Interconnection System Impact Study Report
REQUEST # GI-2004-2

238 MW Wind Facility Near Lamar, Colorado

Xcel Energy Transmission Planning
December 2004

Executive Summary

This Interconnection System Impact Study Report summarizes the analyses performed by the Transmission Planning group of Public Service Company of Colorado (PSCo) to interconnect 238 MW of wind powered generation into the PSCo transmission system at the PSCo Lamar 230 kV Switching Station located near Lamar, Colorado. This project would develop the existing 162 MW Colorado Green Wind Farm to a total of 400 MW. The Customer proposed in-service date for commercial operation of the 238 MW facility is December 1, 2006, with an assumed back-feed date of June 1, 2006. At the request of the Customer, the Project was evaluated as both an Energy Resource (ER) and as a Network Resource (NR) with the power going to PSCo customers.

Energy Resource:
The ER portion of this study determined that the customer could not provide any energy on a firm basis without the implementation of network reinforcements for delivery. Some non-firm capacity may occasionally be available depending upon system conditions in the region.

Network Resource:
Studies indicate that the integration of the full 238 MW of new generation as a stand-alone project would require transmission additions and modifications in order to prevent unacceptable conditions on the regional system. The total estimated cost of the recommended upgrades associated with the interconnection and delivery of the project is approximately $122.91 Million and includes:

- $40,000 for Customer Interconnection Facilities
- $0 for PSCo Network Upgrades for Interconnection
- $122.87 million for PSCo Network Upgrades for Delivery

The basic upgrades for a stand-alone project consist of the following:

- Construct a new 99 mile double-circuit 230 kV line (345 kV capable) from Lamar to Boone;
- Construct a new 43 mile single circuit 230 kV (345 kV, double circuit capable) line from Boone to Midway;
- Install 345/230 kV auto transformers at Midway and Daniels Park Substations
- Operate the two Midway to Daniels Park 230 kV transmission lines at 345 kV.

The estimated time frames required to engineer, permit, and construct the facilities for interconnection is at least three months, and for delivery, at least 54 months.

