broadview 500 kV line has potential to overload the series capacitors on the remaining Colstrip – Broadview 500 kV line if the ATR does not trip any units and Colstrip is at full output. The following contingencies have potential to cause this issue:

- P1.2 – Colstrip – Broadview A/B
- P2.1 – Colstrip – Broadview A/B
- P2.3 – Colstrip Breaker 500-001
- P2.3 – Colstrip Breaker 500-002
- P2.3 – Colstrip Breaker 500-003
- P2.3 – Broadview 500-010
- P2.3 – Broadview 500-011
- P2.3 – Broadview 500-014

The worst case overload on the Broadview - Garrison 500 kV series capacitors was 2157 A. The capacitors have a 2240 amp 30 minute rating and overloads can be mitigated in real time by curtailing generation before the 30 minutes expires. As a backup, the series capacitors will automatically bypass if loaded above 2200 A for 1 hour. Therefore, these overloads are not viewed as an issue.

Judith Gap – Harlowton 100 kV line

In the light winter base case, overloads were seen on the Judith Gap – Harlowton 100 kV line for loss of the Broadview – Judith Gap 230 kV line with ATR tripping. The following contingencies showed this issue:

- P2.3 - Broadview 230-036
- P2.3 - Broadview 230-037
- P4 - Broadview 230-037

The overload is a function of flows on the Broadview – Great Falls 230 kV line and not necessarily Path 8 flows. On top of that, there is a relay scheme in place to open one end of the affected line to mitigate this overload. The overload witnessed is not related to Path 8 and is considered a non-issue.

Columbia Falls – Kalispell 115 kV line

In the light summer base case, an overload was seen on the Columbia Falls – Kerr 115 kV line for a stuck breaker at the Hot Springs 230 kV substation. This overload is mostly a function of SKQ hydro generation levels and Flathead area loading and it’s not uncommon to see the line section open at Kerr to prevent post-contingency violations. There is also relaying in place to open the Kerr end of the line for heavy loading on the line. The overload is seen as an issue not related to Path 8.

Low Voltages

There were no low voltage issues witnessed for Phase 1.

High Voltages

The results of the Phase 1 analysis showed no high voltage issues.

Transient Stability

The transient stability analysis was performed in PSS®E and included all applicable RAS including the ATR simulator. Results of the transient stability study showed that there were no stability issues with Path 8 with westbound flows of 2200 MW.

Conclusion

The results of the Phase 1 analysis is consistent with past TTC studies and showed that there were no issues, CTS or otherwise, associated with Path 8 at 2200 MW.

Phase 2: TTC Operational Study without Colstrip Units 1 and 2

The intent of Phase 2 is to see if the CTS can handle the Path rating of 2200 MW reliably without Colstrip units 1 and 2. This phase was tailored after NWE's established TTC study process, and determines the capacity that can be moved across Path 8, which includes the 500 kV Colstrip system, along with the underlying NWE transmission system, and interconnections to the Avista System. Table 2 shows a summary of key path flows and generation dispatch of the two cases studied.

Table 2: Phase 2 Dispatch Summary

	18ls1ap_p2	18lw2ap_p2
Colstrip Gross Total	1610 MW	1610 MW
Path 8	2200 MW	2200 MW
Path 18	-106 MW	-170 MW
Path 80	-411 MW	-504 MW
Path 83	-88 MW	10 MW
Western Montana Hydro	1645 MW	1695 MW
NWE Control Area Load	1256 MW	1097 MW

Post-Transient Power Flow

The post-transient power flow analysis was performed after the transient stability analysis was performed in order to take into account RAS actions that will only occur in a transient stability simulation. The following is a summary and discussion of issues seen in the study.

Overloads

Judith Gap – Harlowton 100 kV line

In the light summer base case, overloads were seen on the Judith Gap – Harlowton 100 kV line for loss of the Broadview – Judith Gap 230 kV line with ATR tripping. The following contingencies showed this issue:

- P2.3 - Broadview 230-036
- P4 - Broadview 230-036
- P4 - Broadview 230-037

The overload of this line is a function of flows on the Broadview – Great Falls 230 kV line and not necessarily Path 8 flows. On top of that, there is a relay scheme in place to open one end of the affected line to mitigate this overload. The overload witnessed is not related to Path 8 and is considered a non-issue.

