Transmission Study
for the
Northeast Colorado Area

November, 2010

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Transmission Study  
for the  
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Executive Summary

The northeastern Colorado transmission system was analyzed to determine the preferred alternative to mitigate known transmission system deficiencies, and to evaluate system alternatives to improve the future reliability, and capacity and load serving capability of the system. The study identified contingency loading limitations under light winter and heavy summer conditions with various power injections in the Wray and Burlington areas. The study confirmed the need for additional transmission for certain system contingencies.

The performance of the transmission system was studied for several system conditions and identified the construction of a Burlington to Wray 230 kV line as the best solution to solve several existing transmission system deficiencies. The line would complete a continuous 230 kV path through northeastern Colorado and substantially increase the limit of the load serving path through this area. The proposed line improves the reliability of the transmission system, increases Tri-State’s load serving capability, and increases export capability for existing and planned generation.
Figure 1: Burlington/Wray Area in Northeastern Colorado
Transmission Study for the Northeast Colorado Area

Background

Load growth and generation additions in northeast Colorado have put a strain on the current 115 kV transmission system. Under certain system conditions, the ability to schedule local generation is limited by overloading conditions on sections of the Burlington – Wray 115 kV line. This 115 kV line is also the limiting element in Tri-State’s load-serving path from Story to Wray to Burlington to Big Sandy to Midway. Additionally, Tri-State has received several third party generation requests for interconnection to the northeast Colorado system that cannot be accommodated with the existing transmission system. Tri-State performed this study to identify system deficiencies in northeast Colorado and to evaluate alternatives for improving the reliability and load serving capability of the transmission system through feasibility and power flow analyses.

Existing Transmission System Deficiencies

1. Operating restrictions on the existing Limon and Burlington generation.

   Past study work has identified operating conditions where the existing Burlington to Wray 115 kV line limits Tri-State’s ability to dispatch existing generation resources in eastern Colorado. The most critical single-contingency outage, as identified by previous study work and confirmed by this study, is a loss of the existing Lincoln to Midway 230 kV line. Under this outage, and during light loading conditions, the existing generation resources at Limon and Burlington can be restricted from simultaneously operating at their full output without criteria violations on the existing system. A portion of the Limon and Burlington resources are used to meet Tri-State reserve obligations. The existing Burlington generators have the added operating advantage of quick start capability, that is, they can be called upon, made available and dispatched much faster than typical combustion turbine generation. Therefore, to maximize response capabilities to system conditions and to improve system reliability, it is important that existing operating restrictions on the dispatching of these units be eliminated.

2. Interim Restricted Operating Procedure placed on the 51 MW Kit Carson wind project.

   Tri-State Transmission received an application from Tri-State Power Marketing for the designation of the 51 MW Kit Carson wind project as a Network Resource for Tri-State Power Marketing as a part of a Network Service Request dated July 8, 2009. The request was granted conditioned upon an operating restriction applied to the Burlington Network Resources, including the Kit Carson wind project due to overloads on the existing system identified by the System Impact Study performed for the project. A restricted Network
Resource designation was granted for the wind project until such time as network upgrades could be completed. Tri-State Power Marketing and Tri-State Transmission have negotiated an Interim Restricted Operating Procedure\(^1\) to this effect.

Pursuant to Tri-State’s Open Access Transmission Tariff (OATT), all new Network Resources must meet specified reliability design requirements. Specifically, Tri-State requires that any new Network Resource must be able to stay on-line at full output and meet all reliability design criteria for the most severe N-1 outages with all existing Network Resources in the study area also operated at full output. The designation of the 51 MW Kit Carson wind project as a Network Resource requires that this reliability design criteria be met. Therefore, construction of network upgrades will be required to 1) eliminate the current operating restrictions, 2) meet the specific reliability design requirement noted above, and 3) meet Tri-State’s obligations to its Network Customers under its OATT.

3. **Deliverability of Tri-State resources to Tri-State native load.**

Tri-State has an existing need for additional or expanded contractual path rights between Wray and Burlington. Tri-State has some of its most economical base-load Network Resources available to serve native loads in southeastern Colorado located in Wyoming and western Colorado. The existing Wray to Burlington 115 kV line constitutes a portion of a primary contractual transmission path utilized by Tri-State to serve its native load in eastern and southern Colorado from these resources and is limited by its current thermal capacity. This study analyzes these load serving and deliverability deficiencies and requirements.

**Previous Studies**

The Burlington - Bonny Creek – South Fork - Idalia – Vernon Tap - Wray 115 kV line is the common limiting element for each of the existing transmission system deficiencies noted above. The line conductor is Hawk 477 ACSR built for 75 °C and is rated at 120 MVA due to terminal equipment limitations. The thermal capability of this line can be increased from 120 MVA to 140 MVA provided that the terminal equipment is replaced. Previous study work identified this line as a weak link in Tri-State’s northeastern Colorado system. That study work included:

- TI-08-0502 Kit Carson 51 MW generation interconnection SIS, FS and Interim Restricted Operating Procedure (November & December 2009, October 2010)
- TI-06-0929A Burlington Area SIS (February 2010)
- TSGT 2010 L&R study (June 2010)
- CLRTPG08 (June 2008)
- TI-04-1103 & TI-06-0223 SIS (December 2007)
- TI-07-0412B Wray Area IFS (August 2007)

\(^1\) The Interim Restricted Operating Procedure applies to the Burlington Network Resources, including the Burlington CT’s and the Kit Carson Wind project, accounting for the status of the Limon CT’s
Alternative Identification

The existing Tri-State transmission system in the Burlington and Wray areas consists of one 230 kV line extending from Story to North Yuma to Wray and a second 230 kV line extending from Big Sandy to Burlington. The underlying 115 kV system interconnects these 230 kV terminations and serves the Tri-State native load in the region. Since, as noted above, the Burlington - Bonny Creek – South Fork - Idalia – Vernon Tap - Wray 115 kV line is the common limiting element, the first step toward improving the transmission system in eastern Colorado is to increase the transmission capacity of this path.

Various alternatives for alleviating the Burlington – Wray 115 kV path limitation were identified. The alternatives included variations in line voltage and number of circuits to be constructed, and consideration of reuse of the existing Burlington to Wray 115 kV transmission line and associated right-of-way. Those alternatives are discussed in detail in Appendix A. Alternatives that utilized only one circuit between Burlington and Wray, whether trying to upgrade the existing 115 kV line or removing the existing 115 kV line and building a new single circuit line in its place, were eliminated from further consideration since they either cannot solve the transmission system deficiencies identified in this report or do so with significant cost, constructability, operation, and maintenance concerns as discussed in Appendix A.

Another alternative, and one which previous study work had assumed, is the construction of a second transmission line between Burlington and Wray which would electrically parallel the existing 115 kV line. Tri-State’s analysis included in this report and from previous studies shows that a project consisting of a new single-circuit 230 kV transmission line between the existing Burlington and Wray Substations, both owned by Tri-State, is the best solution. The choice of 230 kV completes the 230 kV path from Story to North Yuma to Wray to Burlington to Big Sandy through eastern Colorado. There are presently no higher transmission voltages in operation in eastern Colorado with which to interconnect, and the choice of 230 kV integrates well with the existing substations at Wray and Burlington. A 230 kV line constructed with 1272 MCM ASCR conductor at a maximum design temperature of 100 degrees C would have a rating of 612 MVA (1538 amperes), thereby substantially increasing the present 140 MVA rating of the Burlington to Wray path. This added capacity is sufficient to remove the Burlington – Wray path from limiting the Story – Wray – Burlington – Big Sandy – Midway contractual path.

Transmission line construction to sources other than Burlington and Wray were considered but not studied as a part of this effort, since the transmission limitation being addressed by this study is a path limitation and not a local load-serving limitation. As noted above, the immediate system need is to increase the capacity of the constrained path. Construction of a new 230 kV line between Burlington and Wray will integrate well with future transmission that may interconnect with the 230 kV system. Any new transmission will be able to interconnect to a continuous 230 kV path, thereby providing bi-directional transmission access to loads and resources on the 230 kV system.

While some of the transmission deficiencies identified in this report could individually be met with other transmission alternatives, including transmission connections to other stations, these
alternatives did not resolve all of the identified deficiencies with a common solution. Therefore, this report presents the findings of constructing a new single-circuit 230 kV transmission line from the existing Burlington Substation to the existing Wray Substation. The study evaluates the performance of the transmission system with the proposed Burlington to Wray 230 kV line and evaluates design alternatives that may improve the future reliability, capacity and load serving capability of the transmission system in northeastern Colorado. The proposed Burlington to Wray 230 kV line will electrically parallel the existing 115 kV line and is estimated to be approximately 60 miles long. The proposed in-service date (ISD) for the line is December 2015.

**Study Scope**

A power flow contingency analysis of the northeastern Colorado region was evaluated to determine the system performance both with and without the Burlington – Wray 230 kV line addition. The northeast Colorado system consists of the transmission south of TOT3, east of Pawnee, and north of Midway. The outage list included all single transmission elements in northeastern Colorado (see Appendix B). Any relevant more severe (category C or category D) contingencies were also identified and evaluated. All buses, lines, and transformers in the northeastern Colorado region were monitored for criteria violations, as specified below.

**Base Case**

An evaluation of 2013 summer and 2013 winter conditions was performed. This case selection was made based on the availability of applicable, trustworthy cases and the original projected in-service date of December 2013, which has since been modified to December 2015. The starting cases were Tri-State’s 2013 Heavy Summer (HS) LGIP case and 2013 Light Winter (LW) LGIP case. These cases both originated from the 12hs2ap.sav WECC case, with review and modifications by the CCPG utilities. The major modifications that were made to the starting cases to create the study base cases are in Appendix C.

**Criteria**

Acceptable voltages for all buses in the study area are between 0.95 and 1.05 per unit under system normal conditions. Acceptable loading on any transmission line is less than 80 percent of its continuous rating, and less than 100 percent of its maximum nameplate rating for transformers. System adjustments during solution were allowed, including shunt capacitor switching and LTC tap adjustments. Area interchanges and phase shifter adjustments were not utilized in order to stress flows north to south, particularly on TOT3.

Tri-State’s Engineering Standards Bulletin state’s that the 80 percent system normal line loading criteria applies to Tri-State owned transmission lines. This criterion is in recognition of the high losses, high voltage drop, and possible steady-state stability problems associated with a line loaded above 80% of its static thermal rating. For lines owned by other entities, loading above
this limit was noted, but no facility upgrades were required until the loading reached 100 percent of their continuous ratings under system normal conditions.

In the case of single contingency conditions, acceptable voltages for all buses in the study area are between 0.90 and 1.10 per unit. For Platte River Power Authority (PRPA) buses, the acceptable voltage range is 0.92 to 1.07 per unit. Acceptable loading for all transmission lines and transformers is below 100 percent of their continuous ratings or any applicable emergency ratings as specified by the owner of a particular element. However, no applicable emergency ratings were identified for this study beyond a few terminal equipment ratings discussed below. System adjustments during solution were not allowed, including shunt capacitor switching, LTC tap adjustments, area interchanges and phase shifter adjustments.