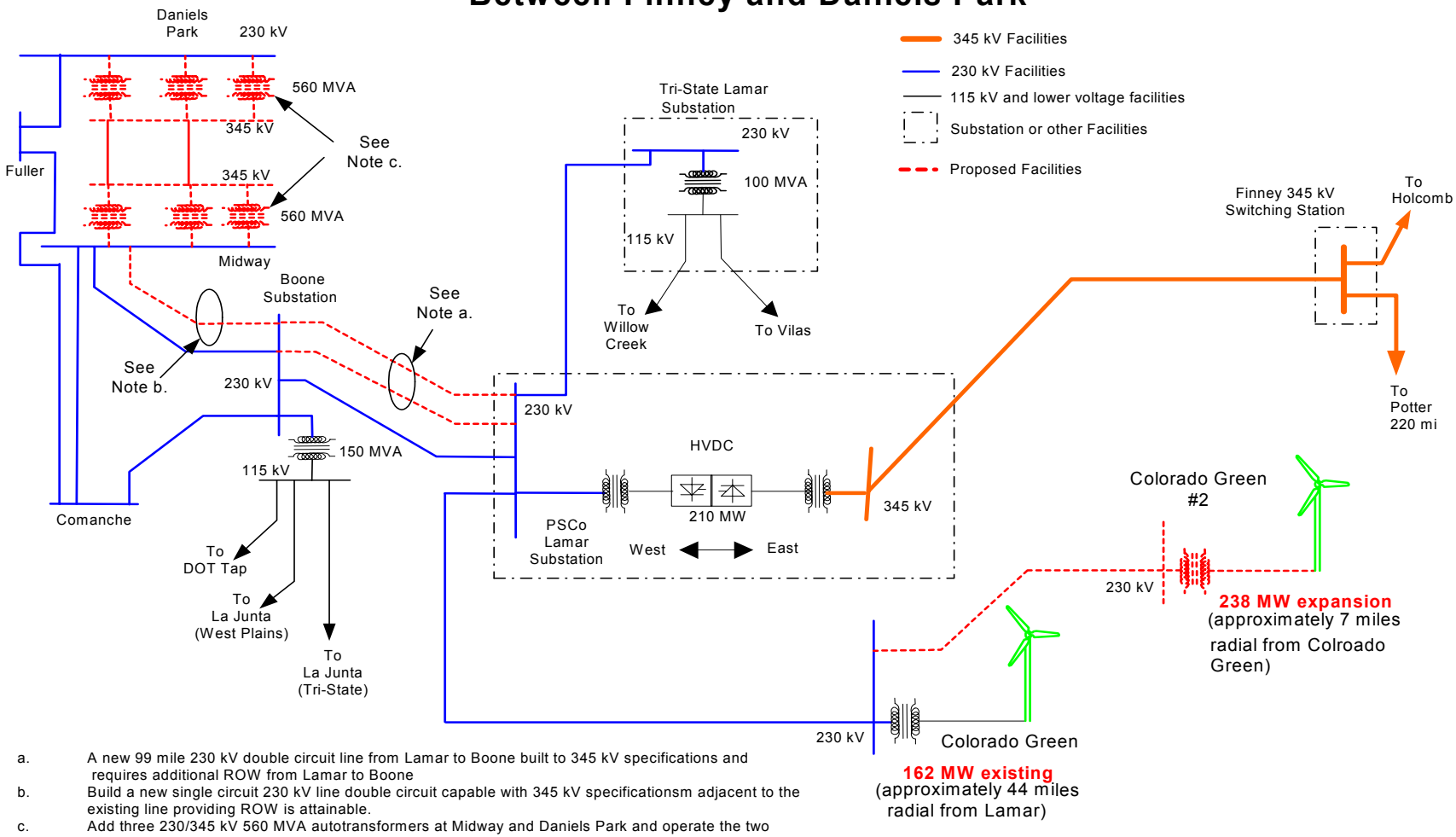
Some sensitivity studies evaluated the system performance considering the higher queued project GI-2003-3. The study results indicated that this project (2004-02) would not impact the 2010 facilities recommended for the GI-2003-3 project. There were no other higher queued projects in the Lamar region.

This study assumed that the Customer would construct a 7-mile 230kV transmission line to interconnect the facility to the existing Colorado Green Substation and utilize their existing 44-mile 230kV transmission line from that substation to the PSCo Lamar substation.

This study revealed the potential for greater than normal bus voltages at the Colorado Green 230kV substation at the 400 MW level of wind injection. The issue is discussed in more detail in the powerflow analysis section.

A simple diagram of the regional transmission system for this request is shown in Figure 1.

Figure 1: Regional Transmission System Between Finney and Daniels Park



a. A new 99 mile 230 kV double circuit line from Lamar to Boone built to 345 kV specifications and requires additional ROW from Lamar to Boone
b. Build a new single circuit 230 kV line double circuit capable with 345 kV specificationsm adjacent to the existing line providing ROW is attainable.
c. Add three 230/345 kV 560 MVA autotransformers at Midway and Daniels Park and operate the two existing Midway-Daniels Park 230 kV lines at 345 kV.
d. Substation expansion at Boone, Midway, Daniels Park, and Lamar.

Introduction

PSCo Transmission received this large generator interconnection request on February 9, 2004, to interconnect one hundred 159 1.5 MW, GE doubly fed induction generator (DFIG) wind turbines, for a 238 MW increase of generation at the 162 MW rated Colorado Green Wind Farm. The location of the Customer's facility is approximately 40 miles South of the town of Lamar, Colorado. The Customer proposed in-service date for commercial operation of the facility is December 1, 2006, with an assumed back-feed date of June 1, 2006. The Feasibility Study was completed and the report issued to the Customer and posted on the RMAO web site in May 2004 and has similar results to this study. An Interconnection System Impact Study Agreement was executed on or around June 29, 2004.