Columbia Falls – Kalispell 115 kV line

In the light winter base case, an overload was seen on the Columbia Falls – Kerr 115 kV line for a stuck breaker at the Hot Springs 230 kV substation. This overload is mostly a function of SKQ hydro generation levels and Flathead area loading and it's not uncommon to see the line section open at Kerr to prevent post-contingency violations. There is also relaying in place to open the Kerr end of the line for heavy loading on the line. The overload is seen as an issue not related to Path 8.

Low Voltages

There were no low voltage issues observed for Phase 2.

High Voltages

The results of the Phase 2 analysis showed no high voltage issues.

Transient Stability

The transient stability analysis was performed in PSS®E and included all applicable RAS including the ATR simulator. Results of the transient stability study showed that there were no stability issues with Path 8 at 2200 MW and Colstrip units 1 & 2 offline.

Conclusion

The results of Phase 2 indicate that the CTS is still capable of maximum transfers without Colstrip units 1 and 2 while adhering to the 2200 MW limit of westbound transfers across Path 8. The results of this phase of the study showed the system behaved very similarly to that of Phase 1. Therefore, the loss of units 1 & 2 should not affect Path 8's rated export capability.

Phase 3: 500 kV CTS Study

The purpose of phase 3 was to study the CTS (Colstrip to Townsend) under typical operating conditions represented by the use of unmodified WECC Operation Base Cases. This portion of the study did not include any re-dispatching of generation except when makeup power was necessary for the shutdown of Colstrip units 1 & 2, in which case Grand Coulee was adjusted. PSTs were also not allowed to move to re-dispatch power around the system. The results of the Phase 3 Study could be mitigated through modified operation of the overall Montana transmission system. In other words, the use of the existing capabilities of the overall Montana Transmission system, which is normal operation, would yield results as shown in Case 2 with no impacts to Path 8's capability.

Phase 3 included three operating base cases; heavy summer 2018, light summer 2018, and light winter 2018. Each case was then modified to look at effects of the system with units 1 & 2 offline as well as what a potential type 4 wind farm replacing Colstrip units 1 & 2 would look like. Table 3 shows a summary of key path flows and generation dispatch of each of the cases and scenarios studied.

Table 3: Phase 3 Dispatch Summary

	18hs4ap_p3a	18hs4ap_p3b	18hs4ap_p3c	18ls1ap_p3a	18ls1ap_p3b	18ls1ap_p3c	19hw3ap_p3a	19hw3ap_p3b	19hw3ap_p3c
Colstrip Gross Total	2270 MW	1610 MW	1610 MW	2270 MW	1610 MW	1610 MW	2270 MW	1610 MW	1610 MW
Replacement CS Wind	0 MW	0 MW	610 MW	0 MW	0 MW	610 MW	0 MW	0 MW	610 MW
Path 8	567 MW	70 MW	571 MW	1507 MW	1012 MW	1507 MW	1163 MW	650 MW	1163 MW
Path 18	268 MW	256 MW	271 MW	107 MW	98 MW	107 MW	149 MW	118 MW	148 MW
Path 80	41 MW	-32 MW	41 MW	-66 MW	-139 MW	-66 MW	-278 MW	-275 MW	-278 MW
Path 83	51 MW	51 MW	52 MW	55 MW	55 MW	55 MW	59 MW	27 MW	60 MW
Western Montana Hydro	1620 MW	1620 MW	1620 MW	1680 MW	1680 MW	1680 MW	1300 MW	1300 MW	1300 MW
NWE Control Area Load	1868 MW	1859 MW	1868 MW	1200 MW	1191 MW	1200 MW	1729 MW	1718 MW	1729 MW

The three scenarios for each base case is as follows:

- Phase 3a (p3a) – base case without modifications
- Phase 3b (p3b) – base case with Colstrip units 1 & 2 removed, power replaced by Grand Coulee
- Phase 3c (p3c) – base case with Colstrip units 1 & 2 removed, power replaced by type 4 wind farm

Post-Transient Power Flow

The post-transient power flow analysis was performed after the transient stability analysis was performed in order to take into account RAS actions that will only occur in a transient stability simulation. The following is a summary and discussion of issues seen in the study.

