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Transmission Report
for the
Clean Air – Clean Jobs Act

(House Bill 10-1365)

Transmission Asset Management
Public Service Company of Colorado

August 13, 2010

I. Executive Summary

This report summarizes the transmission system reliability analyses performed to evaluate potential scenarios for the retirement of coal generation facilities in and around the Denver-metro area. The Colorado Clean Air-Clean Jobs Act[1] requires Public Service Company of Colorado ("Public Service") to evaluate plans that would reduce nitrogen oxide emissions by at least 70 percent (compared to 2008 levels) from the coal plants included in the plan. The coal-fired plants that appear to be the primary candidates for retirement are the older plants located in or near the heart of the Denver-metro area and include the Cherokee, Arapahoe, and Valmont generating stations. Also, purchase power contracts with independent power producer (IPP) units at Arapahoe and Valmont expire in 2012. Figure 1 represents the Denver-metro transmission network. The Cherokee and Arapahoe generating units directly serve customers in the Denver area. Valmont is located just outside of Boulder and provides generation to customers in that area. The Transmission Asset Management (TAM) group within Public Service is concerned that the retirement of these generation resources may severely impact the reliability of the Denver-metro transmission system. This report describes the TAM recommendations based on the results of system studies as well as engineering and operations experience.

II. General Recommendations and Concerns

1. Adequate generation and voltage support equipment must remain at the existing Cherokee and Arapahoe sites.

The Denver-metro area currently consumes about 4900 MW of power on a peak day, which is about 80% of the total Public Service load. About 1300 MW of the Denver-metro load can be served by the existing generation (both owed and purchased) at Cherokee, Arapahoe, and Valmont. In addition to these plants supplying real power for user consumption, they provide reactive power, which maintains local system voltages at acceptable levels. Keeping generation close to load minimizes transmission upgrades and system losses. Reactive power and voltage support cannot be efficiently transferred over long distances and must be provided locally.

Therefore, to maintain essential reliable system performance in the Denver-metro area, real power generation and other voltage support devices must remain at the Cherokee and Arapahoe sites.

2. Operational flexibility is essential to maintain acceptable system performance.

As a normal course of business, generators and other equipment must be taken out of service for planned maintenance and other service reasons. When equipment is out of service, operators must continue to be prepared for the loss of other transmission elements, including the loss of another generation unit (additional contingencies). In the Denver-metro area, a primary concern is the condition where a generating unit is out of service for maintenance. Under that condition, the system must continue to be operated in a configuration that would allow reliability to be maintained in the event of an unplanned

[1] House Bill 1365

outage of another transmission element or generating unit. The loss of a generator, with one generator already out of service can be devastating to a local area that relies on that generation to serve customers.

Therefore, it is critical that the operators of the power system have as many tools and as much flexibility as possible to maintain adequate performance and keep customers on line. This should include a prudent mix of power system devices to provide both real and reactive power and including generators, synchronous condensers, and shunt capacitors. A sufficient amount of equipment must be available to maintain adequate system performance under a wide range of potential operating conditions.

3. Additional studies must be performed to completely assess potential retirement scenarios.

The recommendations made in this report are the result of initial technical studies, engineering judgment, and operations experience. Additional detailed studies will be required to fully understand the potential impacts of retiring coal units in the Denver-metro area and what actions are needed to meet criteria set forth by the North American Electric Reliably Corporation (NERC), the Western Electricity Coordinating Council (WECC), and the Colorado Coordinated Planning Group (CCPG). Detailed studies will clarify the recommendations to provide validation of the alternatives to mitigate system reliability concerns.

4. Staging the retirements will allow operational experience with the system.

The Denver-metro transmission and generation system has been designed to operate reliability and continuously serve customer load. Permanently removing generation from the Denver-metro load center could have dramatic impacts. Therefore, the retirement or replacement of units will need to be done in a prudent and staged manner that allows Public Service Operations personnel time to evaluate the system after each change prior to removing additional equipment.

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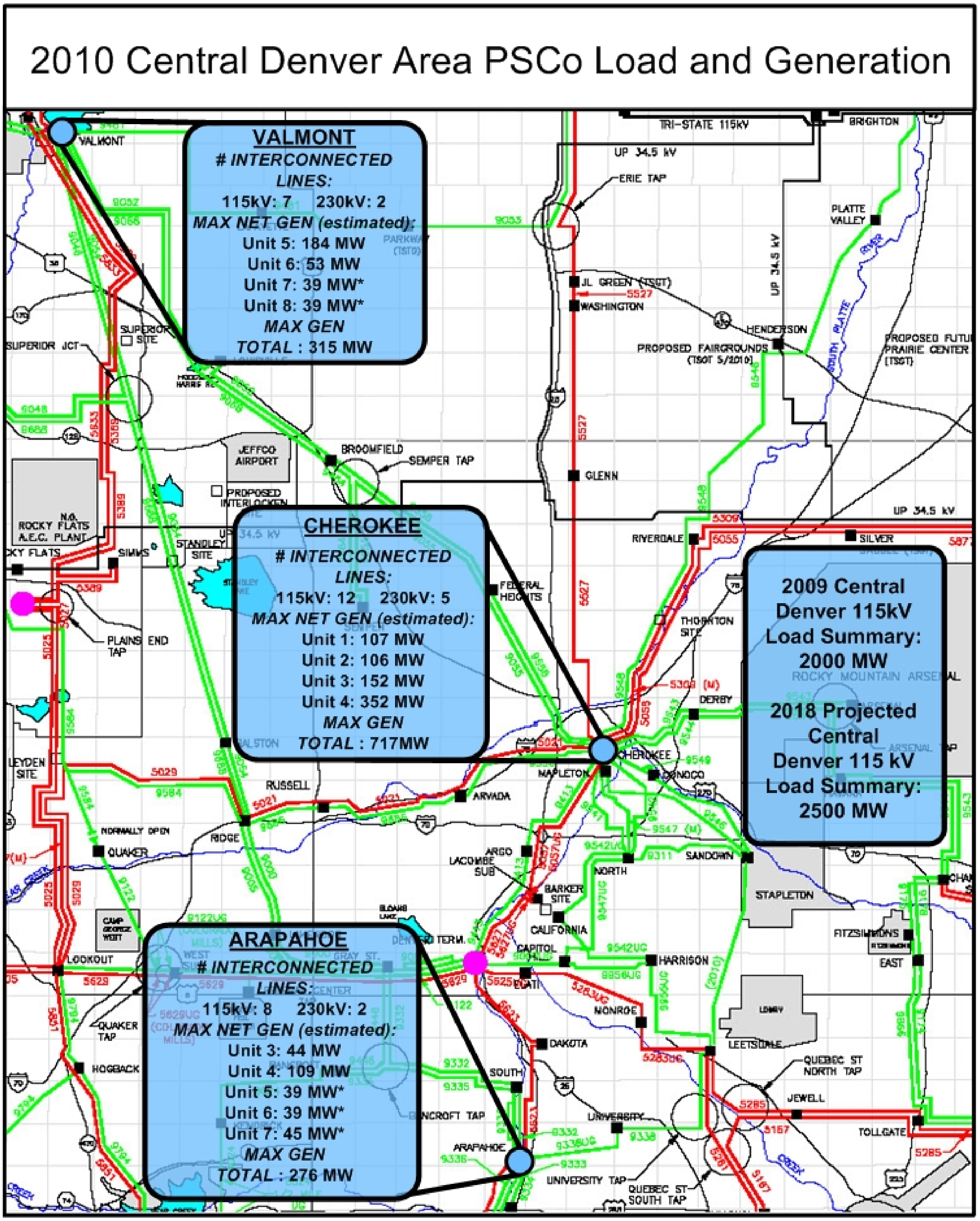
Figure 1