Study Method

A contingency analysis was performed on the study base cases, both with and without the Burlington – Wray 230 kV line. The results with the line addition were compared to the results without it to determine the effects of the line addition.

The analysis was repeated with additional generation injections modeled, consistent with the general locations of interconnection requests that Tri-State has received in its interconnection queue. In particular, the Kit Carson wind interconnection (DEGS) was modeled at 51 MW approximately 5 miles from the Burlington substation along the Burlington – Big Sandy 230 kV line. Two additional injections were analyzed: one injection of power was modeled at up to 200 MW approximately 30 miles from Burlington along the Burlington – Big Sandy 230 kV line (BurlWInc), and a second injection was modeled at the Wray 230 kV bus at up to 200 MW (WrayWInj). The study results identified the approximate amounts of additional generation at these two locations which the 230 kV line addition could accommodate before additional criteria violations occurred.

First, the system with just the Kit Carson wind injection was analyzed with and without the Burlington – Wray 230 kV line. As noted in the Kit Carson Wind System Impact Study and the associated Operating Agreement, the Kit Carson Wind project and the existing Burlington thermal units currently must coordinate operation in order to avoid overloading the Burlington – Wray 115 kV line before the 230 kV line is built. System analysis was subsequently performed on cases with the Kit Carson wind project plus the generation injection near Burlington, and on cases with the Kit Carson wind project plus the generation injection at Wray. As a result, the analysis identified any additional benefits of the Burlington – Wray 230 kV line to accommodate generation interconnections in northeastern Colorado.

Results

The study results are summarized below and in Table 1. Detailed outage results can be found in Appendix D for the 2013 HS case and Appendix E for the 2013 LW case.
In the study cases, the Burlington - Big Sandy 230 kV line was split into 3 line sections: the Burlington – DEGS line section, the DEGS – BurlWInc line section, and the BurlWInc – Big Sandy line section. DEGS is where the Kit Carson (Duke Energy) wind farm will inject power onto the line, and BurlWInc is where an additional injection of wind power was modeled on the line.

The BurlWInc - Big Sandy 230 kV line is limited to 179 MVA due to terminal equipment at Big Sandy. However, the conductor thermal rating of 284 MVA was used for this study. Terminal equipment was not considered limiting since changes to terminal equipment ratings have relatively low cost and small lead times. Similarly, the Burlington – Wray 115 kV line is limited to 120 MVA due to terminal equipment, but the conductor rating of 140 MVA was used in this study.

For both the light winter and heavy summer cases, there were no criteria violations with the Burlington – Wray 230 kV line addition for cases with no generation injections, including no Kit Carson generation. The same is true for heavy summer conditions with the Kit Carson generation injection of 51 MW. Therefore, while previous studies have found limitations on the existing resources at Burlington and Limon, the dispatch and stressing assumptions used in this study allowed the existing generation to operate to its full capacity under heavy summer conditions.

However, in the light winter case with the Kit Carson generation injection at 51 MW, both the Big Sandy – Beaver Creek 115 kV line and the Burlington – Wray 115 kV line overloaded for several contingencies prior to the 230 kV line addition, at a maximum of 120% and 113% respectively. The overloading on both of these lines is mitigated by the 230 kV line addition for all of the associated contingencies (See Table 1).

This verifies the previously defined need for an interim operating procedure on the Kit Carson Wind facility, and also verifies that the Burlington – Wray 230 kV line addition eliminates the need for that operating procedure.
<table>
<thead>
<tr>
<th>Case</th>
<th>Outage</th>
<th>Monitored Element</th>
<th>Rating (MVA)</th>
<th>Loading w/o Burlington-Wray 230 kV Line (%)</th>
<th>Loading w/ Burlington-Wray 230 kV Line (%)</th>
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<td>Bonny Creek - Burlington 115 kV</td>
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<td>LW DukeInj</td>
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<td>Idalia - South Fork 115 kV</td>
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<td>&lt; 100.0</td>
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<tr>
<td>LW DukeInj</td>
<td>Big Sandy - BurlWInc 230 kV</td>
<td>Idalia - Vernon Tap 115 kV</td>
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<td>Big Sandy - BurlWInc 230 kV</td>
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<td>BurlWInc - DEGS Wind 230 kV</td>
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<td>109.6</td>
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Load Serving Analysis

As stated in the Existing Transmission System Deficiencies section of this report, Tri-State has a need for additional contractual path rights between Wray and Burlington. Tri-State’s native load obligation in south and eastern Colorado includes service to K.C. Electric Association, Mountain View Electric Association, San Isabel Electric Association, San Luis Valley Rural Electric Cooperative, Southeast Colorado Power Association and Gunnison County Electric Association. In addition to this transmission path, Tri-State purchases firm transmission from CRSP (Western) and Public Service Company of Colorado for service to these loads. These transmission sources owned by or purchased by Tri-State comprise the Total Transfer Capability (TTC) that Tri-State has available to serve its native load in the south and southeastern Colorado areas and to meet its other existing transmission commitments.

Determining the Available Transmission Capability (ATC) for the existing Wray to Burlington 115 kV line requires an analysis of the Total Transfer Capability (TTC) of the transmission system owned or available to Tri-State to meet its native load-serving needs. A non flow-based analysis of the projected uses of the Wray to Burlington line was conducted. ATC was calculated.

\[
\text{ATC} = \text{Total Transfer Capability (TTC)} - \text{Existing Transmission Commitments (ETC)} - \text{Transmission Reliability Margin (TRM)}
\]

- TTC was determined in accordance with Tri-State’s *Engineering Standards Bulletin – Reliability Criteria for System Planning and Service Standards* which states the maximum loading criteria for transmission lines as a percent of the continuous rating. Based on that criteria, TTC in this study was defined as 100 percent of the thermal rating of the line sections in the transmission path.

- ETC is defined as Tri-State native load-serving needs, existing commitments for transmission service and existing commitments for purchase/exchange/delivery.

- TRM is defined as through flow across the requested path and transfer capability required to ensure reliable system operation as system conditions change. WECC operating practice requires transmission providers to accommodate some through-flow which may decrease ATC. TRM is also utilized to deliver and receive reserve obligations associated with a Reserve Sharing Group.

Tri-State Power System Planning provided a 10 year native load forecast for K.C. Electric Association, Mountain View Electric Association, San Isabel Electric Association, San Luis Valley Rural Electric Cooperative, Southeast Colorado Power Association and Gunnison County Electric Association. Tri-State System Operations provided the firm committed uses for the Story to Wray to Burlington to Big Sandy to Midway transmission path and confirmed Tri-State’s reserve obligations with Tri-State Energy Management. These values were used as follows.
TTC is defined as the thermal rating of the Wray to Burlington 115 kV line section. This rating is 140 MVA and is based on 477 ACSR conductor constructed for 75 degrees C operation.

Transmission MW capacity of the Wray to Burlington 115 kV line: 140 MW

Transmission purchased from others by and for Tri-State native loads:

- Firm transmission from CRSP for Tri-State: 100 MW
- CRSP Preference Power delivered to Midway: 43 MW
- Firm transmission from PSCo (Ault-Comanche): 50 MW

Total TTC: 333 MW

ETC is the sum of native load demand, existing commitments for transmission service and existing commitments for reserves. Tri-State’s 10-year projected coincident native load (Total Maximum Coincident Peak, or MCP) for K.C. Electric, San Isabel, San Luis Valley, Mountain View, Gunnison County, and Southeast Colorado Power is as follows: 419 MW winter peak and 446 MW summer peak.

Firm Committed Uses by Others on the Wray to Burlington Line

- PSCo delivery to MEAN (City of Fountain): 40 MW
- PSCo delivery to ARPA (Las Animas): 3 MW
- ARPA existing firm use: 3 MW

Total: 46 MW

Total ETC = 446 MW (native load summer peak) + 46 MW = 492 MW

No significant variations in firm requirements for transmission capacity (reserve margin) are assumed for the Wray to Burlington path, therefore for purposes of this study the TRM is 0 MW.

Based on the above, the existing ATC for the Wray to Burlington 115 kV line section is calculated as follows:

\[
\text{ATC} = \text{TTC} - \text{ETC} - \text{TRM} \\
\text{ATC} = 333 \text{ MW} - 492 \text{ MW} - 0 \text{ MW} = -159 \text{ MW}
\]
This non flow-based analysis of ATC for the Wray to Burlington 115 kV line demonstrates that Tri-State is presently unable to source its entire south and southeastern Colorado native load via its Story-North Yuma-Wray-Burlington-Big Sandy-Midway path. Therefore, Tri-State is limited to less economical Network Resource dispatch or purchases from others to serve this native load. The above analysis identified committed uses which, together with Tri-State’s native load requirements, results in zero ATC available for third party interconnections.

With the construction of the proposed Burlington to Wray 230 kV line, TTC is defined as the thermal rating of the entire Wray to Burlington path, that is, the sum of the 115 kV line thermal rating and the 230 kV line thermal rating. Tri-State is proposing to construct the Burlington to Wray 230 kV line with 1272 MCM ACSR conductor with a maximum design temperature of 100 degrees C (1538 amperes)(612 MVA). Therefore, TTC with the proposed Burlington to Wray 230 kV line becomes:

MW capacity of the Wray to Burlington path: 612 MW + 140 MW = 752 MW

Based on the above, the existing TTC for the Wray to Burlington line section, as an element of the Story-North Yuma-Wray-Burlington-Big Sandy-Midway path, increases from 140 MW to 752 MW and removes the most limiting element of this path. It should be noted that increasing the TTC of the Wray to Burlington section, by itself, does not permit Tri-State to source all of its native load-serving needs via the Story-North Yuma-Wray-Burlington-Big Sandy-Midway path. The next most limiting element is the Story to North Yuma 230 kV line, which is limited due to its conductor thermal rating and Existing Committed uses for that line. However, Tri-State is investigating the possibility of upgrading the Story to North Yuma 230 kV line to 100 degrees C operation. That upgrade will raise the thermal rating of the line to approximately 512 MW, greatly increasing Tri-State’s contractual load-serving capability over the Story-North Yuma-Wray-Burlington-Big Sandy-Midway path. Therefore, the proposed 230 kV Burlington to Wray line is the first part of a two-part proposal to increase the load serving capability of this contractual path.

**Additional Generation**

The addition of the Burlington – Wray 230 kV line to the eastern Colorado transmission system provides the added benefit of accommodating some amount of additional power injection. In order to quantify this benefit, the study looked at power injection near Burlington and Wray, incrementing that injection from zero up to 200 MW at each location. System limitations were found when the Kit Carson wind generation was combined with 160 MW of additional generation near Burlington or with 175 MW of additional generation near Wray. Study results are summarized below and in Table 2. Detailed results are in Appendix D for heavy summer conditions and Appendix E for light winter conditions.
In the light winter case with 160 MW of additional generation injections near Burlington, all overloads are mitigated by the 230 kV line addition, except for the Big Sandy – Last Chance 115 kV line loading to 100% of its 109 MVA rating for the Midway – Lincoln 230 kV line outage. This establishes the limitation of the Burlington generation injections for the dispatch assumptions modeled in this study. In addition, instances of voltage instability of the system under outage conditions are mitigated by the Burlington – Wray 230 kV line addition, as seen for both the Big Sandy – BurlWInc 230 kV line outage and the Midway – Lincoln 230 kV line outage, which reach solution only after the 230 kV line addition.

