Interconnection System Impact Study Report
REQUEST # GI-2004-11

69 MW Wind Generation Near Lamar, Colorado
Interconnecting at Lamar Substation

Xcel Energy Transmission Planning
March 2005

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 69 MW of wind powered generation located near Lamar, Colorado to the PSCo Lamar 230 kV bus. The Customer proposed in-service date for commercial operation of the facility is December 1, 2005, with an assumed back-feed date of October 1, 2005. At the request of the Customer, the Project was evaluated as a Network Resource (NR) with the power going to PSCo customers. The request was studied primarily as a "stand-alone" project, but some sensitivity analyses were also performed to consider other projects in the Rocky Mountain Area OASIS queue[1].

Network Resource:
The estimated cost to interconnect the project is approximately **$1.18 million** and includes:

- $0.37 million for Customer Interconnection Facilities
- $0.81 million for PSCo Network Upgrades for Interconnection

The time required to engineer, permit, and construct all the required PSCo facilities for interconnection is estimated to be at least **9** months.

For the Project to be considered a firm Network Resource, other studies[2] have indicated that the integration of the full 69 MW of new generation would require transmission additions and modifications in order to prevent unacceptable conditions on the regional system. The estimated cost of the recommended system upgrades for firm delivery of power from the project is approximately **$67.01** million (for a total project cost of $68.19 million) and would include:

- Construct a new 99-mile, 230 kV line from Lamar to Boone
- Construct a new 43-mile, 230 kV line from Boone to Midway

The estimated time required to engineer, permit, and construct the Network Upgrade facilities for delivery is at least **36** months; therefore, it is not feasible to implement the network upgrades for delivery of firm output by the proposed in-service date.

[1] www.rmao.com
[2] Studies for GI-2004-2 and GI-2004-4

According to the interconnection request, the Customer will engineer, permit, construct, and finance the 230 kV transmission line from the generation facility to Lamar substation. A simple diagram of the Network Upgrades and the regional transmission system for this request is shown in Figure 1. Figure 2 shows a simple Lamar substation one-line.

Sensitivity studies evaluated the system performance considering project GI-2004-2, which is a request to interconnect 238 MW near Lamar by December 2005. Studies showed that if the recommended upgrades for interconnection and delivery for GI-2004-2 were in place prior to GI-2004-11, then GI-2004-11 would only require the upgrades necessary for interconnection in order to accommodate full delivery of the project. It is estimated that those upgrades would cost approximately $1.4 million and include:

- $0.42 million for Customer Interconnection Facilities at Lamar Station
- $0.98 million for PSCo Network Upgrades for Interconnection

However, at the time of this report, request GI-2004-2 is not expected to be in service prior to GI-2004-11.

Note that another project GI-2004-4 (280 MW) is also ahead of this project in the PSCO interconnection queue. GI-2004-4 is a request for 280 MW, interconnected at Lamar substation, but with an in-service date of December 2006. Sensitivity studies for GI-2004-4 also took into account request GI-2004-2 for a total of 518 MW of additional wind injection at Lamar. That study estimated that approximately $137 million would be required for the upgrades for delivery of those two projects. Although additional studies would be required to verify the impacts, it is possible that those upgrades could also accommodate the 69 MW from GI-2004-11.