*Indicates Non-Utility Generator

III. Recommendations

A. <u>Arapahoe Units #3 and #4:</u>

In order for Arapahoe units #3 and #4 to be retired from coal-fired operation by 2013:

1. The existing Arapahoe unit #4 should remain as a generator as needed, such as during peak load periods and other adverse system conditions.

2. Additional reactive support equipment must be added at the Arapahoe site. Studies indicate that a total of approximately 150-200 MVARs are needed at Arapahoe to ensure appropriate voltages are maintained. A 45 MVAR shunt capacitor already exists at Arapahoe, so approximately 100-150 MVARs of new reactive support is needed. It is recommended that this be achieved by:
    a. Adding 90 MVARs of new shunt capacitors to the Arapahoe 115kV bus
    b. Modifying Arapahoe unit #3 to operate as a synchronous condenser. This could provide approximately 30 MVARs of support.
    c. Operate Arapahoe unit #4 (on gas) when needed. This could provide approximately 60 MVARs of support.

3. If Arapahoe unit #3 is not utilized as a synchronous condenser and Arapahoe #4 is not available for support, additional studies would be needed to determine how to manage appropriate voltage support.

B. Cherokee Units #1 and #2

In order for Cherokee units #1 and #2 to be retired from coal-fired operation by 2013:

1. The existing Cherokee units #3 and #4 must remain on-line and capable of continuous operation.

2. Additional reactive support equipment must be added at the Cherokee site. Studies indicate that a total of approximately 350-400 MVARs are needed at or near Cherokee to ensure appropriate voltages are maintained with a prior outage of Cherokee unit #4. Cherokee unit #3 can provide about 105 MVARs of support, and the 90 MVARs of shunt capacitors recommended for Arapahoe will also reduce the amount of support needed at the Cherokee site. Therefore, if the 90 MVARs are available at Arapahoe, then approximately 150-200 MVARs of ***new*** reactive support must be added. It is recommended that this be achieved by:
    a. Adding 90 MVARs of new shunt capacitors at Cherokee.
    b. Modifying Cherokee unit #2 to operate as a synchronous condenser. This could provide approximately 80 MVARs of support.

3. If Cherokee unit #2 is not utilized as a synchronous condenser, an additional 90 MVARs or more of shunt capacitors would be required.

C. Cherokee Unit #3

In order for Cherokee unit #3 to be retired from coal-fired operation:

1. The existing Cherokee unit #4 must remain on-line and capable of continuous operation.

2. The recommendations listed for B. above should be maintained:
   a. Continue to operate Cherokee unit #2 as a synchronous condenser (80 MVARs)
   b. Keep 90 MVARs of shunt capacitors at Cherokee 115kV bus

3. To replace the real and reactive support lost by retiring Cherokee unit #3, it is recommended that new gas-fired generation be added at Cherokee. Studies indicate that a generating plant with at least 500 MW & 300 MVARs of capability would meet reliability requirements.

4. If real generation is not replaced at Cherokee, then additional studies will be required to determine alternatives to achieve adequate reliability and voltage support. Conventional reactive devices such as shunt capacitors would not provide the reactive support required.

D. Cherokee Unit #4

In order for Cherokee unit #4 to be retired from coal-fired operation:

1. The recommendations listed in C. above should be maintained:
   a. Continue to operate Cherokee unit #2 as a synchronous condenser (80 MVARs)
   b. Keep 90 MVARs of shunt capacitors at Cherokee 115kV bus

2. To replace the real and reactive support lost by retiring Cherokee unit #4, it is recommended that new gas-fired generation be added at Cherokee. Since the Cherokee unit #4 provides approximately 350 MW of power and 250 MVARs of reactive support a plant with at least those capabilities should be implemented.

3. If real generation is not replaced at Cherokee, then additional studies will be required to determine alternatives to achieve adequate voltage support. Conventional reactive devices such as shunt capacitors would not provide the reactive support required.

E. Valmont Unit #5:

In order for Valmont unit #5 to be retired from coal-fired operation, measures must be taken to ensure adequate voltage and system support at Valmont.

1. The existing Valmont unit #6 gas-fired plant must remain on-line and capable of operation under peak loading periods.

2. The existing 90 MVARs of shunt capacitors must remain in service at Valmont.

3. Measures may need to be taken to reduce potential contingency loading on the Valmont 230/115kV transformers. It is recommended that this be achieved by:
   a. Allowing up to 115% loading under contingency conditions, or
   b. Implementing operating procedures to mitigate potential overloads.

4. Additional studies should be performed to fully assess any necessary upgrades at the Valmont site.

F. Transmission Upgrades:

1. The Capital Hill – Denver Terminal 115kV line

The Capital Hill – Denver Terminal 115kV line is an underground line that has the potential to experience unacceptable loading conditions for certain contingencies. Studies show the overloads increase when generation levels at the Cherokee site are reduced. The situation should be mitigated by upgrading the Capital Hill – Denver Terminal 115kV line with new conductor.