In the light winter case with 175 MW of additional generation injections near Wray, all overloads are mitigated by the 230 kV line addition, except for the Eckley – Wray Tap 115 kV line loading to 101% of its 85 MVA rating for the outage of the North Yuma – Wray 230 kV line. This establishes the limitation of the Wray generation injections for the dispatch assumptions modeled in this study.

In the heavy summer cases with the above generation injections, all pre-project criteria violations are mitigated with the addition of the Burlington – Wray 230 kV line. The instance of voltage instability under outage conditions is also mitigated, as seen for the Big Sandy – BurlWInc 230 kV line outage, which reaches solution only after the 230 kV line addition.

These results do not indicate the exact levels of generation additions that can be expected through a Generation Interconnection (GI) or Transmission Service Request (TSR) study. The assumptions required for those studies may differ from the ones used herein.
Table 2a: LW Results I, Burlinj at 160 MW

<table>
<thead>
<tr>
<th>Case</th>
<th>Outage</th>
<th>Monitored Element</th>
<th>Rating (MVA)</th>
<th>Loading w/o Burlington-Wray 230 kV Line (%)</th>
<th>Loading w/ Burlington-Wray 230 kV Line (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DukeInj + BurlInj</td>
<td>System Normal</td>
<td>Big Sandy - BurlWInc 230 kV</td>
<td>284</td>
<td>80.9</td>
<td>&lt; 80.0</td>
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<tr>
<td>DukeInj + BurlInj</td>
<td>Big Sandy - BurlWInc 230 kV</td>
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<td></td>
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<tr>
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<td>BurlWInc - DEGS Wind 230 kV</td>
<td>Bonny Creek - Burlington 115 kV</td>
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<td>110.6</td>
<td>&lt; 100.0</td>
</tr>
<tr>
<td>DukeInj + BurlInj</td>
<td>BurlWInc - DEGS Wind 230 kV</td>
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<td>Idalia - Vernon Tap 115 kV</td>
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<td>Vernon Tap - Wray 115 kV</td>
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<td>Bonny Creek - Burlngtn 115 kV</td>
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<td>Idalia - South Fork 115 kV</td>
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</tr>
<tr>
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<td>Idalia - Vernon Tap 115 kV</td>
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<td>Last Chance - South Woodrow 115 kV</td>
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<tr>
<td>DukeInj + BurlInj</td>
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<td>South Woodrow - Woodrow 115 kV</td>
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</tr>
<tr>
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<td>Vernon Tap - Wray 115 kV</td>
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</tr>
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<td>DukeInj + BurlInj</td>
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<tr>
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<td>Big Sandy - Last Chance 115 kV</td>
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<td>DukeInj + BurlInj</td>
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<td>Big Sandy - BurlWInc 230 kV</td>
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Table 2b: LW Results II, WrayInj at 175 MW

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<th>Case</th>
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<th>Monitored Element</th>
<th>Rating (MVA)</th>
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<th>Loading w/ Burlington-Wray 230 kV Line (%)</th>
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<tbody>
<tr>
<td>DukeInj + WrayInj</td>
<td>Big Sandy - BurlWInc 230 kV</td>
<td>Bonny Creek - Burlington 115 kV</td>
<td>140</td>
<td>110.4</td>
<td>&lt; 100.0</td>
</tr>
<tr>
<td>DukeInj + WrayInj</td>
<td>Big Sandy - BurlWInc 230 kV</td>
<td>Bonny Creek - South Fork 115 kV</td>
<td>140</td>
<td>110.1</td>
<td>&lt; 100.0</td>
</tr>
<tr>
<td>DukeInj + WrayInj</td>
<td>Big Sandy - BurlWInc 230 kV</td>
<td>Idalia - South Fork 115 kV</td>
<td>140</td>
<td>108.2</td>
<td>&lt; 100.0</td>
</tr>
<tr>
<td>DukeInj + WrayInj</td>
<td>Big Sandy - BurlWInc 230 kV</td>
<td>Idalia - Vernon Tap 115 kV</td>
<td>140</td>
<td>107.1</td>
<td>&lt; 100.0</td>
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<tr>
<td>DukeInj + WrayInj</td>
<td>Big Sandy - BurlWInc 230 kV</td>
<td>Vernon Tap - Wray 115 kV</td>
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<tr>
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<td>Bonny Creek - Burlington 115 kV</td>
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<td>&lt; 100.0</td>
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<tr>
<td>DukeInj + WrayInj</td>
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<td>Bonny Creek - South Fork 115 kV</td>
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<tr>
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<td>Idalia - South Fork 115 kV</td>
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<tr>
<td>DukeInj + WrayInj</td>
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<td>Idalia - Vernon Tap 115 kV</td>
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<td>&lt; 100.0</td>
</tr>
<tr>
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<td>BurlWInc - DEGS Wind 230 kV</td>
<td>Vernon Tap - Wray 115 kV</td>
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<td>106.9</td>
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<td>Bonny Creek - South Fork 115 kV</td>
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<td>Gary - Woodrow 115 kV</td>
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<td>Idalia - South Fork 115 kV</td>
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<tr>
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<td>Idalia - Vernon Tap 115 kV</td>
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<td>DukeInj + WrayInj</td>
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<td>Last Chance - South Woodrow 115 kV</td>
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<td>Vernon Tap - Wray 115 kV</td>
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Table 2c: HS Results, Additional Injections

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<th>Case</th>
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<tr>
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<td>Bonny Creek - Burlington 115 kV</td>
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<td>Bonny Creek - South Fork 115 kV</td>
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<td>Big Sandy - Last Chance 115 kV</td>
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<td>Idalia - South Fork 115 kV</td>
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<tr>
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<td>Idalia - Vernon Tap 115 kV</td>
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<td>Arickaree 115 kV Voltage</td>
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<tr>
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<td>Midway - Lincoln 230 kV</td>
<td>Joes 115 kV Voltage</td>
<td>0.899 pu</td>
<td>&gt;0.90 pu</td>
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</tr>
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<td>Wray 230/115 kV</td>
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</table>
Appendix A: Transmission Alternative Analysis
**Introduction**

To eliminate the existing path limitation, there are a number of possible transmission alternatives between the Burlington and Wray stations. The alternatives available include variations in line voltage and number of circuits (1 or 2), and consideration of reuse of the existing Burlington to Wray 115 kV transmission line and associated right-of-way. This Appendix will discuss issues associated with line ratings and other criteria applied to analyze various options.

**Line Rating Discussion**

This section provides a general overview of line ratings by voltage and conductor type. This is not intended to be an exhaustive look at the types of conductors available for use or every option that can be considered, rather this provides overview descriptions related to this project.

Transmission lines are generally rated using a maximum conductor operating temperature, in degrees Celsius (C), and a corresponding amount of current, in Amperes (A) that the line can safely carry. Without considering the effects of outdoor ambient temperature and weather conditions, the conductor temperature will rise as the current level rises. For example, the existing Burlington-Wray 115 kV transmission line utilizes a 477 ACSR “Hawk” conductor and is rated for a maximum conductor operating temperature of 75 degrees C. Using Tri-State’s methodology for conductor continuous ratings, this line is therefore rated to carry approximately 704 A, equal to 140 MVA at 115 kV, without considering if there are other transmission system elements that could be lower than this conductor rating, such as disconnect switches or instrument transformers in substations included in this path.

Using standard ACSR conductor types, Tri-State utilizes a maximum conductor operating temperature of 100 degrees C, so there is a possibility the existing line could be upgraded to achieve this rating. This would be accomplished by raising the transmission structures to allow for the additional conductor sag resulting from the higher currents associated with this increased maximum conductor operating temperature of 100 degrees C. Again using Tri-State’s methodology for conductor continuous ratings, this line rating could then be raised to approximately 166 MVA.

As the existing 477 ACSR “Hawk” type of conductor that is used on the existing Burlington-Wray 115 kV line has a maximum capability of 166 MVA, replacing this conductor with a new one, or re-conductoring the existing line is an option to try to raise this thermal rating. The existing line was designed to support the 477 ACSR “Hawk” type of conductor, so attempting to re-conductor with a larger diameter ACSR conductor to try to achieve a higher thermal rating is not appropriate due to the higher structural loadings likely requiring replacement of some or all of the transmission structures.

An additional option is to replace the ACSR type of conductor with a different type that can achieve a higher thermal rating, such as an Aluminum Conductor Steel Supported (ACSS), Aluminum Conductor Composite Reinforced (ACCR), or Aluminum Conductor with Composite Core (ACCC) type. These conductors all have higher capacity than the same size ACSR.
conductor, but the increase in conductor costs can be significant. For example, ACCC conductor costs are 7-8 times as expensive as their standard ACSR size equivalent. With the limitations of the conductor size and voltage that the line was designed for, this was eliminated from further evaluation.

Re-building the line in place of the existing line can also be considered as an option. Using the same existing 115 kV line example, an option is to re-build the line with a new 115 kV single circuit line with a higher capacity or possibly replacing with a new 230 kV line. A typical conductor used by Tri-State for a new 115 kV line is a 795 ACSR, which has a thermal rating of 232 MVA using a 100 degrees C maximum operating temperature. A typical conductor for a new 230 kV line is a 1272 ACSR, which has a thermal rating of 612 MVA.

The line ratings for these re-building options would also apply to new line options where the existing 115 kV line would remain. For example, a new 115 kV line constructed using a 795 ACSR would have a thermal rating of 232 MVA and a new 230 kV line constructed using a 1272 ACSR has a thermal rating of 612 MVA. There are other conductor types that could be examined, but these show an example of the large difference in ratings when considering a standard 115 kV line and a standard 230 kV line. Extending this to 345 kV options, a common 345 line construction utilizes two 1272 ACSR conductors per phase. If this line were operated at 230 kV, this would provide a thermal rating equal to twice the 612 MVA rating provided by one 1272 ACSR operated at 230 kV, or 1224 MVA. If it were operated at 345 kV, it would then have a thermal rating of 1838 MVA. Considering double circuit structures, these ratings then apply to each individual circuit.

**Transmission alternatives**

The following alternatives were analyzed to determine their suitability in resolving the system deficiencies:

1. **Existing line and right-of-way alternatives:**
   a. Thermal upgrade of the existing Burlington-Wray 115 kV line.
   b. Re-conductor the existing Burlington-Wray 115 kV line.
   c. Re-build the existing Burlington-Wray 115 kV line.

2. **New line using existing right-of-way alternatives (including removal of existing Burlington-Wray 115 kV line):**
   a. New Burlington-Wray 230 kV single circuit line, operated at 115 kV or 230 kV.