Study Scope and Analysis

The Interconnection System Impact Study evaluated the transmission requirements associated with the proposed interconnection to the PSCo Transmission System.

The Study consisted of power flow, short circuit, and dynamic stability analyses. The power flow analysis identified thermal or voltage limit violations resulting for the interconnection, and was used to develop the Network Upgrades required to deliver the proposed generation to PSCo loads. The short circuit analysis identified circuit breaker short circuit capability limitations and required upgrades due to the interconnection and delivery of the proposed project. The dynamic stability analysis verified that there were no limitations due to angular instability of the system for regional disturbances.

PSCo adheres to NERC / WECC Reliability Criteria, as well as internal Company criteria for planning studies. During system intact conditions, criteria are to maintain transmission system bus voltages between 0.95 and 1.05 per-unit of system normal conditions, and steady state power flows within 1.0 per-unit of all elements thermal (continuous current or MVA) ratings. Operationally, PSCo tries to maintain a transmission system voltage profile ranging from 1.02 per-unit or higher at generation buses, to 1.0 per-unit or higher at transmission load buses. Following a single contingency element outage, transmission system steady state bus voltages must remain within 0.90 per-unit to 1.10 per-unit, and power flows within 1.0 per-unit of the elements continuous thermal ratings.

Impacts on the neighboring utilities were monitored and were addressed during the course of this study. Regional utilities with the potential to be affected by this project include Aquila, Arkansas River Power Authority, Colorado Springs Utilities, Lamar Light and Power, Tri-State Generation and Transmission, and Western Area Power Administration. Those entities will be informed of the results of this study and invited to comment and participate in future studies.

Powerflow Study Models

For this analysis, a power flow model was developed to reflect the 2007 heavy summer loading conditions from the existing 2004 WECC heavy summer operating case. Data representation in the area of study was reviewed and modified to accurately reflect the regional transmission system for 2007. This case is different from the earlier Feasibility Case that examined a 2005 case.

The existing Colorado Green generation was modeled at full output and the Lamar DC Tie was scheduled at 210 MW into the region to model full power transfers in the regional transmission system.
The proposed project was modeled as two 119 MW units connected to the Colorado Green 230 kV bus with a single radial 7-mile 230kV line with modeling data provided by the Customer. The proposed generation was scheduled to PSCo peaking units located in and around Denver. The specified point of interconnection for the new generation is Lamar Switching Station near Lamar, Colorado.

Study Results

Power Flow Analysis

Energy Resource

The studies showed that there is insufficient transmission capacity in the region to accommodate any energy from the proposed project on a long-term firm basis. This is primarily due to the existing generation in the area utilizing the capacity of the single bulk power transmission line out of Lamar. However, non-firm capacity may be available depending upon the regional generation and load patterns and the flow on the Lamar HVDC Tie.

Network Resource

The NR study determined the network upgrade alternatives to accept the full 238 MW from the proposed project. The studies simulated maximum injections into Lamar substation, including a full 210 MW east to west schedule over the Lamar DC tie and 400 MW of injection from Colorado Green. Denver-metro area generation was reduced to simulate heavy power transfers from Lamar to the Front Range. The analysis revealed transmission paths that exhibited unacceptable contingency performance. The areas of concern are described in the following sections.

Lamar - Boone

Under existing conditions, and heavy east to west flows from Lamar, loss of the Lamar to Boone 230kV line results in overloading the Tri-State 230/115 kV autotransformer. Operating procedures have been implemented to alleviate those overloads until additional transmission can be built. The current operating procedures for the loss of the Boone to Lamar 230 kV line are:

1) Trip the existing Colorado Green Wind Farm off-line and

2) Shut down power injections from the Lamar HVDC tie[1].