Overloads

Colstrip – Broadview A or B 500 kV lines

Loss of one Colstrip – Broadview 500 kV line has the potential to overload the series capacitors on the remaining Colstrip – Broadview 500 kV line if the ATR does not trip any units and Colstrip and/or Colstrip replacement wind are at full output. This was only an issue in the phase 3a and 3c scenarios. The following contingencies have potential to cause this issue:

- P1.2 – Colstrip – Broadview A/B
- P2.1 – Colstrip – Broadview A/B
- P2.3 – Colstrip Breaker 500-001
- P2.3 – Colstrip Breaker 500-002
- P2.3 – Colstrip Breaker 500-003
- P2.3 – Broadview 500-010
- P2.3 – Broadview 500-011
- P2.3 – Broadview 500-014

The capacitors have a 2240 amp 30 minute rating and overloads can be mitigated in real time by curtailing generation before the 30 minutes expires. As a backup, the series capacitors will automatically bypass if loaded above 2200 A for 1 hour. Therefore, these overloads are not viewed as an issue.

Garrison – Anaconda BPA 230 kV line

In the heavy summer base case, an overload was seen on the Garrison – Anaconda BPA 230 kV line for the loss of the parallel Garrison – Mill Creek 230 kV line. This overload was consistent across all three heavy summer scenario cases (p3a, p3b, and p3c) and is a function of system load and Path 18 flows. Path 8 has little-to-no impact on this overload situation as seen by the similar loading between the cases with and without Colstrip units 1 & 2 and corresponding reduction in Path 8 flows.

Columbia Falls – Kalispell 115 kV line

In the light summer base case, an overload was seen on the Columbia Falls – Kerr 115 kV line for a stuck breaker at the Hot Springs 230 kV substation. This overload is mostly a function of SKQ hydro generation levels and Flathead area loading and it's not uncommon to see the line section open at Kerr to prevent post-contingency violations. There is also relaying in place to open the Kerr end of the line for heavy loading on the line. The overload is seen as an issue not related to Path 8.

Steamplant – South Huntley 230 kV & Colstrip – Hardin 230 kV lines

In each of the cases with the replacement wind at Colstrip (p3c), loss of both Colstrip – Broadview 500 kV lines can cause overloads on the parallel 230 kV system. This is considered an extreme event per TPL-001-4 standards, however, a RAS may be necessary to alleviate these overloads if Colstrip were ever to be replaced with wind generation.

Low Voltages

Butte Area

A fault on any one of the 230 kV breakers at Garrison and subsequent loss of the Garrison 230 kV substation showed low voltages in the Butte, MT area in each of the heavy summer scenario cases. This is considered to be a very rare event. This is a function of system loading and Path 18 flows, and showed no appreciable difference between differing Path 8 flows.

Billings Area

In each of the cases with the replacement wind at Colstrip (p3c), loss of both Colstrip – Broadview 500 kV lines can cause low voltages in the Billings area. This is considered an extreme event per TPL-001-4 standards, however, a RAS may be necessary to alleviate these voltage issues if Colstrip were ever to be replaced with wind generation.

High Voltages

Billings Area

In the light winter base scenario with replacement wind at Colstrip (p3c), loss of both Colstrip – Broadview 500 kV lines can cause high voltages in the Colstrip area. This is considered an extreme event per TPL-001-4 standards, however, a RAS may be necessary to alleviate these voltage issues if Colstrip were ever to be replaced with wind generation.

Transient Stability

The transient stability analysis was performed in PSS®E and included all applicable RAS including the ATR simulator. Results of the transient stability study showed that there were no stability issues with any of the scenario cases.

Impacts of Limiting ATR Tripping

The impacts of limiting ATR tripping to 50%, or one unit, for Phases 3b and 3c was analyzed. Results showed that tripping of greater than 50% may be necessary to guarantee system stability. Analysis showed that in the heavy summer case with replacement wind generation (p3c), TPL violations would occur for a double Broadview – Garrison outage if the ATR was limited to 50%. A RAS that would trip the replacement wind generation may also prevent the TPL violations from occurring, however this was outside of the scope of this study.

The study also showed that even though ATR tripping was limited to 50%, there were many simulations in each of scenarios that triggered the Individual Unit Overspeed algorithm for the remaining unit. Since the Individual Unit Overspeed tripping was triggered and the contingencies resulted in two units being tripped, it is recommended that the ATR not be limited 50%. This would allow the ATR to take both units sooner, leading to better system stability.

Short Circuit

A short circuit analysis was run for each of the scenarios. The study showed no issues with total fault current or X/R ratio in any of the scenarios. Table 4 shows the results for each of the scenarios.