3. **New line using new right-of-way alternatives (With existing Burlington-Wray 115 kV line staying in service):**
   a. New Burlington-Wray 115 kV single circuit line.
   b. New Burlington-Wray 230 kV single circuit line.
   c. New Burlington-Wray 230 kV double circuit line, with either one circuit or two circuits installed.
d. New Burlington-Wray 345 kV single circuit or double circuit line, considering 230 kV or 345 kV operation and whether one or two circuits are installed on the double circuit option.

**Transmission alternative analysis**

**Existing line and right-of-way alternatives.**

A power flow analysis of the eastern Colorado system found that under certain system conditions the existing Big Sandy to Beaver Creek 115 kV line overloads. The lighter the load in eastern Colorado and the greater the generation injection in the Burlington area, the greater the potential overload of the line. For example, the analysis found that with 51 MW of generation in the Burlington area, the overload of the line reaches 120% for a loss of the Midway to Lincoln 230 kV line. The overload reaches 127% for the same outage with 175 MW of generation modeled in the Burlington area. (Reference Table 1 and Table 2b of this report.) This overload cannot be mitigated with a rebuild or reconductor of the Burlington – Wray 115 kV circuit, but can be entirely mitigated with the construction of a second Burlington – Wray circuit.

Considering this fundamental northeast Colorado 115 kV system overload problem, this first set of transmission alternatives (1.a-1.c) that consider the re-use of the existing 115 kV line and associated right-of-way were eliminated from further analysis as these resulting overload problems on the Big Sandy to Beaver Creek 115 kV line would be expected to persist with these options. This is in addition to the operational and constructability issues, and limited increase in line rating with these options.

**Evaluation criteria.**

The remaining transmission alternatives (2.a-2.b and 3.a-3.d) between Burlington and Wray were evaluated using a number of criteria including:

1. Ability to eliminate operating restrictions on Tri-State’s existing Limon and Burlington generation facilities, without considering the new Kit Carson Windpower Project generation.
2. Ability to eliminate operating restrictions on Tri-State’s Limon, Burlington, and Kit Carson Windpower generation facilities.
3. Ability to eliminate Tri-State’s load-serving constraints for southern and eastern Colorado as identified in the Load Serving Analysis in this study, using a 10 year forecast period.
4. Ability to relieve Tri-State’s load-serving constraints beyond the 10 year forecasted period for southern and eastern Colorado, including the ability to serve loads bi-directionally (i.e. south to north in addition to identified north to south need).
5. Ability to allow additional generation resource injection in the area.
6. Consistency with transmission system and plans in the area.
7. Other considerations, including constructability, operational and maintenance issues.
8. Estimated cost (A summary of cost considerations including assumptions is included in Appendix G.)
The first three criteria are the previously mentioned deficiencies in the northeast Colorado area, and are considered to be the primary criteria in evaluating the alternatives. The remaining five criteria are then considered to be secondary criteria to be used for additional screening.

**New line using existing right-of-way alternatives (including removal of the existing Burlington-Wray 115 kV line).**

Alternative 2.a was eliminated from further consideration due to a number of factors. First, to allow for 230 kV operation, several distribution substations tapping the existing line (at Bonny Creek, South Fork, Idalia and Vernon Tap) would need to be converted from 115 kV to 230 kV, thereby adding substantial cost to the rebuild of the line. Second, rebuilding the line may be difficult during certain times of the year since each of the substations noted would need to be served radially for extended periods of time during construction. Operating the circuit radially could create further operational issues associated with dispatching the generation in eastern Colorado during the construction period. Third, a loss of the single-circuit between Burlington and Wray interrupts the primary contractual transmission path utilized by Tri-State to serve its native load in eastern Colorado, and this contractual path would be necessarily interrupted during the construction period. Finally, the existing 75-100 foot right-of-way along the existing line may not be sufficient for 230 kV H-frame construction and operation, and additional easements and new permits would likely be required. The 115 kV operation option of alternative 2.a would also not address the fundamental south to north overloading issue on the combined Big Sandy to Beaver Creek and Burlington to Wray 115 kV lines.

While alternative 2.b would resolve the first three criteria, or primary deficiencies, and would also adequately address criteria four through six, there are significant concerns regarding criteria 7 and 8. Similar to alternative 2.a, rebuilding the line may be difficult during certain times of the year with multiple tap substations that would need to be served radially for extended periods of time during construction. Operating the circuit radially could create further operational issues associated with dispatching the generation in eastern Colorado during the construction period. Also, a loss of the single-circuit between Burlington and Wray interrupts the primary contractual transmission path utilized by Tri-State to serve its native load in eastern Colorado, and this contractual path would be necessarily interrupted during the construction period. The existing 75-100 foot right-of-way along the existing line may not be sufficient for 230 kV construction and operation, and additional easements and new permits would likely be required. In addition to these concerns, the cost estimate for this alternative is $44,040,000 assuming a line length of 51 miles to match the existing line, approximately $10,000,000 more than constructing a single circuit 230 kV line in a new right-of-way which would provide an electrically equivalent option under normal system operating conditions. It is possible that the line length could be longer depending on siting considerations, which would increase this cost estimate. This option would also introduce an n-2 outage contingency, due to a possible common tower outage.
New line and new right-of-way alternatives (with the existing Burlington-Wray 115 kV line remaining).

A new 115 kV line considered in alternative 3.a may resolve the first two primary deficiencies; however there would be questionable load-serving capability added to address the third primary deficiency. Since the transmission considered in the Story to North Yuma to Wray to Burlington to Big Sandy to Midway path is 230 kV at Burlington and Wray substations, there would be additional transformer capacity required at both substations to be able to utilize the combined capacity provided by the new 115 kV line (232 MVA) and the existing 115 kV line (140 MVA). Even assuming additional transformers were added to allow for this shortfall, with a combined path rating of approximately 372 MVA in this scenario it would still be below the potential 512 MVA rating mentioned in the Load Serving Analysis for the Story to North Yuma to Wray 230 kV line. Considering these deficiencies, in addition to an estimated cost of $27,702,000 for a single circuit 115 kV line versus the estimate of $34,363,000 for a new single circuit 230 kV line without considering the additional costs of 230/115 kV transformers at Wray or Burlington, this alternative was eliminated from further consideration.

A new 230 kV line considered in alternative 3.b would resolve the three primary deficiencies. The new 230 kV line would have a thermal rating of 612 MVA, and adding the 140 MVA available on the existing 115 kV line would provide a new load-serving path rating of 752 MVA between Burlington and Wray. This would, therefore, resolve the forecasted load-serving deficit, and would be consistent with the connected 230 kV system at Burlington and Wray to allow for future load-serving support beyond the 10 year forecasted period. In addition, this new 230 kV line removes this northeast Colorado system limitation and allows for additional generation injection capability in the area.

The remaining alternatives 3.c and 3.d consider double circuit 230 kV construction alternatives and 345 kV construction alternatives. Similar to the new single circuit 230 kV line, these alternatives would each be expected to resolve the three primary deficiencies identified. As they would each have a thermal capacity equal to or higher than a single circuit 230 kV line, each of these would also be expected to provide future load-serving support beyond the 10 year forecasted period identified in the Load Serving Analysis. However, when considering the consistency with the transmission system in the area such as the lack of 345 kV facilities in service today, these options are shown to have deficiencies, especially when considering the significant additional costs of constructing any of these alternatives.

As shown in Appendix G, the cost estimates for alternatives 3.c and 3.d range from approximately $51,000,000 to $82,000,000, which is $17,000,000 to $48,000,000 more than the new 230 kV single circuit alternative without considering additional substation equipment costs. As has been stated previously, Tri-State’s transmission system connected from the west to east to Tri-State’s existing Burlington and Wray Substations consists of a single circuit 230 kV transmission line. These single circuit 230 kV lines serve as the next limit to the Story to North Yuma to Wray to Burlington to Big Sandy to Midway path after the 115 kV Burlington to Wray limitation is addressed. Both of these east-west single circuit 230 kV transmission lines connected to Burlington and Wray are thermally rated below the new 752 MVA thermal rating.
that would be provided by a single circuit 230 kV transmission line between Burlington and Wray. This means additional transmission upgrades or new lines must be completed on these east-west sections in order for Tri-State to realize any benefit of constructing a line between Burlington and Wray larger than a single circuit 230 kV line. Therefore, for Tri-State, the additional costs of these options would be better spent on other transmission upgrades in the area. When considering that no other parties were prepared to financially participate in constructing the line larger than a single circuit 230 kV line that has been shown to address Tri-State’s needs, these options were eliminated from further consideration.

Conclusion

Based on these analyses, a new Burlington – Wray single-circuit 230 kV line, (Alternative 3.b) is the best alternative in order to cost effectively:

1. Remove the operating limitations of existing Tri-State generation in the area,
2. Provide a load-serving path consistent with Tri-State’s forecasted need and also consistent with the long term capability of the path and system in the area,
3. Provide for additional generation development in this area of Colorado that has been identified as having great wind potential, illustrated by the Kit Carson Windpower Project.
4. Complement long term plans in the area, providing an additional electrical path between Burlington and Wray to remove limitations of the existing lone 115 kV Burlington-Wray line.

Alternative Conductors And Loss Analysis

The proposed Burlington – Wray 230 kV line was modeled with 1272 ACSR conductor on wood H frame construction. Other conductor configurations were considered as well, through an economic loss evaluation of different conductor impedances. This included ACSR (954, 1272, and 1590 MCM), and ACSR/TW (1557 MCM) conductors. The loss evaluation is in Appendix F.

As demonstrated in the Conductor Loss Comparison (Appendix F), the differences between the average expected system normal losses on the Burlington – Wray 230 kV line for various conductors are minimal when compared to the additional installation costs. This difference in average expected system normal losses savings compared to installation costs would then be amplified for higher thermal rating conductors such as ACSS, ACCC, and ACCR which have relatively similar impedances and significantly higher costs. This evaluation indicates that a standard 1272 MCM ACSR on wood H-frame construction with a maximum design temperature of 100 degrees C (1538 Amperes) is a good conductor choice for use on the Burlington-Wray 230 kV line from an expected losses standpoint.
Appendix B: Contingency List
Category B Outages

