5. This study indicates that 10 MVAr of 69 kV capacitors at Del Norte improves the San Luis Valley High Voltage System's voltage profile, during the Poncha-San Luis 230 kV line, Rio Grande Tap-Sargent 69 kV line, or Sargent 115-69 kV transformer outages. Public Service Company of Colorado's options are to install the capacitors at an estimated cost of $250,000; or accept the post-disturbance voltage deviation, and bring the Alamosa Terminal generators on-line, to recover to an adequate local voltage profile. Further analysis and implementation is referred to Public Service Company of Colorado.

6. The Ansel-San Luis 69 kV line can load to as much as 117 percent of a 29 MVA rating during an outage of the San Luis 115-69 kV autotransformer. The addition of a second San Luis 115-69 kV autotransformer eliminates this particular overload concern. And, prior to the installation of a second San Luis 115-69 kV autotransformer, bringing the Alamosa Terminal generation on-line will mitigate overloading on the Ansel-San Luis 69 kV line.

   By 2005, the Ansel-San Luis 69 kV line should be rebuilt with 397.5 MCM conductor. This will allow the line to load to an acceptable level during the Rio Grande Tap-Sargent 69 kV line outage. Rebuilding this 8.1 mile-long line, with 397.5 MCM conductor, is estimated to cost $720,000; and this cost is the responsibility of Public Service Company of Colorado.

7. The addition of capacitors at Alamosa Steam and Fort Garland will cause high VAr flows on the Alamosa Steam-Mosca-San Luis 69 kV line, during either the Alamosa Steam-Alamosa Terminal 69 kV line outage or the Alamosa Terminal-San Luis 115 kV line outage. The maximum loading is 122 percent of a 29 MVA rating, during the outage of the Alamosa Steam-Alamosa Terminal 69 kV line. This overload can be mitigated by bringing the Alamosa Terminal generation on-line, and this generation could perhaps be brought on-line quickly enough to prevent the overload. The details of mitigating this overload are left to Public Service Company of Colorado, as their corporate assets. The total cost of rebuilding this 23.7 mile-long line, with 397.5 MCM conductor, would be approximately $2,109,300.

8. The Home Lake-Rio Grande Tap-Sargent 69 kV line loads to 138 percent of a 44 MVA rating during an outage of the Alamosa Terminal-San Luis 115 kV line. Bringing the Alamosa Terminal generation on-line is an effective method to mitigate this overload. The details of mitigating this overload are left to Public Service Company of Colorado. The total cost of rebuilding this 9.1 mile-long line, with 397.5 MCM conductor, is approximately $1,009,900.

9. The Alamosa Terminal 115-69 kV autotransformer loads to 122 percent of a 25 MVA rating, during an outage of the Rio Grande Tap-Sargent 69 kV line. Bringing the Alamosa Terminal generation on-line mitigates this overload. If a second 115-69 kV, 25 MVA Alamosa Terminal autotransformer were added, its cost to Public Service Company of Colorado, including 115 and 69 kV circuit breakers, would be approximately $1,097,000.

10. Several load serving transformers exceed 80 percent of their continuous rating at the 144 MW regional load level. These transformers should be monitored for overloading in the future. The Public Service Company of Colorado transformers are Del Norte 69-25 kV, Home Lake 69-25 kV, Rio Grande 60-25 kV #2, and Saguache 69-13 kV. The San Luis Valley Rural Electric Cooperative transformers are Carmel (North) 69-12.5 kV, Center (East) 69-12.5 kV, Center (West) 69-12.5 kV, Hooper 69-12.5 kV, LaGarita 69-12.5 kV, and Plaza 69-12.5 kV.

11. Reactors are required during periods of low load. This requirement was not explored in any more detail, other than to determine that voltages exceed what is allowed by the voltage criterion, during periods of low power usage. Further studies are required to specifically determine the amount of reactors required, and the optimal locations for reactors.

12. Western Area Power Administration's Blue Mesa-Curecanti, Blue Mesa-Skito, and Gunnison-Skito 115 kV lines overload during contingencies in the vicinity of the San Luis Valley. The worst overload is 120 percent of a 100 MVA rating; and the contingencies that cause these overloads are the Curecanti-Poncha 230 kV, Gunnison-Poncha 115 kV, or any contingency involving the loss of or a stuck breaker on the Poncha 230 kV bus. Solutions to these overloads were not pursued, since the facilities are not in the San Luis Valley, and this information is referred to Western Area Power Administration for further analysis.

Burro Canyon Generation

A second alternative demonstrated acceptable technical performance in mitigating the single contingency voltage collapse concerns of the San Luis Valley High Voltage System. This alternative includes the addition of a 230 kV line from Burro Canyon to San Luis; a 230-115 kV, 100 MVA autotransformer at Burro Canyon; a second 230-115 kV, 100 MVA autotransformer at San Luis, and a total of 90-120 MW of generation, at Burro Canyon. Even though this alternative is not recommended as a transmission addition, it should not be dismissed until its merits as a generation resource have been investigated.

The voltage collapse analyses indicate that a minimum of 60 MW must be generating to meet the single contingency voltage collapse criterion, during a Poncha-San Luis 230 kV line outage. Therefore, the station must be able to withstand the outage of one unit, and still have 60 MW on-line. Therefore, this alternative must have the 90-120 MW distributed in two or more units. For example, two 60 MW units, or three 30 MW units would be acceptable.

The transmission costs of this alternative are estimated to be $14,542,000, $640,000 higher than the recommended alternative. The primary reason that the Burro Canyon generation alternative is not recommended, is the uncertainty associated with fuel costs, and the market price that can be obtained for the generated capacity and energy.

Table 1, below, summarizes the results of some preliminary economic analysis. Slight variations in the economic assumptions can change these results. More detailed economic spreadsheets are in Appendix B.

Table 1

Generation Load Factors Required to Recover Costs

Sale Price of Power ($/MWH)	**Required Load Factor to Break Even (%)**
20	88
25	66
30	52

The data in the above table, is based on recovering an installed cost of $600,000/MW, depreciated over 30 years, with capital borrowed at an annual interest rate of 8%. Fuel cost is assumed to be $3/MWH, and annual O&M is assumed to be $20,000/MW.

Technical Conclusions

Increased loading on the interconnected transmission system, due to increasing customer demands and electric power transfers, may cause voltage stability and collapse to be of greater concern. Voltage stability and collapse are more accurately assessed by including the effects of various components of customer demand which respond differently to changes in system voltage. Since the voltage dependence of loads can have important effects on system performance, two factors were investigated to determine the magnitude of those effects on the San Luis Valley High Voltage System. A composite load synthesis of constant MVA, constant current and constant impedance loads was developed using the LOADSYN program, and data to model the load-tap-changing effects of transformers that serve loads was obtained.