2. Various termination equipment

Studies indicated some termination equipment overloads. These issues will be addressed through the normal planning processes.

IV. Methodology

The technical analysis consisted of powerflow studies using conventional transmission planning models. At the time of this study, the Company was considering a number of potential scenarios for the retirement of the Denver metro coal-fired units. This study is not meant to be a full comprehensive analysis of every possible scenario, but should be used to guide some general direction of the scenario selections.

To maintain essential voltage levels in the Denver-metro area, voltage support and real power generation must remain at the Cherokee and Arapahoe sites. Studies indicate that the Cherokee site is the most critical and requires the most power and voltage support. Arapahoe and Valmont still require some continued voltage support.

A. Existing Generation

The following table describes the existing generation at Cherokee, Arapahoe, and Valmont.

Table 1 Characteristics of Existing Generation

Gen Site	Unit	Fuel	PSCo Owned	MW Gross	MW Net	MVAR Gross
Cherokee	1	Coal	Yes	117	107	82
	2	Coal	Yes	114	106	78
	3	Coal	Yes	165	152	105
	4	Coal	Yes	383	352	240
	Total			779	**717**	505
Arapahoe	3	Coal	Yes	48	44	32
	4	Coal	Yes	118	109	64
	5	Gas	No	41	39	21
	6	Gas	No	41	39	21
	7	Gas	No	45	45	21
	Total			285	**268**	159
Valmont	5	Coal	Yes	196	184	83
	6	Gas	Yes	53	53	30
	7	Gas	No	41	39	18
	8	Gas	No	41	39	18
	Total			323	**307**	149

B. Generation Retirements Modeled in Power Flow Studies

1. By the year 2013:

a) Arapahoe units #3 and #4: Public Service units will be retired from coal-fired operation.
b) Arapahoe unit #4 will remain operational on gas, but not modeled in studies.
c) Arapahoe units #5, #6, and #7: Not owned by Public Service, the contract for these gas-fired units are not be renewed, and the units are not operated in studies.
d) Cherokee units #1and #2: Public Service units will be retired from coal-fired operation.
e) Valmont #7 and #8: Not owned by Public Service, the contract for these gas-fired units is not renewed, and the units are not operated in studies.

2. **By the year 2018:**
   a) Cherokee unit #3: Public Service unit will be retired from coal-fired operation.
   b) Valmont unit #5: Public Service unit will be retired from coal-fired operation.

3. **Beyond the year 2018:**
   a) Cherokee unit #4 will be considered for retirement from coal-fired operation in 2022.

C. Generation Replacement

The Denver-metro transmission and generation system has been designed to operate reliability and continuously serve customer load. Permanently removing generation from the Denver-metro load center could have dramatic impacts on the ability to reliably operate the transmission system. The existing generation Cherokee, Arapahoe, and Valmont, both owned and purchased, are capable of serving as much as 1300 MW of the customer load in the Denver-metro area. If retired generation is not replaced at the existing sites, then it would have to be delivered from areas outside the Denver-metro area.

These studies examined the best location for replacement generation capacity, and focused more on Cherokee given it plays the most critical role in supporting the Denver-metro transmission system, compared to either Arapahoe or Valmont. All of the generation currently located at the Cherokee site is coal-fired, so if all units were retired as part of CACJA without replacement, there would be no generation at Cherokee. At the Arapahoe site, there are gas-fired IPP units as well as the Company owned coal-fired units. Either the IPP facilities or Arapahoe unit #4 operating on gas are capable of providing valuable generation support to south Denver load. At the Valmont site, there are existing gas-fired units as well. The Company owns and operates Valmont unit #6 and plans to continue its operation. As a result, some amount of gas-fired generation will remain at Arapahoe and Valmont, even if all the coal-fired units at those locations are retired.

When evaluating replacement generation at Cherokee, transmission studies must assess how the system will perform for the operating conditions listed above under the Voltage Support section: system intact, prior-outage, and prior-outage plus forced-outage. Three typical configurations of gas-fired generation plants were considered to serve as replacement generation at Cherokee.

1. Combustion Turbine ("CT", or "simple-cycle"): this is a single gas-fired generating unit

2. Combined Cycle ("CC", "one-on-one" or "1x1"): this is a single CT generating unit that is coupled to a steam turbine. Waste heat from the CT is used to power the steam turbine. The CT can run without the steam unit, but the steam unit cannot run without the CT. A forced-outage of the CT will result in all generation being lost.

3. Combined Cycle; ("two-on-one""2x1"): In this configuration, a steam turbine is coupled with two CT's. For this study, it was assumed that a forced outage could take an entire 2x1 plant out of service. Ideally, under a forced outage of one CT, the other CT could still operate and the steam unit output would be reduced by approximately 50%. Although the 2x1 plant may not be as likely to experience loss of the entire generation at

the plant as a 1x1 CC or a simple CT, until operating experience can verify such independent operation, loss of the entire 2x1 is considered a credible disturbance for planning purposes.

D. Models

Powerflow models were developed to represent 2013 and 2018 summer peak loading conditions in Colorado. The years 2013 and 2018 were chosen, since this is the time frame under consideration for retirement of Denver-metro coal generation. The first proposed retirement is at Cherokee in 2012 and the final retirements and retrofits would be completed in 2018 (not considering Cherokee 4 retirement in 2022).

The models were developed from Western Electricity Coordinating Council (WECC) cases. All appropriate planned transmission projects were represented. The Public Service loads were adjusted to represent the latest system load forecasts.

E. Criteria

1. NERC/WECC Criteria

As a member of WECC, Public Service adheres to the WECC and NERC Reliability Criteria. The complete Reliability Criteria document can be found on the WECC web site at www.wecc.biz.

2. Element Loading

a) **System-intact and Prior-Outage Conditions:**

- Line loading monitored for 100% of the established lowest-rated equipment rating, as well as the conductor rating.
- Transformer loading monitored to 100% of the highest name plate rating or appropriate owner's top rating.

b) **Contingency (Forced-Outage) Conditions**

- Line loading monitored for 100% of the established lowest-rated equipment rating, as well as the conductor rating.
- Transformer loading monitored to 100% of the highest name plate rating or appropriate owner's top rating.