Studies have shown that the addition of a second 230kV transmission line from Lamar to Boone will not eliminate all N-1 overload violations. Loss of either Lamar – Boone 230kV line overloads the remaining line and the underlying 115 and 69kV system. Therefore, a third line from Lamar to Boone is required to alleviate the contingency overloads.

Boone – Midway

The proposed generation increase at Lamar also revealed transmission capacity limitations between Boone and Midway. Outages modeled in the Comanche and Midway area resulted in thermal overloads on the Aquila and Colorado Springs Utilities (CSU) systems up to 139 percent of some equipment ratings. A new 230 kV line from Boone to Midway took care of the contingency overloads on the Aquila transmission system.

Midway – Denver

Studies indicated that an outage of either of the 230 kV lines from Midway to Daniels Park would overload parts of the CSU system. Upgrading the two 230 kV lines from Midway to Daniels Park to 345 kV operation removed those contingency overloads. The 345kV upgrade was achieved by adding autotransformers at both Midway and Daniels Park Substations.

Colorado Green - Lamar

Studies revealed large voltage deviations between the Colorado Green and Lamar 230kV Substations. For voltages at Lamar of 1.02 pu, the corresponding voltage at Colorado Green was above 1.05 pu.

Some cursory analysis looked at potential solutions to the voltage issue including a second Colorado Green – Lamar 230kV line, series compensation of this line, and an SVC at Lamar. It is recommended that the Customer determine an appropriate solution and make necessary system modifications to prevent unacceptable voltages on their system.

In summary, the following upgrades are recommended:

- Between Lamar and Boone Substations, construct a new double circuit 230 kV line. To allow for future capacity, the line should be capable of 345 kV operation, but initially operated at 230kV.
- Between Boone and Midway Substations, construct a new single circuit 230 kV line. To allow for future capacity, the line should be capable of double circuit 345 kV operation
- Upgrade the two Midway – Daniels Park 230kV lines to operate at 345kV. This will require the installation 345/230 kV autotransformers: three at Midway Substation, and three at Daniels Park Substation.

[1] The Lamar DC Tie has controls to rapidly (10 cycles) reduce the output to 0 MW, and at the same time provide voltage support to the 230kV west-side system.

- The 230 KV metering unit at Lamar needs to be replaced since it is sized for the original 162 MW Colorado Green Facility.
- The Customer should investigate and resolve the voltage issues at the Colorado Green substation associated with 400 MW of generation.

The recommended upgrades are shown in Figure 1. Powerflow contingency results and tables are available upon request.

Short Circuit Study Results

The short circuit analysis at the Lamar Substation for this System Impact Study consisted of faulting the 230kV bus at Lamar, Boone, and Colorado Green with three-phase and phase to ground faults. Initial results did not show any significant change from the earlier Feasibility study.

According to the previous study the Colorado Green Wind Farm will contribute minimal current to the total fault current at Lamar, but not enough to exceed any of the 40 kA circuit breaker fault duty interrupting capabilities.

Stability Study Results

Transient stability analysis of the Lamar area was performed by modeling three-phase faults and single line to ground fault contingencies in the region of study. All faults were cleared and elements removed after six cycles. Dynamic models for the proposed project were prepared using Customer supplied data. The analysis indicated that the project would not adversely affect the transient stability performance of the system and results met WECC/NERC Reliability Criteria. The system is stable before, during, and after contingencies. The disturbances modeled are shown in Tables 1 and 2. Plots of the stability analysis are available upon request.