The technical conclusions of this report are as follows:

1. The best voltage profile on the San Luis Valley High Voltage System is achieved by running the Alamosa Terminal generation at a total MW output level of between 25 and 31 MW, and allowing the remaining capability of the units to be VAr generation.

2. The level of Tot 5 power transfers do not affect the ability of the San Luis Valley High Voltage System to serve loads. This interaction was thought to be possible, with the Poncha 230 kV bus perhaps located near the low voltage point on the Curecanti-Midway 230 kV line. However, the voltage profile of the San Luis Valley High Voltage System did not significantly change when the power flow case was changed to model lower Tot 5 power transfers.

3. Reasonably accurate, and slightly pessimistic voltage collapse results are obtained by using constant MVA loads and ignoring the effects of load-tap-changing effects of transformers that serve loads.

4. A composite load characteristic should be utilized only when also modeling the load-tap-changing effects of load serving transformers. The use of a composite load characteristic alone results in overly optimistic voltage collapse results.

5. The impact of modifying a typical power flow case, to include more detailed modeling of the load serving transformers (including the load-tap-changing capability), tends to add pessimism to the voltage collapse results. The points-of-collapse of voltage stability cases, with the detailed modeling of load serving transformers, are approximately 10 percent lower than the voltage stability cases without the load serving transformers modeled.

4. The impact of changing the loads of a typical power flow case, from constant MVA to a more representative characteristic, tends to add optimism to the voltage collapse results. The improvement ranged from 2 percent to 30 percent in this study.

5. The combined effect of modifying a typical power flow case, to include more detailed load transformer models and a more representative load characteristic model, tends to add optimism to the voltage collapse results. Table 2, below, compares the results of adding transformer and load-tap-changing data, and of modifying the load model from constant MVA to a combination of constant MVA, constant current, and constant impedance loads. The P-V curves of the non-detailed cases are in Appendix N, and can be compared to P-V curves of the detailed cases in Appendix F.

Table 2

System Normal Points of Collapse (MW)

Load Model	Power Factor	Non-detailed LTC Model	Detailed LTC Model
MVA	1.00	211	190
MVA	0.95	158	143
MVA	0.90	140	126
MVA	0.85	126	113
MVA	0.80	115	102
Actual	1.00	219	194
Actual	0.95	189	163
Actual	0.90	177	153
Actual	0.85	167	145
Actual	0.80	160	138

Study Participants

The study participants include F. David Graeber & Associates; Public Service Company of Colorado; San Luis Valley Rural Electric Cooperative, Inc.; Tri-State Generation & Transmission Association; and the Rocky Mountain Region of Western Area Power Administration. San Luis Valley Rural Electric Cooperative, Inc. is an all-requirements member of Tri-State Generation & Transmission Association. Each of the study participants either serve consumer load; own, operate or maintain facilities; or have an interest in providing nearby generation to support the San Luis Valley region of Colorado. The study was initiated within the Colorado Coordinated Planning Group, and participation was open to all interested parties.

F. David Graeber & Associates, formerly Powerbridge, Inc., is a financial and project consulting firm. F. David Graeber & Associates has been soliciting interest in a natural gas generation project in the vicinity of Burro Canyon Substation, a region with substantial natural gas deposits. Their address, for more information is as follows: 3625 North Hall Street, Suite 620, Dallas, TX 75219.

Public Service Company of Colorado (PSCo) is the largest investor-owned utility in Colorado, and is a combined electric and gas entity. PSCo serves a total of over 1,079,630 electric customers, and has ownership in over 3,240 miles of transmission line at or above 69 kV. PSCo has a total generation capacity of 3,341 MW, and its peak demand in 1995 was 4,011 MW. PSCo is responsible for approximately 55 percent of the load within the San Luis Valley, and owns several transmission and distribution facilities in the study region. PSCo also owns and operates the only local generation within the San Luis Valley, the Alamosa Terminal Generators.

San Luis Valley Rural Electric Cooperative, Inc. (SLVREC) is a non-profit consumer-owned rural electric association, and has a certified service territory that is completely contained in the study area. It serves a total of 8,500 customers, with a 1995 coincident system peak of 59 MW. The historical peak load for SLVREC is 65.9 MW. SLVREC is an all-requirements member of Tri-State. SLVREC owns 111 miles of transmission line, at 69 and 115 kV.

Tri-State Generation and Transmission Association, Inc. (Tri-State) is a non-profit, wholesale power supply cooperative. It provides power to 33 member distribution systems that serve parts of Colorado, Nebraska, and Wyoming. One of these member distribution systems is San Luis Valley Rural Electric Cooperative, which serves customers in the San Luis Valley of Colorado. Tri-State has the responsibility of assuring that the high-voltage transmission system is reliable to serve a population of more than 650,000, system-wide, with a 1996 coincident peak demand of 1,323 MW. Tri-State owns 1,252 MW of generation, and 3,899 miles of transmission line, 69 kV or higher.

Western Area Power Administration (Western) is a Federal Power Marketing Agency, headquartered in Golden, Colorado. It markets the power generated by the Bureau of Reclamation at hydro dams throughout the western United States. The participating office is the Rocky Mountain Region, located in Loveland, Colorado. Western serves no load in the study area, but has facility ownership at Poncha Switching Station, and provides resources to Tri-State to meet its member obligations. Western owns 16,727 miles of transmission line throughout the west, 69 kV or higher.

Study Process

The study process, in broad terms, is to initially perform a technical analysis to identify the conditions which cause the system to violate reliability criteria. Once the critical conditions are defined, alternative solutions are proposed and analyzed to cause the system to meet the reliability criteria. The focus of the technical analyses is to eliminate infeasible alternatives. An economic analysis of feasible alternatives is made to identify the preferred alternative.

The base case includes modeling all San Luis Valley High Voltage System existing facilities, to as low as the 69 kV level, including all load serving transformers on the 69 and 115 kV systems. The loads in the base case are a projected coincident summer peak load for 2006. This allows for the assessment of the capability of existing San Luis Valley High Voltage System facilities to serve future regional loads.

A comprehensive contingency analysis is then completed on the base case, to identify the fundamental limitations of the San Luis Valley High Voltage System, and the critical contingencies in the region. The more severe contingencies are targeted for Voltage Stability analysis. Inadequate voltages and facility loadings are determined by applying reliability criteria to the results of power flow and voltage stability cases. Reliability criteria are discussed on page 19.

Alternatives are then identified, and investigated for effectiveness in meeting the reliability criteria. To focus the investigation, only the system normal and critical single and multiple contingencies are examined. Introductory alternatives generally provide partial system improvement, but are not complete. These system additions are earmarked as a possible component of a later comprehensive alternative. Alternatives which do not improve system performance are eliminated from further consideration.