Table 4: Short Circuit Results

	Scenario 1 (p3a)		Scenario 2 (p3b)		Scenario 3 (p3c)	
	3PH I+ (Amps)	X/R	3PH I+ (Amps)	X/R	3PH I+ (Amps)	X/R
Colstrip 230 kV	20096	21.56	13313	18.13	15250	20.11
Colstrip 500 kV	13397	15.07	11230	12.83	12051	13.60
Broadview 230 kV	16244	7.84	15241	7.49	15787	7.59
Broadview 500 kV	11217	8.89	10167	8.47	10627	8.59
Garrison 230 kV	17383	7.15	16986	7.08	17261	7.04
Garrison 500 kV	10979	7.67	10675	7.60	10817	7.54
Taft 500 kV	14726	8.11	14575	8.06	14679	8.05
Bell 230 kV	29794	6.16	30262	6.11	29851	6.18
Bell 500 kV	15489	8.54	15530	8.56	15501	8.58
Dworshak 500 kV	12855	10.56	12726	10.41	12856	10.54
Hot Springs 230 kV	14992	8.13	14873	8.10	14995	8.09
Hot Springs 500 kV	7939	9.49	7873	9.45	7936	9.43
Grand Coulee 500 kV	36977	11.22	38957	11.74	38852	11.77
Hatwai 230 kV	19923	9.05	19878	9.01	19936	9.05
Hatwai 500 kV	14480	10.55	14400	10.47	1488	10.55
Lower Granite 500 kV	18322	13.74	18263	13.71	18340	13.78
Hardin 230 kV	8077	12.08	7561	12.28	7849	12.35
Crossover 230 kV	8156	12.60	7643	12.74	7914	12.83

Conclusion

The results for Phase 3 showed that the system performed similarly between each scenario. The removal of Colstrip units 1 & 2, as well as the addition of a 610 MW type 4 wind farm showed zero new transient stability issues on the system. If a new 610 MW wind farm were to connect at Colstrip, a RAS may be required to trip the wind farm for the extreme event of the loss of both Colstrip – Broadview 500 kV lines. The results also showed that modifications to the ATR to try to reduce tripping would not be advised. Additional studies may be required to determine the ability of any new generation to deliver electricity to any specific customer or Point of Delivery on a firm or non-firm basis. The additional studies may conclude, for example, that the new generation may be required to participate in a Remedial Action Scheme.

All three portions of the Phase 3 study showed that, from a typical operation perspective, the CTS can still be operated reliably regardless from where the power transferred across the system is coming.

Appendix 1 Puget Sound Energy Request

PUGET SOUND ENERGY

Puget Sound Energy
P.O. Box 97034
Bellevue, WA 98009-9734
PSE.com

August 11, 2017

Via Express Mail

Mr. Michael McGowan
NorthWestern Energy
11 East Park
Butte, MT 59701

Re: Colstrip Transmission Agreement & Shutdown of Colstrip Units 1 & 2 Operational Study Request

Attn: Mr. Michael McGowan, Manager Transmission Services and Operations Support

Dear Mr. McGowan:

This letter is in regards to the Colstrip Transmission Agreement between NorthWestern Energy, Puget Sound Energy, Inc., Avista Corporation, Portland General Electric Company, and PacifiCorp ("Tranmission Owners"). As you are aware Puget Sound Energy, Inc. ("PSE") has announced that PSE plans to shut down Colstrip Units #1 and #2 no later than July 1, 2022.

Many of the studies conducted to date on the shutdown of Colstrip Units #1 and #2 incorporate replacement power scenarios and other mitigating assumptions. Further clarity is needed with respect to specific impacts, limitations, transfer capability, etc. of the shutdown of Colstrip Units #1 & #2 on the Colstrip Transmission System ("CTS") without the assumption of any new generation on either the 500 kV or 230 kV systems. Additionally, when Colstrip Units #1 and #2 are retired, any transmission improvements that may be needed to maintain the reliability and stability of the transmission system in the area should be identified.

PSE is submitting this letter to NorthWestern Energy, the designated operator of the Colstrip Transmission System, as a written request to conduct an operational study of the shutdown of Colstrip #1 and #2. The study should be coordinated with the Transmission Owners for their input and concurrence on scope and timing.

If you have any questions or comments in regards to this request, please feel free to direct them to myself at (425) 462-3706 or Laura Hatfield at (425) 462-3921. We look forward to working with you and the other Transmission Owners on this request.

Sincerely,

Puget Sound Energy, Inc.

By ______________________

George Marshall

Its: Manager Transmission Policy & Contracts

Cc: Transmission Owners

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