Table 1: Base Case

Fault Location	Action	Result
Colorado Green 230 kV	a) Clear fault and Open Colorado Green to Lamar 230 kV	Stable CG1 trips
Lamar 230 kV	a) Clear fault and Open Colorado Green to Lamar 230 kV	Stable CG1 trips
	b) Clear fault and Open Lamar to Boone 230 kV #1	Stable CG1 trips
Lamar 115 kV	a) Clear fault and Open Lamar to Willow Creek 115 kV	Stable CG1 trips
	b) Clear fault and Open Lamar to Vilas 115 kV	Stable CG1 trips
Boone 230 KV	a) Clear fault and Open Lamar to Boone 230 kV #1	Stable CG1 trips
	b) Clear fault and Open Boone to Midway 230 kV #1	Stable CG1 trips
	c) Clear fault and Open Boone to Comanche 230 kV #1	Stable CG1 trips
Boone 115 kV	a) Clear fault and Open Boone to LaJuntaT 115 KV	Stable CG1 trips
	b) Clear fault and Open Boone to LaJuntaW 115 KV	Stable CG1 trips
	c) Clear fault and Open Boone to DOT Tap 115 KV	Stable CG1 trips
Comanche 230 Kv	a) Clear fault and Open Boone to Comanche 230 kV #1	Stable CG1 trips
	b) Clear fault and disconnect Comanche G1	Stable CG1 trips
Midway 230 Kv	a) Clear fault and Open Boone to Midway 230 kV #1	Stable CG1 trips
Midway 345 kV	a) Clear fault and Open Midway to Daniels Park 345 kV #1	Stable CG1 trips
Daniels Park 345 kV	a) Clear fault and Open Midway to Daniels Park 345 kV #1	Stable CG1 trips
Colo. Green 34.5 kV	a) Sudden wind gust dropping wind farm	Stable

Table 2: Case with 238 MW Colorado Green Expansion and Network Upgrades

Fault Location	Action	Result
Colorado Green 230 kV	a) Clear fault and Open Colorado Green to Lamar 230 kV	Stable CG1 & 2 trip
Lamar 230 kV	a) Clear fault and Open Colorado Green to Lamar 230 kV	Stable CG1 & 2 trip
	b) Clear fault and Open Lamar to Boone 230 kV #1	Stable CG1 trips
Lamar 115 kV	a) Clear fault and Open Lamar to Willow Creek 115 kV	Stable No Trip
	b) Clear fault and Open Lamar to Vilas 115 kV	Stable No Trip
Boone 230 KV	a) Clear fault and Open Lamar to Boone 230 kV #1	Stable No Trip
	b) Clear fault and Open Boone to Midway 230 kV #1	Stable No Trip
	c) Clear fault and Open Boone to Comanche 230 kV #1	Stable No Trip
Boone 115 kV	a) Clear fault and Open Boone to LaJuntaT 115 KV	Stable No Trip
	b) Clear fault and Open Boone to LaJuntaW 115 KV	Stable No Trip
	c) Clear fault and Open Boone to DOT Tap 115 KV	Stable No Trip
6) Comanche 230 Kv	a) Clear fault and Open Boone to Comanche 230 kV #1	Stable No Trip
	b) Clear fault and disconnect Comanche G1	Stable No Trip
7) Midway 230 Kv	a) Clear fault and Open Boone to Midway 230 kV #1	Stable No Trip
8) Midway 345 kV	a) Clear fault and Open Midway to Daniels Park 345 kV #1	Stable CG1 trips
9) Daniels Park 345 kV	a) Clear fault and Open Midway to Daniels Park 345 kV #1	Stable No Trip
Colo. Green 34.5 kV	a) Sudden wind gust dropping wind farm	Stable

Power Electronics Control Interactions

Detailed analysis was performed using models supplied by the Customer and the Lamar HVDC Link vender to examine the interactions of the power electronics controls of the HVDC link and the voltage source converters located on the wind turbine generators. The results show that both the Lamar HVDC Link and the Colorado Green wind generators both want to control the voltage at the Lamar 230 kV bus. To remedy this a delay/droop should be installed on the wind farm controls. Other than this, (Subsynchronous Resonance) SSR analysis and harmonic analysis could not be conducted due to the limitations of the wind turbine models. The Lamar HVDC link has SSR controls built in, but impacts with the Colorado Green Wind Farm could not be analyzed due to model limitations.