Summaries of the performance of each system scenario are developed, and included later in this report. A **Failed** power flow case indicates that that particular simulation did not converge to a solution. This is a strong indication of voltage collapse, and the contingency is further analyzed using VSTAB, to determine the voltage stability of that simulation.

As soon as a minimum of two adequate comprehensive alternatives are defined, a cost analysis is completed to determine the preferred alternative. The single-entity planning concept is used to determine the preferred alternative. That is, the costs are developed as if all study participants were one entity.

The software utilized to complete this study was the Power System Simulation (PSS/E) package, version 24, from Power Technologies, Inc. of Schenectady, New York; VSTAB version 4.1, and LOADSYN, version 4.1, developed through Electric Power Research Institute, by Powertech Labs, Inc., of Surrey, British Columbia, Canada. The computer was a Digital microVAX.

Reliability Criteria for System Planning

Each participant utilizes reliability criteria for system planning (also referred to as either reliability criteria, planning criteria, or criteria), that differ slightly from one another. However, the criteria of each entity must be within the guidelines of Western Systems Coordinating Council (WSCC) and North American Electric Reliability Council (NERC). Reliability criteria for system planning are an objective measure of acceptable system performance. Ultimately, the criteria are intended to mitigate widespread cascading interruptions of electricity supply for the types of contingency events normally encountered on electric systems, i.e., more probable contingencies. The ability to withstand more severe contingencies that, although rare, have potential to impose great stress must also be recognized. A summary of the WSCC criteria are included in Appendix C. The steady-state criteria for acceptable system performance used in this study are in accordance with the WSCC criteria, and are summarized, below:

Voltages: The important voltage level on the San Luis Valley High Voltage System is 69 kV. This is the high side voltage for all but one load-serving transformer in the San Luis Valley. Therefore, the monitored system voltage was 69 kV. For system normal conditions, acceptable voltages are between 0.95 and 1.05 per unit (p.u.).

For single contingency outage simulations, acceptable voltages should not drop by more than 0.05 p.u. from their system normal voltages, and under no circumstances will a voltage below 0.90 p.u. be considered acceptable. The study notes where voltages drop by more than 0.05 p.u., but this will be met only after system adjustments are allowed. Although every effort will be made to meet this criterion prior to system adjustments, extreme measures will not be taken.

For credible multiple contingency outage simulations, acceptable voltages are between 0.90 and 1.10 per unit.

Facility Loadings: In system normal simulations, acceptable facility loadings are at or below 80 percent of the facility's continuous rating. For outage simulations, acceptable facility loadings may not be greater than 100 percent of a facility's continuous rating. This report makes no recommendations regarding generator step-up transformers, which must be sized to deliver generator output. Overloads of transformers that serve radial load are noted for the system normal condition only.

Voltage Collapse: None of the entities involved in this joint study have formally developed a voltage collapse or voltage stability criterion. The one under development at Tri-State, is the working criterion for this study. The system will be designed to operate so that the single contingency point-of-collapse is at least 5 percent higher, measured in MW or MVA, with the single most critical VAr source unavailable.

Base Case Description

The study base case is a modified 03HS1 scenario, developed by Western Systems Coordinating Council, and approved in October, 1995. Western Area Power Administration modified the case to represent high power transfers from west to east across Tot 5. Tri-State further revised the case to include all of the existing system detail of the San Luis Valley, at a load level projected to exist in July, 2006.

The San Luis Valley High Voltage System is operated as an interconnected network to as low a voltage as 69 kV. Therefore, the study base case model includes all 69 kV facilities, and models loads on the low sides of any transformers connected to the 69 kV and 115 kV systems.

For use in a power flow program, constant MVA loads are typically modeled. This is usually very accurate for the use of a power flow program as the regulating capabilities of the lower voltage distribution system are simulated with constant MVA loads. However, for determining the point of collapse or determining the voltage stability of a system, constant MVA load tends to produce a pessimistic point-of-collapse. A composite model of the region's loads, has been developed, to account for the voltage dependence of the San Luis Valley loads. The actual load model for Tri-State's member system loads have been developed for July, 1995, using the LOADSYN program. LOADSYN is a load synthesis program developed through the Electric Power Research Institute of Palo Alto, California, and maintained and distributed by Powertech Labs, Inc. of Surrey, British Columbia, Canada.

The base case loads are a composite synthesis of constant current, constant impedance and constant MVA components. The power factors modeled in the base case were not completely available at the start of the study. However, they did become available by the completion of the study, and were added to the base case.

Since voltage collapse concerns exist for the San Luis Valley High Voltage System, the characteristics of the SLVREC loads were also estimated using the LOADSYN program, and the PSCo loads were presumed to have similar characteristics. The inputs to the LOADSYN program for SLVREC are 82 percent Agricultural Pumping, 5 percent Commercial, 3 percent Heavy Industrial, and 10 percent Residential. The LOADSYN results for SLVREC are noted in Table 3, below:

Table 3

Load Synthesis of San Luis Valley Rural Electric Cooperative

Load Type	Real Component	Imaginary Component
Constant Impedance	28%	40%
Constant Current	80%	69%
Constant MVA	- 8%	- 9%

Loads on the 69 kV line from Poncha to Moffat, approximately 10 percent of the region's load, are presumed to have different characteristics, those of Sangre De Cristo Electric Association, Inc (SDCEA). The LOADSYN inputs for SDCEA are 31 percent Commercial, 12 percent Heavy Industrial, and 57 percent Residential. The results of the LOADSYN program to synthesize the components of the region's loads are noted in Table 4, below. The detailed LOADSYN printouts are in Appendix D.

Table 4

Load Synthesis of Sangre De Cristo Electric Association, Inc.

Load Type	Real Component	Imaginary Component
Constant Impedance	21%	138%
Constant Current	61%	- 49%
Constant MVA	18%	11%

The power factors associated with the individual loads were not completely known, at the outset of the study. PSCo had detailed knowledge of their load power factors during peak, however, Tri-State did not have detailed data for the power factors of the San Luis Valley Rural Electric Cooperative loads. The power factors were treated as a variable in the study, both because of the lack of data and because the case performed too poorly, for all but unity power factors. As alternatives were added to the case, and the case became more robust, actual power factors were added to the loads.