PAWNEE 230.-STORY 230. #1
B.CK PS 115.-BEAVERCK 115. #1
B.CK PS 230.-STORY 230. #1
HENRYLAK 230.-STORY 230. #1
BURLWINC 230.-BURLWINJ 230. #1
BURLWINC 230.-B.SANDY 230. #1
BURLWINC 230.-DEGS WIND 230. #1
WRAYINJ 230.-WRAY 230. #1
B.CK TRI 115.-BEAVERCK 115. #1
B.CK TRI 230.-STORY 230. #1
B.SANDY 115.-LSCHANCE 115. #1
B.SANDY 115.-LIMON 115. #1
B.SANDY 230.-LINCOLNT 230. #1
BURLNGTN 230.-WRAY 230. #1
BURLNGTN 230.-DEGS WIND 230. #1
LAR.RIVR 345.-STORY 345. #1
N.YUMA 230.-STORY 230. #1
N.YUMA 230.-WRAY 230. #1
FRENCHCK 115.-WAUNETA 115. #1
DEERINGL 115.-N.YUMA 115. #1
DEERINGL 115.-YUMA 115. #1
KIOWA CK 115.-ORCHARD 115. #1
ECKLEY 115.-ROBB 115. #1
ECKLEY 115.-BETHELLM 115. #1
VERNONT P 115.-VERNONLM 115. #1
MIDWAYBR 230.-LINCOLNT 230. #1
DEGS WIND 230.-DEGS 230 230. #1
BRUSH SS 115.-B.CK PS 115. #1
BRUSH SS 115.-B.CK PS 115. #2
DANIELPK 230.-PAWNEE 230. #1
FTLUPTON 230.-PAWNEE 230. #1
MIDWAYPS 115.-MIDWAYBR 115. #1
MIDWAYPS 230.-MIDWAYBR 230. #1
MIDWAYPS 230.-FULLER 230. #1
PAWNEE 230.-PTZLOGN 230. #1
MIDWAYPS 345.-WATERTON 345. #1
PAWNEE 345.-SMOKYHIL 345. #1
AULT 345.-LAR.RIVR 345. #1
SIDNEY 230.-SIDNEYDC 230. #1
SIDNEY 230.-STEGALL 230. #1
SIDNEY 230.-SPRGNCAN 230. #1
STEGALDC 230.-STEGALL 230. #1
CHEYENNE 230.-SNOWYRNG 230. #1
PAWNEE 230.-BRICKCTR 230. #1
QUINCY 230.-BRICKCTR 230. #1
MIDWAYBR 230.-RD_NIXON 230. #1
MIDWAYBR 230.-W CANON 230. #1
STERLING 69.-STERLING 115. #1 XFMR
B.CK TRI 115.-B.CK TRI 230. #1 XFMR
B.SANDY 115.-B.SANDY 230. #1 XFMR
BURLNGTN 115.-BURLNGTN 230. #1 XFMR
BURLNGTN 115.-BURLNGTN 230. #2 XFMR
BURLNGTN 115.-BRNGTN1 13.8 #1 XFMR
BURLNGTN 115.-BRNGTN2 13.8 #1 XFMR
N.YUMA 115.-N.YUMA 230. #1 XFMR
STORY 230.-STORY 345. #1 XFMR
STORY 230.-STORY 345. #2 XFMR
WRAY 115.-WRAY 230. #1 XFMR
LINCOLNT 230.-LINCOLN1 13.8 #1 XFMR
LINCOLNT 230.-LINCOLN2 13.8 #1 XFMR
DEGS 230 230.-DEGS 34.5 #1 XFMR
PAWNEE 230.-WND_PLN 34.5 #1 XFMR
BRICKCTR 230.-BRICKCTR 115. #T1 XFMR
BRUSH SS 115.-QF BCP2T 13.8 #2T XFMR
BRUSH SS 115.-QF B4-4T 13.8 #4T XFMR
BRUSH SS 115.-QF CPP1T 13.8 #1T XFMR
BRUSH SS 115.-QF CPP3T 13.8 #3T XFMR
BRUSH SS 115.-QF B4D4T 12.5 #4A XFMR
CHEROK1 15.5-CHEMOKEE 115. #U1 XFMR
CHEROK2 15.5-CHEMOKEE 115. #U2 XFMR
CHEROK3 20.0-CHEMOKEE 115. #U3 XFMR
CHEROK4 22.0-CHEMOKEE 115. #U4 XFMR
MIDWAYPS 230.-MIDWAYPS 345. #T1 XFMR
PAWNEE 22.0-PAWNEE 230. #1A XFMR
PAWNEE 22.0-PAWNEE 230. #1B XFMR
PAWNEE 230.-MANCEF1 16.0 #11 XFMR
PAWNEE 230.-MANCEF2 16.0 #12 XFMR
PAWNEE 230.-PAWNEE 345. #1 XFMR
PAWNEE 230.-PAWNEE 345. #2 XFMR
B.CK PS 115.-B.CK PS 230. #T1 XFMR
HENRYLAK 230.-HENRYLAK 115. #1 XFMR
COMANCHE 345.-COMANCHE 3 24.0 #1 XFMR
PTZLOGN1 34.5-PTZLOGN3 230. #1 XFMR
PTZLOGN 230.-PTZLOGN2 34.5 #1 XFMR
PTZLOGN 230.-PTZLOGN3 34.5 #1 XFMR
SPPNGC3 34.5-SPRNGC3 230. #1 XFMR
CEDARCRK 230.-CEDARCRK1 34.5 #1 XFMR
CEDARCRK 230.-CEDARCRK2 34.5 #1 XFMR
LAR.RIVR 230.-LAR.RIVR 345. #1 XFMR
LAR.RIVR 345.-MBPP-1 24.0 #1 XFMR
LAR.RIVR 345.-MBPP-2 24.0 #1 XFMR
SIDNEY 115.-SIDNEY 230. #1 XFMR
MIDWAYBR 115.-MIDWAYBR 230. #1 XFMR
BURLINGTON-BONNY CK-SOFORK 115 kV
SO FORK-IDALIA-VERNON TP-WRAY 115 kV
BRIGHTON-SANDCK-HOYT 115 kV
BCK-AKRON-OTIS-DEERINGLKLK 115 kV
DEERINGLAKE-E_YUMA_TAP-ECKLEY 115 kV
WRAY-SANDHILL-ALVIN-WAUNETA 115 kV
LAST CHANCE-ANTON 115 kV
ARICKAREE-SO FORK 115 kV
LAST CHANCE-SWOOD-WOODROW 115 kV
BURLINGTON-BURLKC 115 kV
DALTON-SIDNEY 115-115 kV
JACINTO-SIDNEY 115-115 kV
SIDNEY-PEETZ-STERLING 115 kV
BCK-MESSEX-STERLING 115 kV
STERLING-FRENCHCK 115 kV
WAUNTEA-N.YUMA 115 kV
HOYT-KIOWACK 115 kV
PROSPECT VALLEY TAP OUTAGE
KIOWA CK-FTMORGANWEST 115 kV
ECKLEY-WRAY 115 kV
WRA-Y-WRAYWAPA 115 kV
SPCN-NYUMA-RAS (NO RUNBACK) 230 kV
BEAVERCK-GARY-WOODROW 115 kV
BC-ADN-HYT 115 kV
BCK-BRUSH-EFM 115 kV
FMWEST-FMS 115 kV

Category C Outages

PROSPECT VALLEY TAP & KIOWA CK-FTMORGANWEST 115
TWO STORY TRANSFORMERS OUTAGE
NYUMA-SPRNGCNYN & NYUMA XFMR OUTAGE
SIDNEY-SPRNGCNYN-NYUMA 230 OUTAGE
SPRNGCNYN-NYUMA-WRAY 230 OUTAGE
DEER LK-NY & NY XFMR OUTAGE
HL-STORY & BC-ADN-HYT
HL-STORY & HYT-SNDCK-BRHTN
STORY-PAWNEE & STORY XFMR OUTAGE
NYUMA-WAUNETA & NY XFMR OUTAGE
DEERING L-NY-RED WILLOW (WAUNETA) OUTAGE
NYUMA-STORY & NYUMA XFMR OUTAGE
STORY-NYUMA-WRAY 230 OUTAGE
STORY-NORTH YUMA & STORY XFMR 1 OUTAGE
BURL-WRAY 230 & BURLINGTON-BONNY CK-SOFORK
BURL-WRAY 230 & SO FORK-IDALIA-VERNON TP-WRAY
Appendix C: Base Case Modifications
Major Modifications to the Heavy Summer and Light Winter Cases

Both Heavy Summer and Light Winter Cases

- Correct the Last Chance - South Fork 115 kV line impedance and the location of the normally open point. Left as Normally Open between Anton and Arickaree.
- Left Archer Configuration out as this has very little impact to the Burlington/Wray area line loadings.
- Correct configuration in the Ft. Morgan loop.
- Status out the duplicate Duke plant.
- Status out duplicate Erie - Sipres - Henry Lake - Story 230 kV line and correct Sipres load.
- Adjust loads to the appropriate levels for Heavy Summer or Light Winter.
- Adjust the switched shunt settings at Ft.MorganWest, Frenchman Creek, Sidney 115 kV, and Spring Creek Tap.
- Adjust transformer tap settings at Sidney and Sterling.
- Deleted LTC on Wray 230/115 kV transformer as this does not exist.
- Adjust rating of the Burlington - Big Sandy 230 kV line.
- Adjust rating of the Burlington - Wray 115 kV line.
- Add the Burlington - Wray 230 kV line, status off; turned on in appropriate cases.
- Set the existing Burlington generating units to their maximums, 100 MW in the summer and 120 MW in the winter.
- Set the existing Limon (Lincoln) generating units to their maximums, 120 MW in the summer and 136 MW in the winter.
- Add the Duke Wind Plant 5 miles west of Burlington on the 230 kV line to Big Sandy. Status out; turned on at 51 MW in appropriate cases.
- Add a generation injection 30 miles west of Burlington on the 230 kV line to Big Sandy, representing example wind interconnections. Status off; turned on at up to 200 MW in appropriate cases.
- Add a generation injection at Wray, representing example wind interconnections. Status off; turned on at up to 200 MW in appropriate cases.

Heavy Summer Case Only

- Adjust the switched shunt settings at Sterling and Story.
- Left generation at Peetz, Spring Canyon, and Peetz-Logan at 12.5% of maximum (61.5 MW total).

Light Winter Case Only

- Increase wind generation at Peetz, Spring Canyon, and Peetz-Logan to their maximums.
Appendices D and E contain output report data. These appendices are very large, and are contained in separate files. Please contact Tri-State G&T System Planning Department for a copy of these files.
Appendix D: Heavy Summer Results
Appendix E: Light Winter Results
Appendix F: Burlington – Wray 230 kV Loss Calculations
Conductor Loss Comparison

The following losses on the Burlington – Wray 230 kV line were calculated for system normal conditions with alternative conductors in the indicated cases. All cases have the existing generators at Burlington and Limon at full output. Some cases have additional power injections, as indicated by the case title. These load and generation dispatch assumptions produced a maximum loss value for projected system normal line conditions.

Due to seasonal variations in load and in the operation of local generation, the projected system normal line losses vary hour by hour throughout the year and will not remain at the maximum calculated value. Therefore, an average loss value across seasons and generation injection values was used to account for these variations. The average loss values are identified by conductor in the following table 3.