3. Voltage Criteria

The reactive power supply must be made up of both static and dynamic sources. If a system condition causes a shortage of reactive power, voltages will decline until measures are taken to restore voltage to nominal levels. Small shortages of reactive power result in small degradation of system voltage. Larger shortages of reactive power can lead to voltages that are unacceptably low voltage or even to voltage collapse. Therefore, some form of reactive power adjustment is needed to maintain the appropriate voltage levels in the power system. Crude adjustment is achieved by switching "static" sources like shunt capacitor banks on and off. However, these adjustments can be slow and major voltage swings on the system can occur. Better precision and faster action can be achieved from continuously adjustable reactive power sources such as generators and synchronous condensers. These constantly adjusting sources of reactive power are referred to as "dynamic" sources. Generation units inherently provide dynamic reactive support by design. Dynamic reactive resources are typically used to adapt to rapidly changing conditions on the transmission system, such as sudden loss of generators or transmission facilities. In contrast, switched static devices are typically used to adapt to slowly changing system conditions. To keep the voltage balanced, and ensure reliable operation of the transmission system, both static and dynamic sources are needed. The amount of reactive support required to achieve a particular voltage set point depends on many things, including whether the support is coming from static or dynamic devices, where the support is located electrically, and whether the support comes from real generation plants.

The Colorado Coordinated Planning Group (CCPG) developed and maintains the Rocky Mountain Voltage Coordination Guidelines (VCG). Included in the VCG are recommendations for voltages for various regions in the CCPG footprint. The VCG categorizes voltages as "ideal", "acceptable", and "emergency" and the voltage levels depend on whether a bus in regulating or non-regulating. The recommended voltages for the Denver-metro area are shown in the table below.

Table 2 CCPG Voltage Coordination Guidelines Suggested Voltages for Denver-Metro Area

	Low Voltage Limit		High Voltage Limit	
	115kV Bus	230kV Bus	115kV Bus	230kV Bus
Regulating Bus: Ideal Voltage Range	117kV (1.02 PU)	234kV (1.02 PU)	118kV (1.03 PU)	236kV (1.03 PU)
**Ideal Voltage Range (unusual conditions)	119kV (1.03 PU)	239kV (1.04 PU)	121kV (1.05 PU)	242kV (1.05 PU)
Non-Regulating Bus: Ideal Voltage Range	115kV (1.0 PU)	230kV (1.0 PU)	118kV (1.03 PU)	236kV (1.03 PU)
Regulating Bus: Acceptable Voltage Range	110kV (0.96 PU)	221kV (0.96 PU)	121kV (1.05 PU)	242kV (1.05 PU)
Regulating Bus: Emergency Voltage Range	107kV (0.93 PU)	214kV (0.93 PU)	124kV (1.07 PU)	247kV (1.07 PU)

In addition to referring to the Voltage Coordination Guidelines, Public Service Operations was also consulted for their recommendations on Denver-metro bus voltages. Between the VCG and advice from Public Service Operations, the following voltages were recommended for this study:

For Cherokee and Arapahoe 115kV buses, the ideal voltage is at least 1.02 per unit. Effort should be taken to achieve this voltage for both system-intact and prior-outage conditions. The acceptable voltage level is at least 1.00 per unit, and effort should be taken to achieve this voltage under forced-outage conditions.

The Valmont site is also important, but not as critical as Cherokee and Arapahoe, due to the lower load served. The ideal voltage level is 1.01-1.02 per unit for both system-intact and prior-outage conditions, and acceptable is 1.00 under forced-outage conditions.

V. 2013 Results

A. Modeling

The 2013 powerflow models used recent forecasts to model the Public Service customer loads at approximately 6745 MW. Several cases were created to assess system performance. Pertinent cases are described below.

Case 13-0 – The 2013 pre-retirement system-intact case with Cherokee 1 and 2 in service

Case 13-1 – The 2013 retirement case (system-intact) with the following units out of service:

- Cherokee units 1, 2
- Arapahoe units 3, 4, 5, 6, 7
- Valmont units 7, 8

Case 13-2 – Same as Case 13-1, except assume the Cherokee unit #4 is out of service for maintenance or other planned reason. This is the "prior-outage" case. The loss of generation at Cherokee was made up by increasing generation at various regional plants.

Case 13-3 – Same as Case 13-2, except assume Cherokee unit #3 is out of service in addition to Cherokee unit #4. This case was used to evaluate system performance for an unexpected loss of Cherokee unit #3. It was also used to start to assess the importance of having some generation remain at Cherokee when the remaining coal-fired units are retired. This is a "prior-outage plus forced-outage" case.

B. Element Loading

Single contingency outages were performed for each of the 2013 models. Studies assessed the loss of every transmission element in the Public Service area. Each of the cases exhibited some contingency overloads of existing of termination equipment, such as switches, jumpers, and line traps. These issues associated with termination equipment are addressed in the normal planning processes. There were only two notable contingency overloads that appeared to be a direct result of the unit retirements. First, the Capital Hill – Denver Terminal 115kV line experienced overloads for loss of the Leetsdale 230/115kV transformer. With Cherokee 4 out of service (Case 13-2) for a prior-outage condition, the Capitol Hill – Denver Terminal line loaded to 119% of its 131 MVA rating.

Table 3 2013 Contingency Loading Results

Overloaded Element	Contingency	Rating (MVA)	Limit	% Loading		
				13-1	13-2	13-3
Cap Hill – Denver Term 115	Leetsdale 230/115	131	Conductor	81%	119%	136%
Lookout 230/115 #1	Lookout 230/115 #2	150	Transformer	<99%	<99%	105%

The 2013 studies also showed the importance of having generation replaced at Cherokee. If no generation is on line at Cherokee, as with Case 13-3, the contingency loading of the

Capitol Hill – Denver Terminal 115kV line could reach 136%. Also, loss of one Lookout 230/115kV transformer overloaded the parallel unit by 5%.

C. Voltage Performance

The 2013 models were fine-tuned to ensure that voltage control equipment was modeled accurately. This included some adjustments to the load tap changing transformers, shunt reactive devices, and the reactive capabilities of generating units.

There is currently 45 MVARs of shunt capacitors at Arapahoe and 90 MVARs of shunt capacitors at Valmont. There are no shunt capacitors at Cherokee.

Studies revealed an interaction between Cherokee and Arapahoe in terms of voltage support. Adding reactive capability at one location can provide some benefit to voltages at the other location. The table below summarizes the voltage studies for 2018.