Tot 5

Tot 5 is a monitored path of transmission lines and transformers that transfer power from the west slope of Colorado, where large generation resources are located, to the east slope of Colorado, where most of the state's loads exist. The facilities which comprise Tot 5, and the metering locations are summarized in Table 5, below:

Table 5

Tot 5 Description
(Meter location is denoted by Bold Lettering)

West Bus	East Bus
Craig 345 kV	Ault 345 kV
Hayden 230 kV	**Archer 230 kV**
Gore Pass 230 kV	**Blue River 230 kV**
Curecanti 230 kV	**Poncha 230 kV**
Basalt 230 kV	Malta 230 kV
Rifle 230 kV	Hopkins 230 kV
Hayden 138 kV	**Gore Pass 138 kV**
Gore Pass 230 kV	Gore Pass 138 kV
Gunnison 115 kV	**Poncha 115 kV**
Basalt 115 kV	Hopkins 115 kV

The limit of Tot 5 is 1,675 MW, from west to east. Its relevance to the San Luis Valley was investigated in this study. The Poncha 230 kV bus is located near the mid-point of the Curecanti-Midway 230 kV line. On a transmission line with high power flows, the mid-point is the point with the lowest voltage on the line. The possibility that this would adversely impact the performance of the San Luis Valley High Voltage System, was quantified.

Operating and Control Strategies

The purpose of this report is primarily to address long-term solutions, so that loads in the San Luis Valley can be adequately served in the future. However, the system is single contingency inadequate, and the solutions recommended in this report will not be constructed for several years.

Some operating and control strategies are suggested, as interim measures until the recommendations of this report can be implemented. The diagram on the following page displays the various operating states that can exist on any given system. This concept has been suggested and published by Mr. Roy Billinton, of the University of Saskatchewan; Mr. Prabha Kundur, of Powertech Labs, Inc.; and Mr. Carson Taylor, of Bonneville Power Administration.[1]

Normal State: All system variables satisfy criteria and the system is capable of withstanding any single contingency and all credible multiple contingencies.[1]

Alert State: All system variables are still within criteria, however, a contingency may cause an overload or a voltage outside criteria. If a severe disturbance occurs, the *in extremis* (or extreme emergency) state may result directly from the alert state.[1]

Emergency State: Possible after a disturbance of sufficient severity has occurred while in the alert state. Acceptable voltage and/or loading criteria are not satisfied, although no loads are interrupted.

***In Extremis* State:** Cascading outages and a major portion of the system is shut down.[1]

Restorative State: A condition in which control action is taken to restore all facilities and system load.[1]

Several levels of control involving a complex array of devices are used to meet the planning criteria. These also have a profound effect on the dynamic performance of the power system and its ability to cope with disturbances.[1]

Control objectives are dependent on the operating state of the power system. Under normal conditions, the objective is to optimize system operation with voltages around 1.03 p.u., and frequency close to nominal. When abnormal conditions develop, new objectives must be met to restore the system to the normal state.[1]

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[1]Prabha Kundur, Power System Stability and Control, McGraw-Hill, Inc., 1994.

To provide reliable service, a high-voltage electrical system must remain intact and be capable of withstanding a wide variety of disturbances. Optimizing the design of a large interconnected transmission network to assure stable operation is a complex endeavor. However, the economic gains to be realized through this endeavor are substantial. The Reliability Criteria for System Planning are intended to keep the high-voltage transmission network in the normal state or, at a minimum, identify alert states.[1]

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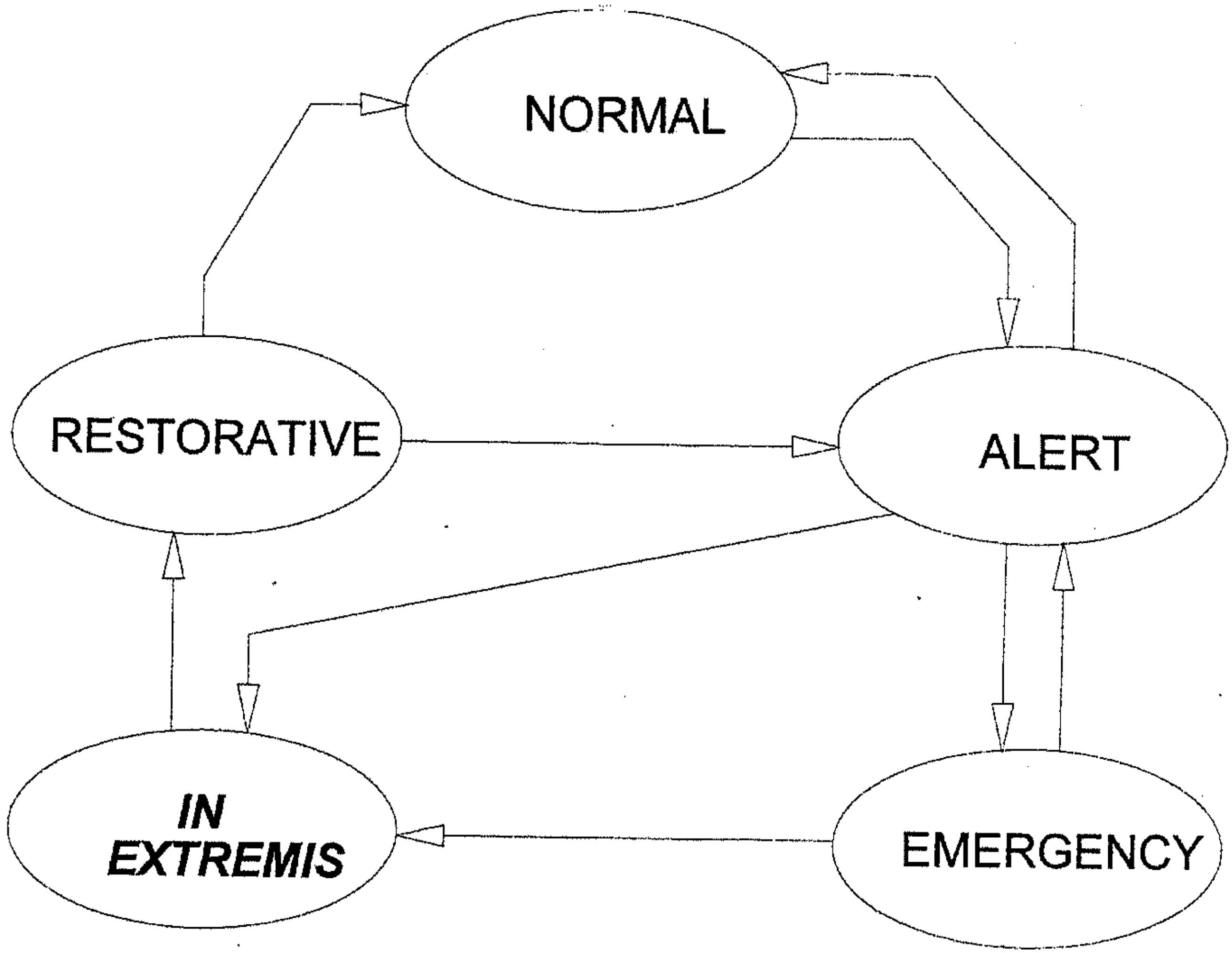
[1] Prabha Kundur, Power System Stability and Control, McGraw-Hill, Inc., 1994.