Table 3: Loss evaluation for selected conductors

<table>
<thead>
<tr>
<th>Case</th>
<th>954 ACSR Losses (MW)</th>
<th>1272 ACSR Losses (MW)</th>
<th>1590 ACSR Losses (MW)</th>
<th>1557 ACSR/TW Losses (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LW_NoInj</td>
<td>0.03089</td>
<td>0.02391</td>
<td>0.01973</td>
<td>0.01974</td>
</tr>
<tr>
<td>LW_DukeInj</td>
<td>0.20192</td>
<td>0.15602</td>
<td>0.12865</td>
<td>0.1285</td>
</tr>
<tr>
<td>LW_DukeInj+BurlInj</td>
<td>1.23662</td>
<td>0.95704</td>
<td>0.78941</td>
<td>0.78922</td>
</tr>
<tr>
<td>LW_DukeInj+WrayInj</td>
<td>0.0074</td>
<td>0.00566</td>
<td>0.00463</td>
<td>0.00461</td>
</tr>
<tr>
<td>HS_NoInj</td>
<td>0.08144</td>
<td>0.06293</td>
<td>0.05187</td>
<td>0.05185</td>
</tr>
<tr>
<td>HS_DukeInj</td>
<td>0.00401</td>
<td>0.00311</td>
<td>0.00256</td>
<td>0.00256</td>
</tr>
<tr>
<td>HS_DukeInj+BurlInj</td>
<td>0.4317</td>
<td>0.33432</td>
<td>0.27595</td>
<td>0.27592</td>
</tr>
<tr>
<td>HS_DukeInj+WrayInj</td>
<td>0.14648</td>
<td>0.11352</td>
<td>0.09373</td>
<td>0.09372</td>
</tr>
<tr>
<td>Average Losses</td>
<td>0.267558</td>
<td>0.207064</td>
<td>0.170816</td>
<td>0.170765</td>
</tr>
<tr>
<td>PWRR of Losses</td>
<td>$2,937,416</td>
<td>$2,273,277</td>
<td>$1,875,329</td>
<td>$1,874,767</td>
</tr>
<tr>
<td>PWRR of Project</td>
<td>$28,612,265</td>
<td>$29,361,574</td>
<td>$30,942,370</td>
<td>$30,961,003</td>
</tr>
</tbody>
</table>

For each of the above conductor alternatives, annual costs (revenue requirements) for demand and energy losses were calculated. The Present Worth of all future Revenue Requirements (PWRR) for those losses was determined. The PWRR for the total project costs were also determined for each alternative. The PWRR calculations were based on a 30 year project life, 3% per year inflation, an 8% interest rate, a 12% fixed charge rate, 15% planning generation reserve, $2,100/kW installed generation cost, and $75/MWh energy generation cost. The PWRR of the project also accounts for differences in major construction costs for the different conductors studied. The following assumptions were made for the major construction costs:
a. Engineering, ROW, Environmental, and permitting costs are assumed to be the same for any conductor chosen.

b. Costs are based on construction and major materials only. There will be some minor variances in the construction costs, but not sufficient to change the approximate per mile costs. Costs are based on an assumption of a line length of 60 miles.

c. All lines were evaluated assuming 10000 pound maximum design tension and 800 foot ruling spans. Structures assumed were wood H-frames. By using the same tensions, the dead end structures and guying were assumed to be the same. The tangent and angle poles would be taller and heavier depending on the varying sag of the line. All other components on the structures including the cross arms and braces would be similar, therefore the cost differential is basically the cost of the conductors and the poles.
Appendix G: Cost Comparisons
<table>
<thead>
<tr>
<th>Construction Alternatives</th>
<th>Cost² ($000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>115 kV single circuit wood H-frame design, 60.4 miles, 1-795 ACSR Drake conductor, 100°C design temperature, 100 ft ROW, OPGW</td>
<td>$27,702</td>
</tr>
<tr>
<td>230 kV single circuit wood H-frame design, 60.4 miles, 1272 ACSR Bittern conductor, 100°C design temperature, 150 ft ROW, OPGW</td>
<td>$34,363</td>
</tr>
<tr>
<td>230 kV double circuit steel, 60.4 miles, 1-1272 ACSR Bittern conductor, 100°C design temperature, 150 ft ROW, OPGW, one side strung only</td>
<td>$51,335</td>
</tr>
<tr>
<td>Stringing the other side at a future date³</td>
<td>$9,397</td>
</tr>
<tr>
<td>230 kV double circuit steel, 60.4 miles, 1-1272 ACSR Bittern conductor, 100°C design temperature, 150 ft ROW, OPGW, both sides strung</td>
<td>$56,599</td>
</tr>
<tr>
<td>230 kV double circuit⁴, 51 miles, 1272 ACSR Bittern conductor, 100°C design temperature, 150 ft total ROW, OPGW</td>
<td>$44,040</td>
</tr>
<tr>
<td>345 kV single circuit steel, 60.4 miles, 2-1272 ACSR Bittern conductor, 100°C design temperature, 175 ft ROW, OPGW</td>
<td>$53,856</td>
</tr>
<tr>
<td>345 kV double circuit steel, 60.4 miles, 2-1272 ACSR Bittern conductor, 100°C design temperature, 200 ft ROW, OPGW, one side strung only</td>
<td>$75,393</td>
</tr>
<tr>
<td>Stringing the other side at a future date⁵</td>
<td>$12,792</td>
</tr>
<tr>
<td>345 kV double circuit steel, 60.4 miles, 2-1272 ACSR Bittern conductor, 100°C design temperature, 200 ft ROW, OPGW, both sides strung</td>
<td>$81,824</td>
</tr>
</tbody>
</table>

² Costs are for line construction only and do not include associated substation equipment costs.
³ Estimate does not include escalation to any particular future date.
⁴ This option replaces the existing 115 kV line; the status of the taps along this line may be compromised during construction activities.
⁵ Estimate does not include escalation to any particular future date.
Energy Efficiency, Demand Side Management, and Distributed Generation Study
for the Northeast Colorado Area

November, 2010
Energy Efficiency, Demand Side Management, and Distributed Generation Study for the Northeast Colorado Area

Introduction

In evaluations of the northeast Colorado electric system, Tri-State’s studies have shown the system to have three significant deficiencies that require attention. As part of an alternative evaluation to determine the best way to address these, Tri-State developed this study to determine whether energy efficiency (EE), demand side management (DSM), and distributed generation (DG) alternatives were both appropriate and the optimum solutions to resolve these deficiencies. The three deficiencies are summarized in the following section, and more detail can be found on each of these deficiencies as well as transmission alternatives that are considered in Tri-State’s separate Transmission Study for the Northeast Colorado Area.

Identified System Deficiencies

1. Operating restrictions on the existing Lincoln and Burlington generation.

   The existing generation resources at Lincoln and Burlington can be restricted from simultaneously operating at their full output without criteria violations on the existing system. This is due to potential overloads on the existing Burlington to Wray 115 kV transmission line limiting Tri-State’s ability to economically dispatch these existing generation resources in eastern Colorado.

2. Interim Restricted Operating Procedure placed on the 51 MW Kit Carson wind project.

   Similar to the first deficiency summarized above, the combination of the existing generation resources at Lincoln and Burlington and the new Tri-State Kit Carson wind project can be restricted from simultaneously operating at their full output without criteria violations on the existing system. This is again due to potential overloads on the existing Burlington to Wray 115 kV transmission line limiting Tri-State’s ability to economically dispatch these existing generation resources in eastern Colorado. An Interim Restricted Operating Procedure has been put in place to account for this operating restriction until network upgrades can be completed.

3. Deliverability of Tri-State resources to Tri-State native load.

   The existing Wray to Burlington 115 kV transmission line constitutes a portion of a primary contractual transmission path utilized by Tri-State to serve its native load in eastern and southern Colorado from existing resources and is limited by its current thermal capacity. Tri-State’s native load obligation in south and eastern Colorado
includes service to K.C. Electric Association (K.C.), Mountain View Electric Association (Mountain View), San Isabel Electric Association (San Isabel), San Luis Valley Rural Electric Cooperative (San Luis Valley), Southeast Colorado Power Association (Southeast) and Gunnison County Electric Association (Gunnison County). Using Tri-State’s Power System Planning 10 year native load forecast for these six member systems, the Load Serving Analysis of the aforementioned Transmission Study for the Northeast Colorado Area concluded that there was a forecasted Available Transmission Capacity (ATC) deficiency of 159 MW in 2020 to serve these members, demonstrating Tri-State’s inability to source these loads via its Story-North Yuma-Wray-Burlington-Big Sandy-Midway transmission path.

Energy Efficiency, Demand Side Management, and Local Distributed Generation Alternative Analysis

1. Definitions (from the U.S. Energy Information Administration\(^1\) (EIA)):

Energy Efficiency (EE) – Refers to programs that are aimed at reducing the energy used by specific end-use devices and systems, typically without affecting the services provided. These programs reduce overall electricity consumption (reported in megawatthours), often without explicit consideration for the timing of program-induced savings. Such savings are generally achieved by substituting technologically more advanced equipment to produce the same level of end-use services (e.g. lighting, heating, motor drive) with less electricity. Examples include high-efficiency appliances, efficient lighting programs, high-efficiency heating, ventilating and air conditioning (HVAC) systems or control modifications, efficient building design, advanced electric motor drives, and heat recovery systems.

Demand Side Management (DSM) – The planning, implementation, and monitoring of utility activities designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand. It refers to only energy and load-shape modifying activities that are undertaken in response to utility-administered programs. It does not refer to energy and load-shaped changes arising from the normal operation of the marketplace or from government-mandated energy-efficiency standards. Demand-Side Management covers the complete range of load-shape objectives, including strategic conservation and load management, [and demand response] as well as strategic load growth.

Distributed Generation or Distributed Generator (DG) - A generator that is located close to the particular load that it is intended to serve. General, but non-exclusive, characteristics of these generators include: an operating strategy that supports the served load; and interconnection to a distribution or sub-transmission system (138 kV or less).

\(^1\) [http://www.eia.doe.gov/glossary/index.cfm](http://www.eia.doe.gov/glossary/index.cfm)
2. **Overview of Existing Tri-State Programs Systemwide**

Programs have already been implemented throughout Tri-State’s Member Systems to promote energy conservation, efficiency, demand response and local generation, including small renewable projects. Some of these programs have been in place for more than 20 years and have been successful in helping to minimize the energy used and the maximum coincident peak load and some of these programs are relatively new and have the effect of offsetting against local demand.

**Energy Efficiency and Demand Side Management:**
Since 1985, Tri-State (through their Member System cooperatives) has been offering financial assistance toward the purchase of high-efficiency motors and pumps to reduce the electrical demand. The cooperatives have had the Energy Efficiency Credits (EEC) Program in place for more than 25 years. This program provides cash rebates to encourage and reward wise use of energy through energy-efficient purchases and practices. Through the EEC Program, Tri-State and the Tri-State Member System cooperatives have already reduced demand by over 75 MW (over the entire system) and saved more than 80,000 MWh of energy through the end of 2009. Tri-State and the Member Systems have expanded the EEC program to make it Energy Star based. Additional measures and programs have also been offered beginning at the first of 2009 and expanded during 2010.