Table 4 2013 Voltage Results

	13-1-A	13-1-B	13-2-A	13-2-B	13-2-C	13-2-D	13-3-A	13-3-B
Mvar Losses - PSCo (Area 70)	2137	2131	2289	2291	2236	2233	2410	2455.5
Mvar Losses - Denver Metro (Zone 700)	627	623	668	669	663	661	700	732.1
Arapahoe - Total Mvar at 115kV	**0**	**110**	**135**	**116**	**96**	**103**	**122**	**45**
New Static Mvar at Arapahoe 115	**0**	**90**	**135**	**90**	**0**	**45**	**90**	0
Gross Dynamic Mvar at Arapahoe	**0**	**20**	**0**	**26**	**96**	**58**	**32**	**0.0**
Cherokee - Total Mvar at 115kV	**345**	**262**	**262**	**275**	**275**	**275**	**170**	**405**
New Static Mvar at Cherokee 115	0	0	**90**	**90**	**90**	**90**	**90**	0
Gross Dynamic Mvar at Cherokee	**345**	**262**	**172**	**185**	**185**	**185**	**80**	**405**
	Voltage (pu)	Voltage (pu)	Voltage (pu)	Voltage (pu)	Voltage (pu)	Voltage (pu)	Voltage (pu)	Voltage (pu)
CHEROKEE 115	1.020	1.020	1.020	1.020	1.019	1.020	1.003	1.020
ARAPAHOE A 115	1.006	1.020	1.023	1.020	1.017	1.019	1.009	1.012
VALMONT 115	1.014	1.016	1.021	1.020	1.020	1.020	1.011	1.019
	Qgen (Mvar)	Qgen (Mvar)	Qgen (Mvar)	Qgen (Mvar)	Qgen (Mvar)	Qgen (Mvar)	Qgen (Mvar)	Qgen (Mvar)
ARAP3 13.800	0	**20**	0	**26**	**32**	0	**32**	0.0
ARAP4 13.800	0	0	0	0	**64**	**58**	0	0.0
CHEROK1 15.500	0	0	0	0	0	0	0	0.0
CHEROK2 15.500	0	0	**80**	**80**	**80**	**80**	**80**	**405**
CHEROK3 20.000	**105**	**86**	**92**	**105**	**105**	**105**	**0**	**0**
CHEROK4 22.000	**240**	**175**	**0**	**0**	**0**	**0**	**0**	**0**
VALMONT5 20.000	83	83	83	83	83	83	83	83
VALMONT6 13.800	0	0	30	30	30	30	30	30

1. Series 13-1 Cases (Retirement Cases)

Case 13-1-A modeled the retirement of Cherokee #1 and #2. Arapahoe units #3, #4, #5, #6, & #7 were also out of service in this case. There was enough reactive capability from Cherokee units #3 and #4 to enable the Cherokee 115kV voltage to remain at 1.02 per unit. Also, there is enough reactive capability from the Valmont unit #5 to enable the Valmont 115kV bus to maintain 1.01-1.02 per unit. However, the Arapahoe 115kV voltage was only about 1.01 per unit.

Case 13-1-B added reactive support at Arapahoe to increase the voltage there. To achieve 1.02 per unit, Arapahoe unit #3 was used as a synchronous condenser and 90 MVARs of shunt capacitors were added. Although the Arapahoe synchronous condenser is capable of producing 30 MVARs, only 20 MVARs were required to achieve the ideal voltage. Case 13-1-B also shows how adding reactive support at Arapahoe can provide some amount of benefit at Cherokee. Because of the additional reactive support at Arapahoe from the SC and the shunt caps, the reactive requirement to achieve 1.02 per unit at Cherokee was about 83 MVARs less (345-262) than in case 13-1-A.

2. Series 13-2 Cases (Prior Outage of Cherokee #4)

The 13-2 series of cases represent a prior-outage of the Cherokee unit #4 (352 MW). In order to maintain 1.02 per unit voltages at Cherokee and Arapahoe, additional reactive support was required at both locations. In each of these cases, ideal voltage was maintained at Cherokee by using Cherokee unit #2 as a synchronous condenser with 80 MVARs of capability and adding 90 MVARs of shunt capacitors at Cherokee. However, Cases A through D show four options to achieve the reactive capability needed to maintain ideal voltages at Arapahoe.

Case 13-2-A added shunt capacitors, but no dynamic voltage support at Arapahoe. In order to achieve 1.02 at Arapahoe, 135 MVARs of shunt capacitors were added at Arapahoe in addition to the 45 MVAR shunt capacitor that is presently there.

Case 13-2-B used a combination of shunt capacitors and a synchronous condenser. Arapahoe unit #3 was used as a synchronous condenser with 30 MVAR capability and an additional 90 MVARs of shunt capacitors were required to achieve 1.02 per unit voltage there.

Case 13-2-C turned on generation at Arapahoe unit #4 in addition to the 30 MVAR SC there. Arapahoe unit #4 provided 64 MVARs of support. For this case, no additional shunt capacitors were needed at Arapahoe.

Case 13-2-D kept the Arapahoe unit #4 on, but removed the Arapahoe unit #3 synchronous condenser. In this case, 45 MVARs of additional shunt capacitors were required to maintain ideal voltage at Arapahoe.

To maintain adequate reactive support as well as operational flexibility, it is recommended that Arapahoe unit #3 be converted to a synchronous condenser and that 90 MVARs of shunt capacitors be added at Arapahoe. These sources of reactive power would always be available to provide voltage support. In addition, the Arapahoe unit #4 is recommended to provide additional real and reactive power on an as needed basis.

3. Series 13-3 (No Generation at Cherokee)

The 13-3 series cases have no generation at Cherokee. This could occur for a prior-outage plus forced-outage condition.

Case 13-3-A shows that for the prior-outage plus forced-outage condition, acceptable (1.00 per unit) voltages can be maintained at Cherokee and Arapahoe as long as the reactive support recommended in the 13-2 series cases is in place. At Cherokee, the synchronous condenser at unit #2 and 90 MVARs of shunt capacitors are needed to maintain 1.00 per unit voltage. At Arapahoe, the synchronous condenser at unit #3 and the 90 MVARs of shunt capacitors are needed to maintain 1.00 per unit.