Power System Operating States

Power System Stability and Control, Prabha Kundur, McGraw-Hill, Inc., 1994

Presently, when the San Luis Valley regional load exceeds 65 MW, the region is at risk of voltage collapse if a single contingency occurs, the loss of the Poncha-San Luis 230 kV line. At a load level below 65 MW, the San Luis Valley is in a normal operating state. At a regional load level above 65 MW, The San Luis Valley High Voltage System changes, to the alert operating state. In the alert operating state, the Alamosa Terminal generators should be on-line, or prepared to come on-line as quickly as possible, if a system contingency occurs.

At a regional load level above 96 MW, the Alamosa Terminal generation will no longer prevent region-wide voltage collapse during an outage of the Poncha-San Luis 230 kV line (or the San Luis 230-115 kV transformer outage). The only course of action, during an outage of the Poncha-San Luis 230 kV line, is to trip load, in either a controlled manner or an uncontrolled manner. A long-term alternative would be to install automatic undervoltage load shedding, which could be armed in intervals as regional load increased, to assure that the regional load would not exceed 65 MW, during a Poncha-San Luis 230 kV line outage.

This study indicates that a smaller-scale voltage collapse, in the area south of Alamosa, is possible for an outage of the Alamosa Terminal-San Luis 115 kV line outage. Running the Alamosa Terminal generators eliminates voltage collapse, at the 144 MW regional load level. The generation may be able to be brought on-line after the disturbance, in time to prevent the voltage collapse south of Alamosa. Capacitors are still recommended, at Antonito and Fort Garland, primarily for the Alamosa Steam-Alamosa Terminal 69 kV line outage.

Bringing the Alamosa Terminal generators on-line improves the voltage profile of the system and relieves overloading on the San Luis 230-115 kV transformer during system normal operation. The Alamosa Terminal generation can also mitigate or reduce the severity of the following contingencies:

1. The Alamosa Steam-Alamosa Terminal 69 kV line outage--This contingency overloads the San Luis 230-115 kV transformer, and causes a 0.10 per unit post-disturbance voltage deviation at Alamosa Steam and Fort Garland 69 kV. Running the Alamosa Terminal generators mitigates the overload of the transformer, but does not improve the post-disturbance voltage deviation.

2. The Alamosa Terminal 115-69 kV transformer outage--All excessive post-disturbance voltage deviations and overloads are eliminated by running the Alamosa Terminal generation.

3. The Curecanti-Poncha 230 kV line outage--All excessive post-disturbance voltage deviations on the San Luis Valley High Voltage System are eliminated by running the Alamosa Terminal generation.

4. The Gunnison-Poncha 115 kV line outage--Overloading on the San Luis 230-115 kV transformer is mitigated by running the Alamosa Terminal generation.

5. The Midway-Poncha 230 kV line outage--Overloading on the San Luis 230-115 kV transformer is reduced from 133 percent to 105 percent by running the Alamosa Terminal generation.

6. The Poncha-San Luis 230 kV line outage--Voltage collapse can be prevented by running the Alamosa Terminal generation, as long as the total regional load does not exceed 96 MW. The speed of the voltage collapse may also cause this measure to be ineffective. The speed of voltage collapse was not determined in this study.

7. The Poncha-Sargent 115 kV line outage--Overloading on the San Luis 230-115 kV transformer is eliminated by running the Alamosa Terminal generation.

8. The Rio Grande Tap-Sargent 69 kV line outage--All excessive post-disturbance voltage deviations and overloads are mitigated by running the Alamosa Terminal generation.

9. The San Luis 115-69 kV transformer outage--All overloads are mitigated by running the Alamosa Terminal Generation. The Ansel-San Luis 115 kV line overloaded with 2006 peak loads, and with all the recommended system facilities added to the system.

10. The Sargent 115-69 kV transformer outage--All excessive post-disturbance voltage deviations and overloads, with the exception of the San Luis 230-115 kV transformer overloading, were eliminated by running the Alamosa Terminal generation.

11. Running the Alamosa Terminal generation provides insufficient system support during credible multiple contingencies in the region.

Voltage Collapse and Voltage Stability

Voltage stability is a subset of overall power system stability, and voltage instability results in voltage collapse. A system is voltage stable if Q-V sensitivity is positive (voltage rises as VArs are added) for every bus and voltage unstable if Q-V sensitivity is negative (voltage drops as VArs are added) for at least one bus.[2] A power system at a given operating state is small-disturbance voltage stable if, following any small disturbance, voltages near loads are identical or close to the pre-disturbance values (within 0.05 p.u., by our study criteria).[3]

A power system at a given operating state and subject to a given disturbance is voltage stable if voltages near loads approach post-disturbance equilibrium values. The disturbed state is within the region of attraction of the stable post-disturbance equilibrium.[3] A power system at a given operating state and subject to a given disturbance undergoes voltage collapse if post-disturbance equilibrium voltages are below acceptable limits. Voltage collapse may be total (blackout) or partial.[3]

Voltage stability normally involves large disturbances (including rapid increases in load or power transfer). The term voltage security, refers to the ability of a system, not only to operate stably, but also to remain stable following credible contingencies or load increases.[3]

For the purposes of this study, voltage stability exists if the operating point, measured in MW, is lower than the point-of-collapse of the San Luis Valley High Voltage System. Voltage collapse on the San Luis Valley High Voltage System will occur at loads above 65 MW and during the loss of the Poncha-San Luis Valley 230 kV line. The speed of voltage collapse is unknown at this time. However, since no dynamic source of VArs is typically on-line, the collapse is likely to occur in the matter of seconds, after the contingency.

Further reading on this subject can be found in the bibliography in Appendix E.

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[2] Prabha Kundur, Power System Stability and Control, McGraw-Hill, Inc., 1994, p. 27 (comments in parenthesis added by Frank McElvain).

[3] Carson W. Taylor, Power System Voltage Stability, McGraw-Hill, Inc., 1994, p. 18.

Contingency Selection

A full contingency analysis was completed for the base case, to identify the critical outages. Those contingencies that are not a part of the San Luis Valley High Voltage interconnected network, and simulate the loss of load are not considered critical. These contingencies actually perform better than the system normal case, because the overall effect is that the system serves a lower regional load level. Other contingencies are not considered critical because they either duplicate the system performance of other contingencies, or create criteria violations which are not as severe as other contingencies. An example of this is the San Luis 230-115 kV transformer outage. This contingency produces the same system results as the Poncha-San Luis 230 kV line outage. Therefore, since line outages are more probable than transformer outages, the Poncha-San Luis 230 kV line outage is considered critical, and the San Luis 230-115 kV transformer outage is not.