Tri-State also works with each of its Member Systems for appropriate DSM programs, such as time of use rates and load control using time clocks or load signals. During 2009 and 2010, Tri-State conducted a comprehensive system evaluation to understand the technical and practical potential of EE and DSM for each of the regions served by Tri-State’s Member Systems. This study is discussed in more detail below as it relates to the Member Systems identified as affected by the current electric system deficiencies, and can be found on the Tri-State website at the following link:

[http://www.tristategt.org/eeecPrograms/energy-efficiency-study.cfm](http://www.tristategt.org/eeecPrograms/energy-efficiency-study.cfm)

**Distributed Generation:**
Distributed generation is built on the concept of installing generation at or near the point of use. Solar, wind, or other alternative types of generation could be installed by the end user to meet the specific needs of the various types of loads, including residential, commercial, industrial, and irrigation. Residential and commercial loads, for example, can be reduced with the application of small solar or wind energy systems. This would tend to reduce the loads in the seven Member Systems and would also reduce the maximum coincident peak (MCP). For the Member Systems with significant amounts of irrigation loads, these represent a scheduled load and are generally not a good candidate for solar- or wind-generated power. However, these irrigation loads could be served with some type of generator located near one or more of the irrigation pumps. Typically, this would need to be powered by gasoline or diesel engines to be available when irrigation was required. The owners and operators of irrigation systems currently have the option of installing local generation; however, the electric cooperative’s obligation is to serve the member consumer loads with the best option based on economic and environmental choices.
Tri-State has adopted several Board Policies that enable and provide incentives to Member Systems and their member consumers to participate in and install local renewable projects that can count for renewable portfolio standard (RPS) compliance in Colorado. These policies and the policies of the Member System Boards will provide for net metering at the member-consumer premises and for small community-based projects. Each of the Member Systems offer net metering programs and are evaluating local renewable projects. They also participate through Tri-State in EPRI and CRN research into distributed generation and distributed energy systems. Notwithstanding the attraction of such small distributed generation projects, they remain costly.

3. Application of EE/DSM/DG Programs within the Project Area

DSM/EE programs related to the Burlington-Wray Transmission Project:
The Tri-State Member Systems have different EE/DSM programs they offer. The six Member Systems previously mentioned in the native load serving analysis (deficiency #3 above) in addition to Y-W Electric Association (Y-W) were considered to be member-consumers with load service affected by this project. These seven Member Systems offer consumers appliance use information, energy use information, conservation guides, web-based conservation strategies and links, web-based energy calculators, free energy audits and conservation programs, CFL programs, and time-of-use rates. Each of them has line loss reduction strategies in place and participates through Tri-State in EPRI and CRN research into EE/DSM programs, measures and products.

Tri-State staff has conducted and participated in planning sessions with these Member Systems to expand their programs to include additional demand response through which the load can be shifted. For summer irrigation load, this will require installation of expensive communications and metering equipment, and upgrading their current distribution infrastructure. These investments take time and planning which is well underway. Tri-State is working with one of the Member Systems to support smart grid pilot projects that will support additional demand response. Tri-State is also developing project offering structures through which Member Systems can aggregate load modification activity of their member-owner/consumers to provide products to Tri-State.

As mentioned previously pertaining to EE/DSM, Tri-State has completed a comprehensive end-use energy efficiency/demand side management/demand response study across the entire system. This study examined the technical, economic, and practically achievable energy and demand reduction potential, focusing on program and measure potential in discrete geographic regions, such as those served by the Member Systems with load affected by this Project. There were a total of eight geographic regions analyzed in the study to account for sector diversity and climate. The seven Member Systems identified previously were spread across four of these geographic regions, with K.C., Southeast, and Y-W in the Eastern Colorado region, Mountain View and San Isabel in the Front Range Colorado Region, San Luis Valley in the Western Colorado Region, and Gunnison County in the Mountain Colorado Region. Based on this diversity, individual recommendations by region can be investigated to some extent, but Tri-State felt it was more appropriate to look at the combination of these seven specific Member Systems for the purposes of this study.
For the seven Member Systems, Tri-State determined their cumulative low potential in 2020 is 17,348,018 kWh energy and 3,258kW (3.258 MW) demand savings to a high potential of 30,949,400 kWh energy and 5,833 kW (5.833 MW) demand savings potential and ramping up for years thereafter. Additionally, given the caveats contained in the study about the ability to deploy EE/DSM/DR in rural, low density systems, the low potential is the more likely and planned to amount in considering EE/DSM/DR alternatives. The demand savings potential is more applicable to the purposes of resolving deficiency #3 identified, with a forecasted peak load serving ATC deficit of 159 MW for the six members identified that are affected by the load-serving limitations of the existing Wray to Burlington path. With a 159 MW need by the 2020 forecasted period, and a range of 3,258 to 5,833 MW of demand savings potential identified for the seven member group, the savings represent roughly 2-4% of the forecasted need. Clearly these potential savings do not materially contribute to meeting the purposes of resolving this identified deficiency and are not considered a viable alternative.

While this EE/DSM option has already been shown to be quantitatively insufficient for the purposes of resolving the third deficiency identified, it was also examined in more qualitative terms for resolving the first two deficiencies. As shown in the Transmission Study for the Northeast Colorado Area, these operating restrictions are generally more severe in the Light Winter loading condition rather than the Heavy Summer loading associated with higher system loads. The Eastern Colorado Region, especially in the area around Burlington where the operationally constrained network resources exist, has high amounts of irrigation loads in the summer that make the local loads significantly higher during this season. The Light Winter loading conditions are much lower, which results in higher loads on the transmission system when local generation is operated since there are fewer local loads to serve. With DSM/EE programs having the goal of reducing electrical loads, these lower loads would tend to exacerbate these operating restrictions rather than removing them as exhibited by the Light Winter loading conditions as compared to the Heavy Summer conditions. For this reason, these programs are also not considered a viable alternative.

Distributed generation (DG) programs related to the Burlington-Wray Transmission Project:
As with DSM/EE programs, DG also needs to be analyzed separately for how it relates to the first two operating condition deficiencies compared to how it relates to the third deficiency related to load-serving. With the amount of generation near Burlington already being operationally constrained due to insufficient transmission, additional DG in the same area would be expected to exacerbate the overloads experienced on the transmission system by reducing local loads with DG and increasing the total export of local generation out of the area. Based on this, DG is not considered a viable alternative to solve these first two deficiencies.

When evaluating the impacts of DG with regards to their potential to resolve the remaining third deficiency, the potential of each of the Member Systems affected by the load serving constraints would need to be evaluated. The Member Systems each have the right to meet up to five percent of their member-owner/consumers’ needs through local generation projects that the Member Systems own or control. If the seven Member Systems identified installed this entire five percent as local generation projects, the maximum kWh amount that they could deploy is approximately 117,000,000 kWh. However, the more likely amount being experienced is approximately 20% of the total potential for the 10 year future, or approximately 34,000,000 kWh. This figure is
comparable to the high potential of DSM/EE savings, which will have little impact in terms of the total 159 MW forecasted shortfall in load-serving capability and therefore not considered to be a viable alternative to resolve the third deficiency identified. In addition, the type of DG installed would also have to be analyzed for its ability to meet peak demands.

**Conclusion**

In summary, programs have already been implemented that are designed to be compatible with the primary loads experienced on the Member Systems. These programs are effective in promoting energy conservation and local renewable energy development. Some programs have been in place for more than 25 years, have already been successful in helping to minimize the energy used in the seven Member Systems and should encourage more in the future. However, it takes years to build out EE/DSM and distributed generation/local renewable projects that will have a material impact on local load and energy requirements. In addition, load growth in the area continues to be positive. Based on the evaluations in this study, these programs are not viewed as representing a viable alternative to meet the purposes of the Project.
Burlington-Wray Transmission Line Project

Magnetic Fields and Audible Noise

Prepared for

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October, 2010
Burlington-Wray Transmission Line Project

Introduction

The Tri-State Generation and Transmission Association, Inc. (Tri-State) is adding a 230 kilovolt (kV) single circuit electric transmission line from Burlington to Wray in eastern Colorado. The project is called the Burlington-Wray 230 kV Transmission Line Project (the "Project").

This report describes the modeling of magnetic fields and the audible noise produced from corona for the Project.

Magnetic Fields from Burlington-Wray Transmission Line Project

Electric transmission lines produce EMF when they are in operation. EMF is a term that refers to electric and magnetic fields. These fields are caused by different aspects of the operation of a transmission line and can be evaluated separately. According to the PUC Certificate of Public Convenience and Necessity (CPCN) rules in section 3206, only magnetic fields are addressed in this evaluation and electric fields are not mentioned further.

Magnetic fields are produced whenever an electrical current flows in a conductor. An example of this is the plugging of a lamp into a wall outlet in a home. If the lamp is turned on allowing electricity to flow to the lamp, a magnetic field is created around the lamp cord.

Modeling Methodology

The magnetic fields for the Project were predicted using EMF Workstation: ENVIRO (Version 3.52), a Windows-based model developed by the Electric Power Research Institute (EPRI). It is a program that accurately predicts the magnetic fields produced by linear transmission lines such as those in the Project.

To perform this modeling, detailed information was received from Tri-State on the design of the line, which included projected electrical power flows, operating voltage, tower configuration, conductor size and type, the height and horizontal location of each conductor, conductor sag, and conductor phasing. The modeling was conducted for three scenarios: a new 230 kV single circuit line adjacent to that portion of the existing 115 kV single circuit line having a right-of-way (ROW) width of 100 feet (scenario A1), a new 230 kV single circuit line adjacent to that portion of the existing 115 kV single circuit line having a ROW width of 75 feet (scenario A2), and a new 230 kV single circuit line on a separate, non-adjacent ROW (scenario B). In all cases, the ROW for the 230 kV line was assumed to be 150 feet. For scenario A1 the section of the existing 115 kV single circuit line from Burlington to Idalia has a ROW width of 100 feet. For scenario A2 the section of the existing 115 kV single circuit line from Idalia to Wray has a ROW width of 75 feet. Two power flow
cases were modeled for scenarios A1 and A2: heavy summer and light winter. One power flow case was modeled for scenario B: the maximum thermal capacity. Table 1 of Attachment 1 shows the transmission line characteristics used to perform this modeling.

The scenario A cases were modeled according to CPCN rule 3206(e)(II), which states "For a right-of-way containing multiple circuits, the magnetic field level will be presented at the maximum pre-outage currents wherein the outage of a single circuit loads the remaining circuits to their continuous MVA rating." The scenario A cases are the maximum pre-outage currents for heavy summer and light winter conditions that result in the 115 kV Burlington-Wray line being loaded to its continuous mega volt ampere (MVA) rating upon loss of the new proposed 230 kV Burlington-Wray line.

Scenario B was modeled according to CPCN rule 3206(e)(I), which states "For a right-of-way containing a single circuit, the magnetic field level will be presented at the continuous MVA rating of that circuit."

These data were input into the ENVIRO program which produced the lateral profiles of the magnetic fields out to 75 feet from the left and right ROW edges for the three scenarios. These profiles were then plotted to produce the graphs that are presented below. The profiles were calculated with the lowest phase conductor at 28 feet above the ground for the 230 kV line and at 24 feet above the ground for the 115 kV line, which meets or exceeds the minimum ground clearance per the National Electrical Safety Code (NESC) and the Rural Electric Service (RUS) "Design Manual for High Voltage Transmission Lines", Bulletin 1724E-210, which coincides with the lowest point of conductor sag, providing the most conservative results. The calculations are computed at a height of 1 meter (3.3 feet) above the ground. The accuracy of the modeling is dependent on the accuracy of the input data. The resulting field plots are within a few percent of the true value for the conditions modeled.