Case 13-3-B shows the importance of having real power generation at Cherokee. In this case a fictitious synchronous condenser was modeled to determine how much reactive support would be needed to maintain ideal voltage (1.02) at Cherokee if there was no generation there. For this condition, over 400 MVARs of reactive support was needed to achieve 1.02 per unit voltage. If Cherokee unit #2 were used as a synchronous condenser, over 300 MVARs would still be required. That amount of support could not be managed by the addition of shunt capacitors alone. Therefore, it is recommended that real power generation be maintained at the Cherokee site.

D. Conclusions for 2013

1. Arapahoe

a) Additional reactive support equipment must be added at the Arapahoe site. Studies indicate that a total of approximately 150-200 MVARs are needed at Arapahoe to ensure appropriate voltages are maintained. A 45 MVAR shunt capacitor already exists at Arapahoe, so approximately 100-150 MVARs of new reactive support is needed. It is recommended that this be achieved by:

(i) Adding 90 MVARs of new shunt capacitors to the Arapahoe 115kV bus

(ii) Modifying Arapahoe unit #3[2] to operate as a synchronous condenser. This could provide approximately 30 MVARs of support

[2] The Company has found that Arapahoe unit #3 is the most likely candidate for this modification.

b) The existing Arapahoe unit #4[3] should remain as a generator to provide real and reactive power support when needed, such as during peak load periods and other adverse system conditions.

c) If Arapahoe unit #3 is not utilized as a synchronous condenser and Arapahoe #4 is not available for support, an additional 45-90 MVARs or more of shunt capacitors may be required.

2. Cherokee

a) The existing Cherokee units #3 and #4 must remain on-line and capable of continuous operation. This will allow Cherokee units #1 and #2 to be retired from coal-fired operation by 2013.

b) Additional reactive support equipment must be added at the Cherokee site. Studies indicate that if Cherokee unit #3 remains on line, a total of approximately 350-400 MVARs are needed at or near Cherokee to ensure appropriate voltages are maintained with a prior outage of Cherokee unit #4. The Cherokee unit #3 can provide about 105 MVARs of support. Also, the 90 MVARs of shunt capacitors recommended for Arapahoe will also reduce the amount of support needed at the Cherokee site. As a result, approximately 150-200 MVARs of new reactive support is needed at Cherokee. It is recommended that this be accomplished by:

(i) Adding 90 MVARs of shunt capacitors to the Cherokee 115kV bus

(ii) Modifying Cherokee unit #2 to operate as a synchronous condenser. This could provide approximately 80 MVARs of support.

c) If Cherokee unit #2 is not utilized as a synchronous condenser, an additional 90 MVARs or more of shunt capacitors may be required at Cherokee.

3. Valmont

a) The 90 MVARs of existing shunt capacitors should remain in service. The shunt capacitors and the reactive capability of the Valmont unit #6 allow appropriate voltages to be maintained at Valmont.

4. Other

a) The continuous rating of the Capitol Hill – Denver Terminal 115kV line should be increased by replacing the conductor. This would increase the rating from 131 to approximately 180 MVA.

[3] Resource Planning has indicated that Arapahoe unit #4 may only be available during peak loading and other adverse operating conditions

VI. 2018 Results

A. Modeling

The 2018 powerflow models used recent forecasts to model the Public Service customer loads at approximately 7211 MW. This is about a 4% increase from the 2013 case.

Several 2018 cases were created to assess system performance. Pertinent cases are described below.

Case 18-0 – The 2018 pre-retirement case. Cherokee unit #3 and Valmont #5 are in service.

Case 18-1 – The 2018 retirement case with the following generator modeling:

1. Cherokee unit #3: (coal): retired and removed from service.
2. Cherokee unit #4: remains in service.
3. Cherokee unit #5: added as replacement generation at Cherokee; modeled at 500 MW / 300 MVAR.
4. Valmont unit #5 (coal): retired and removed from service.
5. Arapahoe unit #4 available as needed.

Case 18-2 – Same as Case 18-1, except assume the Cherokee unit #4 is out of service for maintenance or other planned reason. This is the "prior-outage" case. The loss of generation at Cherokee was made up by increasing generation at various regional plants.

Case 18-3 – Same as Case 18-2 (prior-outage of Cherokee unit #4), but assumes that the new generation at Cherokee unit #5 is only 250 MW / 150 MVAR (instead of 500 MW / 300 MVAR).

Case 18-4 – This case has all generation at Cherokee out of service. This case represents two possible conditions. One is a prior-outage plus forced-outage condition, where Cherokee unit #4 is the prior-outage and there is a forced-outage of the entire plant at Cherokee #5. The case is also representative of a condition where no generation is replaced at Cherokee after retirement of existing generation.

Case 18-5 – Same as Case 18-4, but increase Public Service loads by 5%. This case was used to provide additional stress to the 2018 model. The load increase can be related either to a 5% error in the current load forecast, or can be considered representative of current forecast for the year 2023.

B. Element Loading

The table below summarizes the contingency loading results for the 2018 scenarios.

Table 5 2018 Contingency Loading Results

Description	Case	Cherok 3	Cherok 4	Cherok 5	Total Cherok	Contingency / Loaded Element	Leetsdale 230/115 Cap Hill – Den Term115	Valmont 230/115 #1 Valmont 230/115 #2	Chambers 230/115 BarrLake-Reunion 230	Cherokee 230/115 #1 Cherokee 230/115#2	Ridge 230/115#1 Ridge 230/115#2	Arapahoe 230/115 Leetsdale 230/115	Lookout 230/115#1 Lookout 230/115#2
						MVA Rating →	131	280	280	120	100	280	150
18-0	Benchmark	152	351	0	503		102%	<99%	<99%	<99%	<99%	<99%	<99%
18-1	Cherok 4 + 5	0	351	500	851		<99%	103%	<99%	<99%	<99%	<99%	<99%
18-2	Cherokee 4 out	0	0	500	500		<99%	110%	<99%	<99%	<99%	<99%	<99%
18-3	Cherokee 5 reduced	0	0	250	250		119%	117%	119%	<99%	<99%	<99%	<99%
18-4	No gen at Cherokee	0	0	0	0		156%	128%	156%	117%	114%	103%	101%
18-5	No gen at Cherokee Increase loads 5%	0	0	0	0		165%	133%	165%	118%	122%	110%	105%

1. Case 18-0

This is the pre-retirement case, prior to retiring Cherokee unit #3. The only contingency issue was a slight overload of the Capitol Hill – Denver Terminal 115kV line for an outage of the Leetsdale 230/115kV transformer.