Below is a list of the contingencies that result in load loss and, therefore, eliminated from consideration as critical contingencies:

1. Alamosa Terminal 115-13.2 kV Transf. (2)
2. Alamosa Terminal 115-13.2 kV Transf. (3)
3. Alamosa Steam 69-13.2 kV Transformer
4. Alamosa Steam-Fort Garland 69 kV Line
5. Alamosa Terminal-Romeo 69 kV Line
6. Ansel 69-12.5 kV Transformer
7. Antonito 69-13.2 kV Transformer
8. Antonito 69-25 kV Transformer
9. Antonito-Romeo 69 kV Line
10. Carmel 69-12.5 kV Transformer (North)
11. Carmel 69-12.5 kV Transformer (South)
12. Carmel-Waverly 69 kV Line
13. Carmel-Zinzer 69 kV Line
14. Center 69-12.5 kV Transformer (East)
15. Center 69-12.5 kV Transformer (West)
16. Center-Hooper Tap 69 kV Line
17. Center-LaGarita 69 kV Line
18. Creede 69-12.5 kV Transformer
19. Creede-Highland 69 kV Line
20. Del Norte 69-25 kV Transformer
21. Del Norte-Rio Grande 69 kV Line
22. Fort Garland 69-13.2 kV Transformer (1)
23. Fort Garland 69-25 kV Transformer (2)
24. Fort Garland 69-25 kV Transformer (3)
25. Highland 69-12.5 kV Transformer
26. Highland-South Fork 69 kV Line
27. Home Lake 69-25 kV Transformer
28. Hooper 69-12.5 kV Transformer
29. Hooper-Hooper Tap 69 kV Line
30. Hooper Tap-San Luis 69 kV Line
31. Kerber Creek 69-13.2 kV Transformer
32. Kerber Creek-Villa 69 kV Line
33. LaGarita 69-12.5 kV Transformer
34. LaGarita-Plaza 69 kV Line
35. Mears Junction-Poncha 69 kV Line
36. Mears Junction-Villa 69 kV Line
37. Mirage Junction-Moffat 69 kV Line
38. Mirage Junction-Saguache 69 kV Line
39. Moffat 69-25 kV Transformer
40. Moffat-Moffat (TS) 69 kV Tie Line
41. Moffat-Mosca 69 kV Line
42. Moffat (TS) 69-12.5 kV Transformer
43. Mosca 69-13.2 kV Transformer
44. Plaza 69-12.5 kV Transformer
45. Poncha 115-25 kV Transformer
46. Poncha 115-69 kV Transformer
47. Ramon 115-69 kV Transformer
48. Ramon-Stanley 115 kV Line
49. Rio Grande 69-25 kV Transformer (1)
50. Rio Grande 69-25 kV Transformer (2)
51. Rio Grande-Rio Grande Tap 69 kV Line
52. Romeo 69-13.2 kV Transformer
53. San Acacio 69-12.5 kV Transformer
54. San Acacio-Stockade 69 kV Line
55. Saguache 69-13.2 kV Transformer
56. San Luis-Stanley 115 kV Line
57. San Luis-Waverly 115 kV Line
58. Sargent 69-25 kV Transformer
59. South Fork 69-12.5 kV Transformer (1,2)
60. Stanley 115-12.5 kV Transformer
61. Stockade 69-12.5 kV Transformer
62. Stockade-Waverly 69 kV Line
63. Waverly 115-69 kV Transformer
64. Zinzer 69-12.5 kV Transformer

The following contingencies resulted in violations of the reliability criteria that were duplications or not as severe as other violations, in other contingency simulations. These contingencies are, therefore, also not critical:

1. Alamosa Steam-Mosca 69 kV Line
2. Alamosa Terminal-Home Lake 69 kV Line
3. Ansel-city of Center 69 kV Line
4. Ansel-San Luis 69 kV Line
5. Buena Vista Tap-Poncha 115 kV Line
6. city of Center-Sargent 69 kV Line
7. Home Lake-Rio Grande Tap 69 kV Line
8. Mears Junction-Villa 69 kV Line
9. Mosca-San Luis 69 kV Line
10. Poncha-Smeltertown 115 kV Line
11. Ramon-South Fork 69 kV Line (circuits 1 and 2)
12. San Luis 230-115 kV Transformer

The remaining San Luis Valley High Voltage System contingencies include those contingencies that produce all criteria violations in the region, in the severest degrees. These are the critical contingencies in the region:

1. Alamosa Terminal Unit 1
2. Alamosa Terminal Unit 2
3. Alamosa Steam-Alamosa Terminal 69 kV Line
4. Alamosa Terminal 115-69 kV Transformer
5. Alamosa Terminal-San Luis 115 kV Line
6. Curecanti-Poncha 230 kV Line
7. Gunnison-Poncha 115 kV Line
8. Midway-Poncha 230 kV Line
9. Poncha-Sargent 115 kV Line
10. Poncha-San Luis 230 kV Line
11. Rio Grande Tap-Sargent 69 kV Line
12. San Luis 115-69 kV Line
13. San Luis-Sargent 115 kV Line
14. Sargent 115-69 kV Transformer

Existing System Contingency Analysis

Prior to the evaluation of alternatives to improve the performance of the San Luis Valley High Voltage Transmission System, analysis of the factors which influence the behavior of the San Luis Valley System are completed and quantified. These factors are as follows:

1. The load power factors in the San Luis Valley
2. The types of loads in the San Luis Valley
3. The level of local generation in the San Luis Valley
4. The level of Tot 5 power transfers
5. The load level in the San Luis Valley

Load power factors in the San Luis Valley were initially not well-documented. Depending on the specific location, they are estimated to range between 0.95 lagging, at best, to 0.80 lagging (at worst). To quantify the effects of power factors on the behavior of the San Luis Valley High Voltage System, the San Luis Valley's regional power factors are uniformly varied from 1.00 to 0.80 lagging, in increments of 0.05. The lower the lagging power factor, the higher the VAr demand of the load. Therefore, intuitively, the lower the power factor, the worse the San Luis Valley High Voltage System voltage profile will become during high load periods. In light load periods, the voltage problems may be caused by the higher power factors, which may cause unacceptably high regional voltage profiles.

For comparison purposes, the region's loads were uniformly modeled as constant MVA, in one set of cases; constant impedance in a second set of cases; constant current in a third set of cases; and the actual load model, developed by LOADSYN, in a fourth set of cases.

As load is increased in the San Luis Valley, additional current will be required by the San Luis Valley, and the region's voltage profile will become lower. Each of the load models will respond to this lower voltage profile in different ways. The constant MVA loads will respond with a requirement for even more current, to maintain the constant MVA characteristic of the loads. This characteristic is why the constant MVA load model produces the most pessimistic voltage stability results. Constant impedance loads will respond with a requirement for less current, to maintain the constant impedance characteristic. This accounts for past experience which has shown constant impedance loads to produce more optimistic voltage stability results than constant MVA loads, by about 10 percent. Finally, constant current loads will be unaffected by the lower voltage profile, causing its voltage stability results to be less optimistic than the constant impedance results, and more optimistic than constant MVA results. Tri-State has no experience with an actual load model prior to this study.