Cost Estimates

The estimated total cost for the required upgrades is **$122.9 Million**

The estimated cost shown is an "scoping" (+/-30%) preliminary budgetary cost in 2006 dollars and is based upon typical construction costs for previously performed similar construction. These estimated costs include all applicable labor and overheads associated with the engineering, design, and construction of these new PSCo facilities. This estimate does not include any costs for any Customer-owned, supplied, and installed equipment and associated design and engineering. This estimate also does not include any costs that may, or may not be required for other entities' systems because this study did not find any requirements for any Affected Systems as the results of the 238 MW generation increase at Colorado Green.

The following tables list the improvements required to accommodate the interconnection and the delivery of the proposed 238 MW increase of the existing Colorado Green facility. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines.

Table 3: PSCo Network Upgrades Required for Interconnection

Substation	Description	Cost
Lamar Switching Station	Replace 230 kV bi-directional revenue metering: • associated control and relaying changes and additions.	**$40,000**
	Total Cost	**$40,000**
Time Frame		**3.5 Months**

Table 4: PSCo Network Upgrades for Delivery

Facility	Description	Cost (Million)
Lamar	Two new 230 kV Line terminals to Boone requiring the following equipment: • (6) 2000 Amp, 40 kA circuit breakers • (10) 230 kV switches • Associated steel • Electrical bus work • Associated metering, control, and relaying (See One-line in Appendix C)	**$2.54**

Facility	Description	Cost (Million)
Boone Substation	Three (3) new 230 kV 2000 Amp Line Terminals; two to Lamar and one to Midway. The following equipment will be required: • (5) 2000 Amp, 40 kA circuit breakers • (8) 230 kV switches • Misc. supporting steel • Electrical bus work • Associated metering control and relaying (See One-line in Appendix C)	**$ 2.67**
Midway Substation	Expand the 230kV station to allow one line and three transformer terminations. Construct a new 345kV station with allowance for two line and three transformer terminations. The following equipment is included: • three 345/230 kV 560 MVA autotransformers • six 2000 Amp, 40 kA, 230 kV circuit breakers • ten 230 kV switches • Twelve 3000 Amp, 50 kA, 345 kV circuit breakers • sixteen 345 kV switches • Misc. supporting steel • Electrical bus work • Associated metering, control, and relaying (See One-line in Appendix C)	**$17.61**
Daniels Park Substation	Three 345/230 kV 560 MVA autotransformers, two 345 kV line terminations all of which includes the following: • (6) 2000 Amp, 40 kA, 230 kV circuit breakers • ten 230 kV switches • eight 3000 Amp, 50 kA, 345 kV circuit breakers • sixteen 345 kV switches • Misc. supporting steel • Electrical bus work • Associated metering, control, and relaying (See One-line in Appendix C)	**$21.05**
Transmission	Construct a new double circuit 230 kV line, 345 kV capable from Lamar to Boone requiring new ROW	**$55.95**
	One new 230 kV line from Boone to Midway requiring new ROW.	**$23.05**
	TOTAL COST	**$122.87**
Time Frame		**54 Months**

Assumptions

Substations

- PSCo (or its contractor) crews will perform all construction and wiring associated with PSCo-owned and maintained equipment.
- Siting, permitting and land acquisition is included in the substation estimates
- Detailed field investigations have not been conducted and could increase these estimates.
- No screening has been estimated at any of the substations. If this is required the cost will be significant at each location.
- The estimated time for design and construction for the PSCo network upgrades is at least 54 months after authorization to proceed has been received, and based upon other identified assumptions for Siting and Land Rights, and Transmission (see below). If there are problems with local and state approvals, this could require an additional year.