2. Case 18-1

This case assumed that Cherokee unit #4 was in service, and that unit #3 would be replaced with a generator of 500 MW (unit #5) for a total generation level at the Cherokee site of approximately 850 MW. The only contingency issue was a slight overload of one Valmont 230/115kV transformer for an outage of the other parallel unit.

3. Case 18-2

This case assumed that Cherokee unit #4 would be off line. This modeled a prior-outage condition. Cherokee unit #5 would remain on line. The only contingency issue is the Valmont 230/115kV transformer outage with loading on the parallel unit to 110%. This is likely due to the dispatch of generation to replace Cherokee unit #4. Since some generation was increased at Valmont #6 and Ft. St. Vrain to make up for the generation lost at Cherokee, more power is transferred through the Valmont transformers. The loading is acceptable under forced-outage conditions, but should be monitored in subsequent studies.

4. **Case 18-3**

This case also has Cherokee unit #4 out for prior-outage, but assumed that the replacement for Cherokee unit #3 would only be 250 MW. As seen in the table, with only 250 MW at Cherokee, there are risks of contingency overloads on the Capitol Hill – Denver Terminal 115kV line and the loading on the Valmont 230/115kV transformer is unacceptable at 119%. An overload of the Chambers 230/115kV transformer appears for loss of the Barr Lake – Reunion 230kV line.

5. **Cases 18-4 and 18-5**

These cases show the impacts of a prior-outage plus forced-outage condition, or not having any replacement generation at Cherokee. Case 18-5 is the same as 18-4, except loads in the Public Service area were raised 5%. This 5% increase sensitivity was modeled to show the impacts of the load forecast having an error of 5% in 2018, or it could represent the year 2023 based on the current forecast. If no generation is replaced at Cherokee, there are several potential contingency overloads of transformers. These include the Cherokee 230/115kV, the Ridge 230/115kV, the Leetsdale 230/115kV, and the Lookout 230/115kV transformers.

It is recommended that Cherokee unit #3 be replaced with generation at the Cherokee site in order to avoid potential contingency overloads that would become evident if no generation were placed there.

C. Voltage Performance

As with the 2013 models, the 2018 models were also adjusted to ensure that voltage control equipment was modeled accurately.

The table below summarizes the voltage studies for 2018.

1. **Series 18-1 Cases (Retirement Cases)**

Case 18-1-A modeled the retirement of Cherokee #3, but added a CC at Cherokee #5. As seen in the table, the new generation was modeled as two CTs coupled to a steam turbine. There was enough reactive capability from Cherokee units #3 and #5 to enable the Cherokee 115kV voltage to remain at 1.02 per unit. Also, the existing 90 MVARs of capacitors at Valmont enabled the Valmont 115kV bus to maintain 1.01 per unit. In case 18-1-A, Arapahoe unit #4 was off-line and no synchronous condenser was modeled at unit #3. As a result, 135 MVARs of shunt capacitors were required at Arapahoe to achieve 1.02 per unit voltage.

Case 18-1-B was used to assess how much additional reactive support would be needed at Valmont to increase the voltage there to 1.02. In Case 18-1-B, approximately 76 MVARs of dynamic reactive support was needed to reach 1.02. There are plans to add approximately 50 MVARs of shunt capacitors at the Boulder Terminal substation, which is approximately two miles from Valmont. These shunt capacitors were not modeled in these cases, but should enable Valmont voltage to achieve 1.01-1.02 per unit voltage.

Table 6 2018 Voltage Results

	18-1-A	18-1-B	18-2-A	18-2-B	18-2-C	18-3-A	18-3-B	18-4-A	18-4-B	18-4-C
Mvar Losses - PSCo (Area 70)	2094	2096	2235	2232	2187	2357	2283	2547	2447	2457
Mvar Losses - Denver Metro (Zone 700)	652	648	714	713	694	741	712.8	812	775	797
Arapahoe - Total Mvar at 115	**135**	**135**	**135**	**122**	**115**	**135**	**158**	**135**	**186**	**166**
Static Mvar Arapahoe 115	**135**	**135**	**135**	**90**	**45**	**135**	**90**	**135**	**90**	**90**
Gross Dynamic Mvar Arapahoe	0	0	0	**32**	**70**	0	**68**	0	**96**	**76**
Cherokee - Total Mvar at 115	**305**	**263**	**319**	**330**	**324**	**227**	**317**	**80**	**170**	**401**
Static Mvar Cherokee 115 bus	0	0	0	0	0	0	**90**	0	**90**	**90**
Gross Dynamic Mvar Cherokee	**305**	**263**	**319**	**330**	**324**	**227**	**227**	**80**	**80**	**311**
Net Dynamic Mvar Valmont 115	0	**76**	**26**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
	Volts (pu)	**Volts (pu)**	**Volts (pu)**	**Volts (pu)**	**Volts (pu)**	**Volts (pu)**	**Volts (pu)**	**Volts (pu)**	**Volts (pu)**	**Volts (pu)**
CHEROKEE 115.00	1.020	1.020	1.020	1.020	1.020	1.005	1.020	0.979	0.998	1.020
ARAP_A 115.00	1.020	1.021	1.020	1.019	1.018	1.008	1.023	0.988	1.013	1.025
VALMONT 115.00	1.007	**1.020**	1.012	1.012	1.013	1.003	1.012	0.987	1.000	1.011
	Qgen (Mvar)	**Qgen (Mvar)**	**Qgen (Mvar)**	**Qgen (Mvar)**	**Qgen (Mvar)**	**Qgen (Mvar)**	**Qgen (Mvar)**	**Qgen (Mvar)**	**Qgen (Mvar)**	**Qgen (Mvar)**
ARAP3 13.800	0	0	0	**32**	**32**	0	32	0	32	32
ARAP4 13.800	0	0	0	0	**38**	0	**36**	0	**64**	**44**
CHEROK1 15.500	0	0	0	0	0	0	0	0	0	0
CHEROK2 15.500	0	0	**80**	**80**	**80**	**80**	**80**	**80**	**80**	**311**
CHEROK3 20.000	0	0	0	0	0	0	0	0	0	0
CHEROK4 22.000	**153**	**132**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
CHEROK5 22.000	**46**	**39**	**72**	**75**	**73**	**0**	**0**	**0**	**0**	**0**
CHEROK5 22.001	**46**	**39**	**72**	**75**	**73**	**85**	**85**	**0**	**0**	**0**
CHEROK5 22.002	**61**	**53**	**96**	**100**	**98**	**62**	**62**	**0**	**0**	**0**
VALMONT 20.000	0	0	0	0	0	0	0	0	0	0
VALMONT6 13.800	0	0	**30**	**30**	**30**	**30**	**30**	**30**	**30**	**30**