The San Luis Valley region has two generation units with a total of 36 MW of local generation, located at Alamosa Terminal. These units do not typically run, but are available for emergencies. Intuitively, these generators would offset load in the region, and provide some additional voltage support. Therefore, one can expect the point-of-collapse of the San Luis Valley High Voltage System to be approximately 40 MW higher with the generation on, than with it off.

The possibility that high Tot 5 power flows affect the Poncha 230 kV bus voltage and, therefore, affect the voltage profile of the San Luis Valley High Voltage System is explored in this study. This is intuitively possible, but has not been documented.

The level of San Luis Valley regional loads is the most influential factor on the behavior of the San Luis Valley High Voltage System. The peak load of the region, on a coincident basis in 1995, was 135 MW. At a growth rate of 1 percent per year, the region's load will be approximately 144 MW by 2006. Therefore, to assure that the system can meet peak demands in the future, 144 MW is the peak load modeled in this study. To assure that the system is also acceptable during light load periods, a regional load of 20 MW is modeled in light load cases.

Based on the results of the these existing system cases, the constant MVA and actual load model should continue to be studied. The constant impedance and constant current models do not add significant information, and should be eliminated from further review.

Existing System Contingency Analysis
Constant MVA

Load Level = 144 MW   Tot 5 Transfers = 1678 MW   SLV Generation = 0 MW

The following summaries indicate the performance of the existing system with a regional load level of 144 MW, with constant MVA loads at a 1.00 power factor. The voltage stability and power flow plots are in Appendix F. Tot 5 is at its maximum west-to-east power flow capability (1675 MW), and no local San Luis Valley generation is on-line. Cases simulating lagging power factors of 0.95, 0.90, 0.85, and 0.80 were also prepared.

The results of the variation of power factors are consistent with previously stated intuition. The lower the power factor of the loads, the worse the San Luis Valley regional voltage profile becomes. In fact, the VAr demands of the loads at power factors of 0.90, 0.85, and 0.80 are too great, and the system normal power flow case failed to reach at solution. Furthermore, at a load power factor of 0.95, the system normal voltage profile was too poor to proceed with a contingency analysis. Voltage stability simulations confirm that 144 MW of load at power factors of 0.95, and lower, are beyond the point-of-collapse for these cases. A contingency analysis was completed for the case modeling load power factors of 1.00, and these are the only power flow plots included in the report.

Table 6

System Normal Voltage Stability versus Load Power Factor
(Constant MVA Loads & Lagging Power Factors)

Load Power Factor	System Normal Point-of-Collapse
1.00	190 MW
0.95	143 MW
0.90	126 MW
0.85	113 MW
0.80	102 MW

Existing System Contingency Analysis Summary

Load Level = 144 MW	Tot 5 Transfers = 1678 MW	PSCo/UC Losses = 152/172 MW
Power Factor = 1.00	SLV Generation = 0 MW	Load Model = Constant MVA

System State	High & Low Voltages	Overloads
System Normal SLV Load @ Pt. of Collapse = 190 MW	Fort Garland 69 kV = 0.93 p.u.	San Luis 230-115 kV xfmr = 109%(100) 10 Load transformers > 80% of rating
Alamosa Steam-Alamosa Terminal 69 kV Line Outage	Alamosa St 69 kV Deviation = 0.13 p.u. Ft Garland 69 kV Deviation = 0.14 p.u.	Mosca-San Luis 69 kV Line= 112% (29) San Luis 230-115 kV xfmr = 111% (100)
Alamosa Term 115-69 kV xfmr Outage	5 - 69 kV Deviations > 0.05 p.u.	San Luis 230-115 kV xfmr = 110% (100)
Alamosa Term-San Luis 115 kV Outage SLV Load @ Pt. of Collapse = 142 MW	Failed (Voltage Collapse)	Failed
Curecanti-Poncha 230 kV Line Outage	Alamosa Term 115 kV Dev = 0.05 p.u. Poncha 115 kV Deviation = 0.05 p.u. Sargent 115 kV Deviation = 0.05 p.u. Smelter 115 kV deviation = 0.05 p.u.	Blue Mesa-Skito 115 kV = 120% (100) Gunnison-Skito 115 kV = 107% (100)
Gunnison-Poncha 115 kV Line Outage	None	San Luis 230-115 kV xfmr = 126% (100) Blue Mesa-Curecanti 115 = 110% (72)
Midway-Poncha 230 kV Line Outage	None	San Luis 230-115 kV xfmr = 132% (100)
Poncha-San Luis 230 kV Line or San Luis 230-115 kV xfmr Outage SLV Load @ Pt. of Collapse = 68 MW	Failed (Voltage Collapse)	Failed
Poncha-Sargent 115 kV Line Outage	None	San Luis 230-115 kV xfmr = 142% (100)
Rio Grande Tap-Sargent 115 kV Outage	Alamosa Steam 69 kV Dev = 0.07 p.u. Alamosa Term 69 kV Dev = 0.06 p.u. Antonito 69 kV Deviation = 0.07 p.u. Del Norte 69 kV Deviation = 0.12 p.u. Ft Garland 69 kV Deviation = 0.07 p.u. Rio Grande 69 kV Deviation = 0.12 p.u. Romeo 69 kV Deviation = 0.07 p.u.	Alamosa Term 115-69 xfmr = 135% (25) Mosca-San Luis 69 kV Line= 113% (29) San Luis 230-115 kV xfmr = 117% (100)
San Luis 115-69 kV xfmr Outage	None	Ansel-San Luis 69 kV Line = 123% (29) San Luis 230-115 kV xfmr = 109% (100) Sargent 115-69 kV xfmr = 101% (63)
Sargent 115-69 kV Transformer Outage	None	San Luis 115-69 kV xfmr = 145% (42) San Luis 230-115 kV xfmr = 112% (100)
Stuck Poncha CB 386 Curecanti-Poncha 230 kV Line & Midway-Poncha 230 kV Line Outage	Failed (Voltage Collapse)	Failed
Stuck Poncha CB 586 Curecanti-Poncha 230 kV Line & Poncha-San Luis 230 kV Line Outage	Failed (Voltage Collapse)	Failed
Stuck Poncha CB 1186 Midway-Poncha 230 kV Line & Poncha-San Luis 230 kV Line Outage	Failed (Voltage Collapse)	Failed

Existing System Contingency Analysis
Constant Impedance

Load Level = 144 MW | Tot 5 Transfers = 1678 MW | SLV Generation = 0 MW

This set of cases, which model constant impedance loads in the San Luis Valley, are included to document the differences in results from cases that model constant MVA loads. These power flow and voltage stability cases model the existing system, with the San Luis Valley at its projected peak load in 2006 (144 MW), Tot 5 at its maximum west-to-east power flow capability (1,680 MW), and no local San Luis Valley generation on-line. As with the constant MVA cases, only the case with a load power factor of unity was suitable for contingency analysis. Power flow and voltage stability plots are in Appendix G.