Transmission Engineering and Line Construction:

- Any NEPA requirements imposed on transmission as a result of the generation addition will most likely have adverse effects on schedule and deliverables.
- Detailed field investigations have not been conducted and could increase these estimates.
- New transmission ROW is assumed to be adjacent to the existing transmission lines.
- These estimates do not include any cost for legal fees.
- Permitting to convert the Midway to Daniels Park 230 kV line to 345 kV operation will be difficult and may require legal action.

The overall timeline to complete all required transmission and substation facilities is expected to require a minimum of 54 months. If there are problems with local and state approvals, this could require an additional year.

The figures below show the substation arrangements for each substation and are color coded for interconnection and delivery.

FIGURE 2 LAMAR SUBSTATION

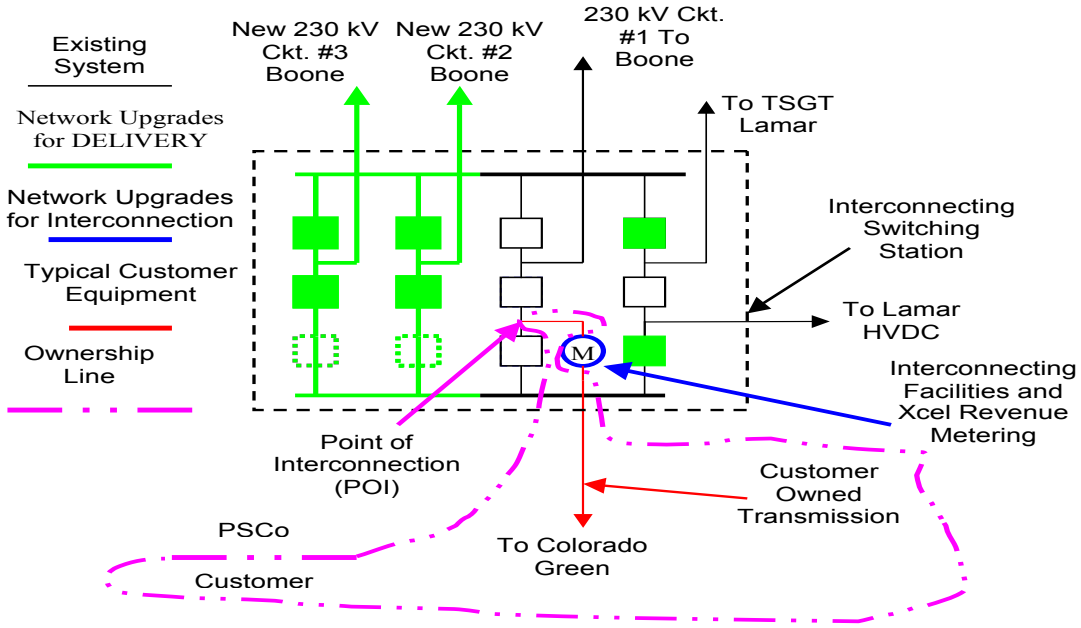


FIGURE 3 BOONE SUBSTATION

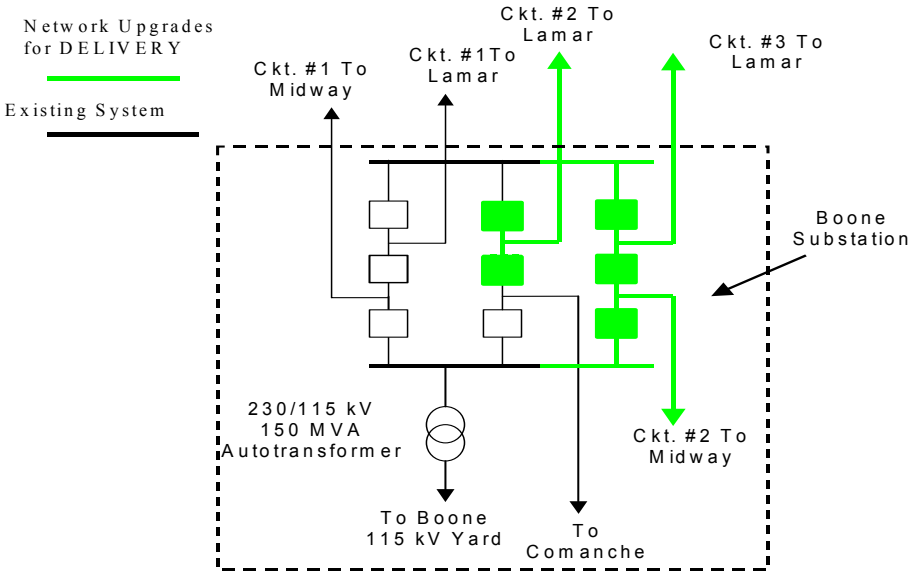


FIGURE 4 MIDWAY SUBSTATION

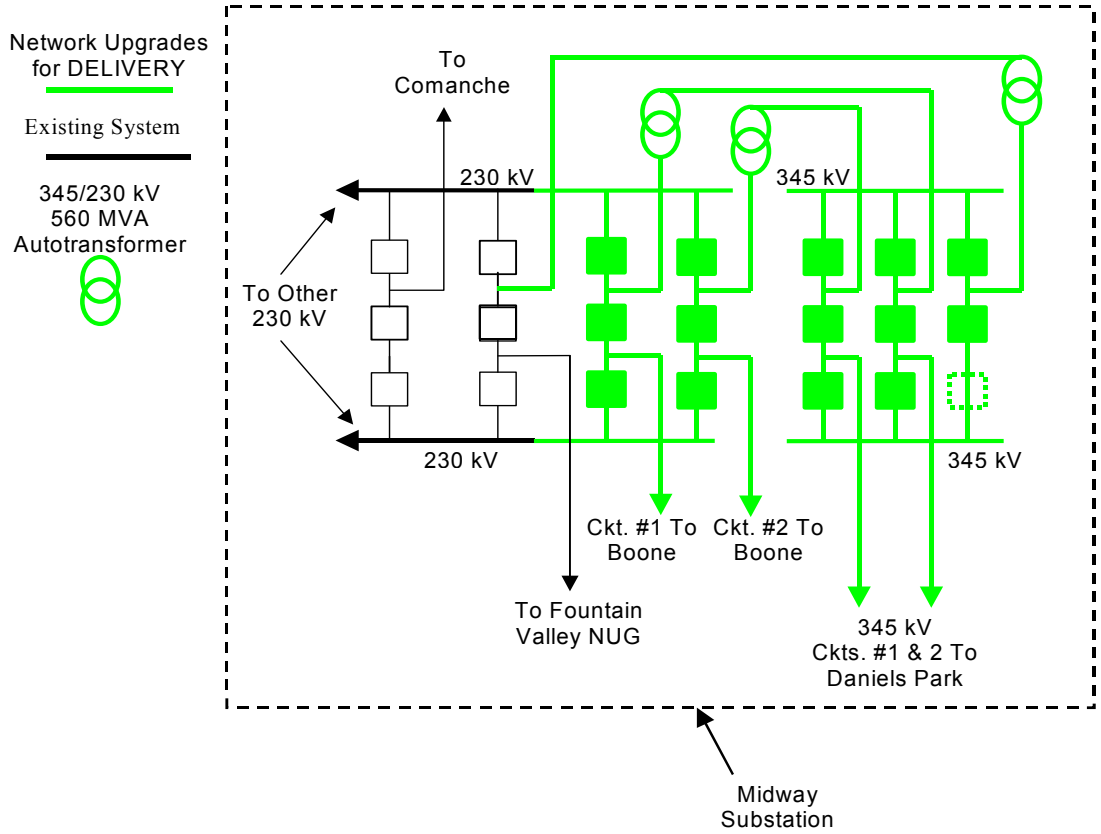


FIGURE 5 DANIELS PARK SUBSTATION ONE-LINE