Modeling Results

The new 230 kV single circuit line, modeled in all three scenarios, was modeled as an H-frame structure, specifically the RUS TM-230. The existing 115 kV single circuit line, modeled in scenarios A1 and A2 only, was modeled as an H-frame structure, specifically the TH-10. Table 1 of Attachment 1 shows the transmission line characteristics used to perform this modeling.

Figures 1 and 2 present the magnetic field results for both the heavy summer and light winter power flow cases for scenario A1 and A2, respectively. In both scenario A1 and A2 the new 230 kV line will be located on a 150 foot wide ROW. In scenario A1 the new 230 kV line will be adjacent to the existing 115 kV line on a 100 foot ROW. In scenario A2 the new 230 kV line will be adjacent to the existing 115 kV line on a 75 foot ROW. The outer edges of the combined ROWs are shown as vertical dashed lines in Figures 1 and 2.

The magnetic field results for scenario B are presented in Figure 3. In scenario B the new 230 kV line will be located on a 150 foot wide ROW. The outer edges of the ROW are shown as vertical dashed lines in Figure 3.
FIGURE 1
Magnetic Fields for New 230 kV Single Circuit adjacent to Existing 115 kV Single Circuit on 100' ROW (Scenario A1)

The results of the magnetic field modeling plotted in Figure 1 show that on the left ROW edge the magnetic field is approximately 13 milliGauss (mG) for the heavy summer power flow case and approximately 16 mG for the light winter power flow case. On the right ROW edge the magnetic field is approximately 26 mG for the heavy summer power flow case and approximately 20 mG for the light winter power flow case. The maximum magnetic field within the ROW is approximately 96 mG for the heavy summer power flow case and approximately 90 mG for the light winter power flow case.
FIGURE 2
Magnetic Fields for New 230 kV Single Circuit adjacent to Existing 115 kV Single Circuit on 75' ROW (Scenario A2)

The results of the magnetic field modeling plotted in Figure 2 show that on the left ROW edge the magnetic field is approximately 13 mG for the heavy summer power flow case and approximately 16 mG for the light winter power flow case. On the right ROW edge the magnetic field is approximately 41 mG for the heavy summer power flow case and approximately 32 mG for the light winter power flow case. The maximum magnetic field within the ROW is approximately 96 mG for the heavy summer power flow case and approximately 89 mG for the light winter power flow case.
FIGURE 3
Magnetic Fields for New 230 kV Single Circuit (Scenario B)

The results of the magnetic field modeling plotted in Figure 3 show that on the left ROW edge the magnetic field is approximately 56 mG and approximately 57 mG on the right ROW edge. The maximum magnetic field within the ROW is approximately 336 mG.
Corona Audible Noise from Burlington-Wray Transmission Line Project

Corona is the electrical ionization of the air that occurs near the surface of the energized conductor and suspension hardware due to very high electric field strength. Corona may result in audible noise being produced by the transmission lines.

The amount of corona produced by a transmission line is a function of the voltage of the line, the diameter of the conductors, the locations of the conductors in relation to each other, the elevation of the line above sea level, the condition of the conductors and hardware, and the local weather conditions. Power flow does not affect the amount of corona produced by a transmission line. Corona typically becomes a design concern for transmission lines at 345 kV and above and is less noticeable from lines like those from the Project that are operated at lower voltages.

The electric field gradient is greatest at the surface of the conductor. Large-diameter conductors have lower electric field gradients at the conductor surface and, hence, lower corona than smaller conductors, everything else being equal.

Irregularities (such as nicks and scrapes on the conductor surface or sharp edges on suspension hardware) concentrate the electric field at these locations and thus increase the electric field gradient and the resulting corona at these spots. Similarly, foreign objects on the conductor surface, such as dust or insects, can cause irregularities on the surface that are a source for corona.

Corona also increases at higher elevations where the density of the atmosphere is less than at sea level. Audible noise will vary with elevation with the relationship of A/300 where A is the elevation of the line above sea level measured in meters (EPRI 2005). Audible noise at 600 meters elevation will be twice the audible noise at 300 meters, all other things being equal. The Project was modeled with an elevation of 4,000 feet.

Raindrops, snow, fog, hoarfrost, and condensation accumulated on the conductor surface are also sources of surface irregularities that can increase corona. During fair weather, the number of these condensed water droplets or ice crystals is usually small and the corona effect is also small. However, during wet weather, the number of these sources increases (for instance due to rain drops standing on the conductor) and corona effects are therefore greater. During wet or foxtail weather conditions, the conductor will produce the greatest amount of corona noise. However, during heavy rain the noise generated by the falling rain drops hitting the ground will typically be greater than the noise generated by corona and thus will mask the audible noise from the transmission line.

Corona produced on a transmission line can be reduced by the design of the transmission line and the selection of hardware and conductors used for the construction of the line. For instance the use of conductor clamps that hold the conductor in place should have rounded rather than sharp edges and no protruding bolts with sharp edges will reduce corona. The
conductors should be handled so that they have smooth surfaces without nicks or burrs or scraps in the conductor strands.

**Modeling Methodology**

CPUC Rule 3206 requires that the applicant for a CPCN for a new transmission line model the potential noise levels that the line could produce. The audible noise for the Project was predicted using FMF Workstation: ENVIRO (Version 3.52), the same program used to predict magnetic fields from the Project. The ENVIRO program calculated audible noise for the Project using two methods: the Bonneville Power Administration (BPA) method and the EPRI-High Voltage Transmission Research Center (HVTRC) method. The BPA method is based on research performed at the BPA in Oregon and Washington in the 1980’s and 90’s. Much of this research was conducted by Mr. Vernon Chartier and others at BPA who took measurements of corona effects from operating transmission lines. The EPRI-HVTRC method is a more analytical approach based on calculations presented in the *EPRI AC Transmission Line Reference Book—200 kV and Above* (EPRI 2005). The wet weather audible noise results between the two methods are quite similar, while the fair weather audible noise results vary a bit more. The BPA method was selected for the Project, and the results are presented in Figures 4 through 6 below.

The modeling was conducted for the same three scenarios as for magnetic fields: a new 230 kV single circuit line adjacent to that portion of the existing 115 kV single circuit line having a ROW width of 100 feet (scenario A1), a new 230 kV single circuit line adjacent to that portion of the existing 115 kV single circuit line having a ROW width of 75 feet (scenario A2), and a new 230 kV single circuit line on a separate, non-adjacent ROW (scenario B). Power flow does not affect the amount of corona produced by a transmission line; therefore, the two power flow cases for scenarios A1 and A2 produced the same amount of corona.

The data presented in Table 1 of Attachment 1 were input into the ENVIRO program to calculate the corona audible noise, with the addition of elevation of the line above sea level. The Project was modeled with an elevation of 4,000 feet. Because the equations that predict audible noise were created from empirical measurements, the accuracy of the model is as good as these measurements that produced the original equations. In addition, the model is as good as the accuracy of the parameters input to the model (e.g. the actual elevation of the transmission line at a particular location rather than the average elevation of the entire project). Therefore given these potential uncertainties, the resulting field plots are within a few percent of the true value for the conditions modeled.

**Modeling Results**

The structures modeled for magnetic fields were also used in modeling corona for the new 230 kV single circuit line, modeled in scenario A1, scenario A2, and scenario B, and the existing 115 kV single circuit line, modeled in scenarios A1 and A2 only.

The corona audible noise results for scenarios A1 and A2 are presented in Figures 4 and 5, respectively. In both scenario A1 and A2 the new 230 kV line will be located on a 150 foot wide ROW. In scenario A1 the new 230 kV line will be adjacent to that portion of the
existing 115 kV line on a 100 foot ROW. In scenario A2 the new 230 kV line will be adjacent to that portion of the existing 115 kV line on a 75 foot ROW. The outer edges of the combined ROWs are shown as vertical dashed lines in Figures 4 and 5.

The corona audible noise results for scenario B are presented in Figure 6. In scenario B the new 230 kV line will be located on a 150 foot wide ROW. The outer edges of the ROW are shown as vertical dashed lines in Figure 6.

The figures show two weather conditions for the corona audible noise results, fair and rain. This is to show the range in corona effects due to changing weather. CPCN rule 3206(f)(I) specifies that the audible noise modeling must assume "that the proposed facility is operating at its highest continuous design voltage under L50 rain conditions." The figures present the audible noise results for L50 rain conditions.

![Audible Noise: Tri-State Burlington-Wray](image)

**FIGURE 4**
Corona Audible Noise for New 230 kV Single Circuit adjacent to Existing 115 kV Single Circuit on 100' ROW (Scenario A')

The results of the corona audible noise modeling plotted in Figure 4 show that on the left ROW edge the audible noise is approximately 17 dBA in fair weather and 42 dBA in wet weather. On the right ROW edge the audible noise is approximately 13 dBA in fair weather and 38 dBA in wet weather. Figure 4 also shows that 25 feet from the left ROW edge the audible noise is approximately 15 dBA in fair weather and 40 dBA in wet weather, and that 25 feet from the right ROW edge the audible noise is approximately 12 dBA in fair weather.
and 37 dBA in wet weather. The maximum noise that occurs within the ROW is 22 dBA in fair weather and <7 dBA in wet weather.

![Graph](image)

**FIGURE 5**
Corona Audible Noise for New 230 kV Single Circuit adjacent to Existing 115 kV Single Circuit on 75' ROW (Scenario A2)

The results of the corona audible noise modeling plotted in Figure 5 show that on the left ROW edge the audible noise is approximately 17 dBA in fair weather and 42 dBA in wet weather. On the right ROW edge the audible noise is approximately 13 dBA in fair weather and 38 dBA in wet weather. Figure 5 also shows that 25 feet from the left ROW edge the audible noise is approximately 15 dBA in fair weather and 40 dBA in wet weather, and that 25 feet from the right ROW edge the audible noise is approximately 13 dBA in fair weather and 38 dBA in wet weather. The maximum noise that occurs within the ROW is 22 dBA in fair weather and 47 dBA in wet weather.
FIGURE 6
Corona Audible Noise for New 230 kV Single Circuit (Scenario B)

The results of the corona audible noise modeling plotted in Figure 6 show that on both the left and right ROW edges the audible noise is approximately 17 dBA in fair weather and 42 dBA in wet weather. Figure 6 also shows that 25 feet from both the left and right ROW edges the audible noise is approximately 15 dBA in fair weather and 40 dBA in wet weather. The maximum noise that occurs within the ROW is 22 dBA in fair weather and 47 dBA in wet weather.
References Cited

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<tr>
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<th>Scenario B</th>
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<td>New 230-kV SC</td>
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<td><strong>ROW</strong></td>
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<td>230-kV: Centered in 150'</td>
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<td>115-kV: Centered in 75' (Scenario A2 for section between Idalia and Wray)</td>
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<td>Pre-outage loading on Burlington - Wray 230 kV line is 345 A (22.4% of 613 MVA line rating).</td>
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<td>Pre-outage loading on Burlington - Wray 230 kV line is 427 A (28% of 613 MVA line rating).</td>
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**Notes**

Audible noise is calculated at an average elevation of 4,000 feet.