The results of these case are very similar to the constant MVA cases, and the results are consistent with previously stated intuition. The primary difference of the constant impedance cases with the constant MVA cases is that the San Luis Valley's regional voltage profile is better in the constant impedance cases. Therefore, the points-of-collapse of the constant impedance cases are higher than the corresponding constant MVA cases.

A comparison of the points of collapse of the constant impedance and constant MVA cases are below:

Table 7

Comparison of Points-of-Collapse between Constant MVA and Constant Z Loads

Case	Constant MVA	Constant Impedance
System Normal 1.00 Power Factor	190 MW	199 MW
System Normal 0.95 Power Factor	143 MW	155 MW
System Normal 0.90 Power Factor	126 MW	137 MW
System Normal 0.85 Power Factor	113 MW	124 MW
System Normal 0.80 Power Factor	102 MW	113 MW
Poncha-San Luis Outage 1.00 Power Factor	68 MW	69 MW
Alamosa Term-San Luis Outage 1.00 Power Factor	142 MW	171 MW

Existing System Contingency Analysis Summary

Load Level = 144 MW
Power Factor = 1.00

Tot 5 Transfers = 1678 MW
SLV Generation = 0 MW

PSCo/UC Losses = 152/172 MW
Load Model = Constant Z

System State	High & Low Voltages	Overloads
System Normal SLV Load @ Pt. of Collapse = 199 MW	Fort Garland 69 kV = 0.93 p.u.	San Luis 230-115 kV xfmr = 109%(100) 12 Load transformers > 80% of rating
Alamosa Steam-Alamosa Terminal 69 kV Line Outage	Alamosa St 69 kV Deviation = 0.10 p.u. Ft Garland 69 kV Deviation = 0.10 p.u.	Mosca-San Luis 69 kV Line= 102% (29) San Luis 230-115 kV xfmr = 109% (100)
Alamosa Term 115-69 kV xfmr Outage	None	San Luis 230-115 kV xfmr = 108% (100)
Alamosa Term-San Luis 115 kV Outage SLV Load @ Pt. of Collapse = 171 MW	Alamosa Steam 69 kV Dev = 0.10 p.u. Alamosa Term 69 kV Dev = 0.10 p.u. Antonito 69 kV Deviation = 0.10 p.u. Ft Garland 69 kV Deviation = 0.10 p.u. Romeo 69 kV Deviation = 0.10 p.u.	Mosca-San Luis 69 kV = 102% (29) San Luis 115-69 kV xfmr = 103% (42) San Luis 230-115 kV xfmr = 104% (100)
Curecanti-Poncha 230 kV Line Outage	None	Blue Mesa-Skito 115 kV = 120% (100) Gunnison-Skito 115 kV = 107% (100)
Gunnison-Poncha 115 kV Line Outage	None	San Luis 230-115 kV xfmr = 126% (100) Blue Mesa-Curecanti 115 = 110% (72)
Midway-Poncha 230 kV Line Outage	None	San Luis 230-115 kV xfmr = 133% (100)
Poncha-San Luis 230 kV Line or San Luis 230-115 kV xfmr Outage SLV Load @ Pt. of Collapse = 69 MW	Failed (Voltage Collapse)	Failed
Poncha-Sargent 115 kV Line Outage	None	San Luis 230-115 kV xfmr = 142% (100)
Rio Grande Tap-Sargent 115 kV Outage	Alamosa Steam 69 kV Dev = 0.05 p.u. Del Norte 69 kV Deviation = 0.10 p.u. Ft Garland 69 kV Deviation = 0.05 p.u. Home Lake 69 kV Deviation = 0.08 p.u. Rio Grande 69 kV Deviation = 0.10 p.u.	Alamosa Term 115-69 xfmr = 133% (25) Mosca-San Luis 69 kV Line= 109% (29) San Luis 230-115 kV xfmr = 112% (100)
San Luis 115-69 kV xfmr Outage	None	Ansel-San Luis 69 kV Line = 119% (29) San Luis 230-115 kV xfmr = 107% (100)
Sargent 115-69 kV Transformer Outage	None	San Luis 115-69 kV xfmr = 143% (42) San Luis 230-115 kV xfmr = 110% (100)
Stuck Poncha CB 386 Curecanti-Poncha 230 kV Line & Midway-Poncha 230 kV Line Outage	Failed (Voltage Collapse)	Failed
Stuck Poncha CB 586 Curecanti-Poncha 230 kV Line & Poncha-San Luis 230 kV Line Outage	Failed (Voltage Collapse)	Failed
Stuck Poncha CB 1186 Midway-Poncha 230 kV Line & Poncha-San Luis 230 kV Line Outage	Failed (Voltage Collapse)	Failed

Existing System Contingency Analysis
Constant Current

Load Level = 144 MW   Tot 5 Transfers = 1678 MW   SLV Generation = 0 MW

These cases developed to document the effects of modeling the San Luis Valley High Voltage System loads as constant current. These cases model San Luis Valley regional load at 144 MW, Tot 5 at its maximum west-to-east power transfer capability (1,680 MW), and no local San Luis Valley generation on-line. Power flow and voltage stability plots for these cases are in Appendix H. As with previous cases modeling the existing system, only load power factors of 1.00 were suitable for completing a contingency analysis.

The results of these case are very similar to the constant MVA cases, and the results are consistent with previously stated intuition. The results of the constant current cases are that the voltage profile of the San Luis Valley region is not as optimistic as the constant impedance cases, and not as pessimistic as the constant MVA cases. Therefore, the points-of-collapse of the constant current cases are lower than the corresponding constant impedance cases, and higher than the corresponding constant MVA cases.

A comparison of the points of collapse of the constant impedance and constant MVA cases are below:

Table 8

Comparison of Points-of-Collapse between Constant MVA and Constant I Loads

Case	Constant MVA	Constant Current
System Normal 1.00 Power Factor	190 MW	194 MW
System Normal 0.95 Power Factor	143 MW	149 MW
System Normal 0.90 Power Factor	126 MW	132 MW
System Normal 0.85 Power Factor	113 MW	119 MW
System Normal 0.80 Power Factor	102 MW	108 MW
Poncha-San Luis Outage 1.00 Power Factor	68 MW	68 MW
Alamosa Term-San Luis Outage 1.00 Power Factor	142 MW	168 MW