2. Series 18-2 Cases (Prior Outage of Cherokee #4)

The 18-2 series of cases represent a prior-outage of the Cherokee unit #4 (352 MW). In order to maintain 1.02 per unit voltages at Cherokee and Arapahoe, additional reactive support was required at both locations. In each of these cases, ideal voltage was maintained at Cherokee from the Cherokee unit #5 generation and by using Cherokee unit #2 as a synchronous condenser with 80 MVARs of capability. Cases A through C show three options to achieve the reactive capability needed to maintain ideal voltages at Arapahoe.

Case 18-2-A added shunt capacitors, but no dynamic voltage support at Arapahoe. In order to achieve 1.02 at Arapahoe, 135 MVARs of shunt capacitors were added at Arapahoe in addition to the 45 MVAR shunt capacitor that is presently there.

Case 18-2-B added the synchronous condenser at Arapahoe. When Arapahoe unit #3 was used as a synchronous condenser with 30 MVAR capability the shunt capacitor requirement was reduced from Case 18-2-A to 90 MVARs to achieve 1.02 per unit voltage at Arapahoe.

Case 13-2-C added generation at Arapahoe unit #4 in addition to the 30 MVAR SC there. Arapahoe unit #4 provided 38 MVARs of support. For this case, 45 MVARs of additional shunt capacitors were also needed at Arapahoe to maintain 1.02 voltage there. Note that Arapahoe unit #4 could provide up to 64 MVARs, but that would not be enough to keep from needing some shunt capacitance.

In summary, the recommendations for 2018 at Arapahoe are the same as for 2013. To maintain adequate reactive support as well as operational flexibility, it is recommended that Arapahoe unit #3 be converted to a synchronous condenser and that 90 MVARs of shunt capacitors be added at Arapahoe. These sources of reactive power would always be available to provide voltage support. In addition, the Arapahoe unit #4 is recommended to provide additional real and reactive power on an as needed basis.

3. Series 18-3 Cases (Only 250 MW at Cherokee #5)

Case 18-3-A has Cherokee unit #4 out for prior-outage, but assumed that the replacement for Cherokee unit #3 would only be 250 MW. This represents a condition where replacement generation is less than the capability of Cherokee unit #3. The case shows that with only the reactive generation from Cherokee unit #5 and shunt capacitors at Arapahoe, only 1.00 voltage can be achieved.

Case 18-3-B shows that in order to increase the voltage to 1.02, 90 MVARs of shunt capacitors would be needed at Cherokee, and at Arapahoe, the synchronous condenser and the Arapahoe unit #4 generation would be needed.

4. Series 18-4 Cases (No Generation at Cherokee Site)

The 18-4-A case has no generation at Cherokee. This could occur for a prior-outage plus forced-outage condition, or could represent a condition where no replacement generation is at Cherokee. For the prior-outage plus forced-outage condition, acceptable (1.00 per unit) voltages cannot be maintained at Cherokee and Arapahoe unless additional reactive support is added.

Case 18-4-B shows that adding 90 MVARs of shunt capacitors at Cherokee, using Arapahoe unit #4 generation and a synchronous condenser at Arapahoe will achieve 1.00 voltages at Cherokee and Arapahoe.

Case 18-3-C shows the importance of having real power generation at Cherokee. In this case a fictitious synchronous condenser was modeled to determine how much reactive support would be needed to maintain ideal voltage (1.02) at Cherokee if there was no generation there. For this condition, over 400 MVARs of reactive support was needed to achieve 1.02 per unit voltage. Even if Cherokee unit #2 were used as a synchronous condenser, over 300 MVARs would still be required. That amount of support could not be managed by the addition of shunt capacitors alone. Therefore, it is recommended that real power generation be maintained at the Cherokee site.

D. Conclusions for 2018

1. Arapahoe

a) No additional reactive support equipment is required at the Arapahoe site beyond what was recommended for 2013. Although the reactive support requirements increased, studies indicated that the following reactive components would continue to be sufficient for appropriate voltage levels.

(i) Add 90 MVARs of new shunt capacitors to the Arapahoe 115kV bus

(ii) Modify Arapahoe unit #3 to operate as a synchronous condenser. This could provide approximately 30 MVARs of support

b) The existing Arapahoe unit #4 should remain as a generator to provide real and reactive power support when needed, such as during peak load periods and other adverse system conditions.

c) If Arapahoe unit #3 is not utilized as a synchronous condenser and Arapahoe #4 is not available for support, additional studies would be required to determine how to achieve adequate voltage levels.

2. Cherokee

In order for Cherokee unit #3 to be retired from coal-fired operation:

a) The existing Cherokee unit #4 must remain on-line and capable of continuous operation.

b) The recommendations listed for 2013 should be maintained:
(i) Continue to operate Cherokee unit #2 as a synchronous condenser (80 MVARs)
(ii) Keep 90 MVARs of shunt capacitors at Cherokee 115kV bus

c) To replace the real and reactive support lost by retiring Cherokee unit #3, it is recommended that new gas-fired generation be added at Cherokee. Studies indicate that a generating plant with at least 500 MW & 300 MVARs of capability would meet voltage and reliability needs.

d) If real generation is not replaced at Cherokee, then additional studies will be required to determine alternatives to achieve adequate reliability and voltage support. Conventional reactive devices such as shunt capacitors would not provide the reactive support required.

3. Valmont

a) The 90 MVARs of existing shunt capacitors should remain in service. The shunt capacitors and the reactive capability of the Valmont unit #6 allow appropriate voltages to be maintained at Valmont.

b) The Company should proceed with plans to add approximately 50 MVARs of shunt capacitors at the Boulder Terminal substation.

4. Other

a) The continuous rating of the Capitol Hill – Denver Terminal 115kV line should be increased by replacing the conductor. This would increase the rating from 131 to approximately 180 MVA.