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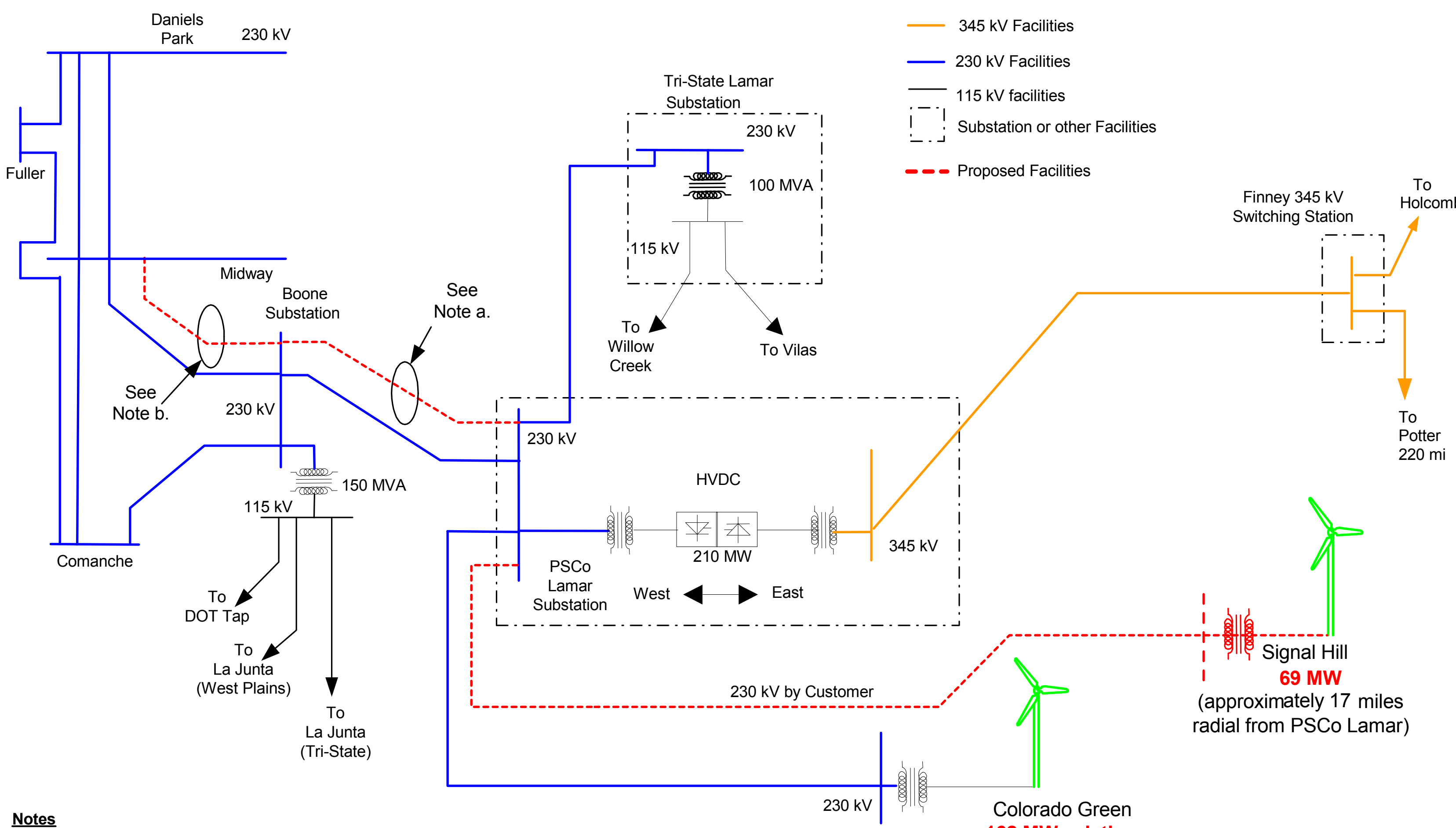
Figure 1 - Regional Transmission Network with Recommended Upgrades for Delivery



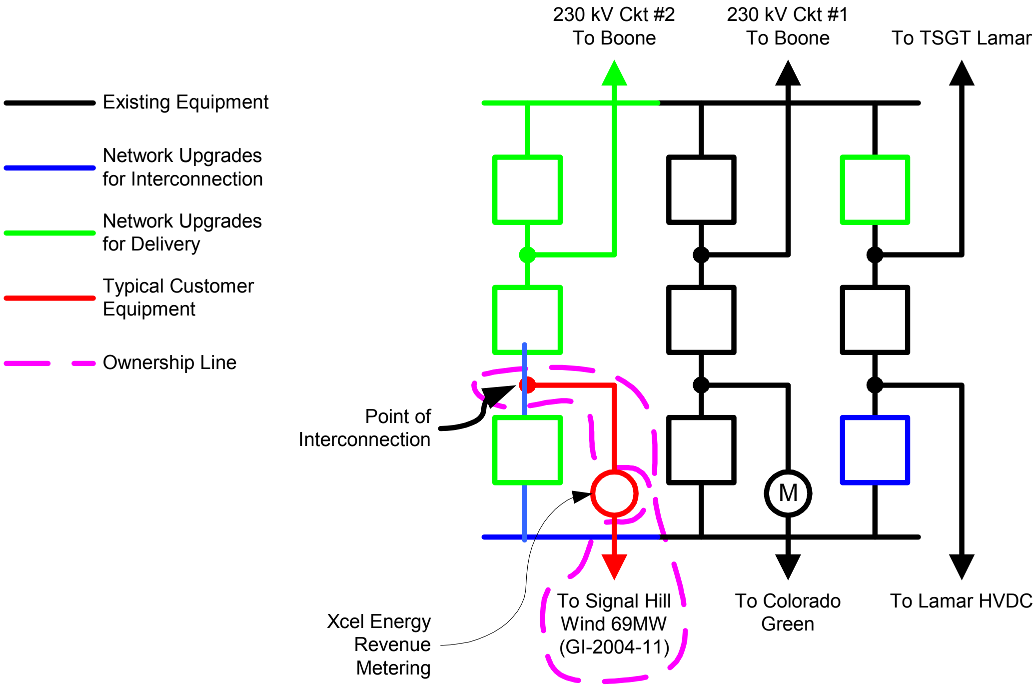
Notes

a. A new 99 mile 230 kV single circuit line from Lamar to Boone, built to 345 kV specifications on double circuit structures. Requires additional ROW from Lamar to Boone.

b. A new single circuit 230 kV line double circuit capable with 345 kV specifications adjacent to the existing line providing ROW is attainable.

c. Substation expansion at Boone and Lamar.

Figure 2 – Lamar Substation One-line with GI-2004-11



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 identified Network Upgrades required to deliver the proposed generation to PSCo loads. The short circuit analysis identified circuit breaker short circuit capability limits that could be exceeded because of the Interconnection, and the delivery of the proposed generation to PSCo loads. The dynamic stability analysis identified any 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.

The proposed transmission for delivery alleviates any impacts to affected utilities in the area of study. These results have been shared with Aquila, Arkansas River Power Authority (ARPA), Colorado Springs Utilities (CSU), Lamar Light and Power (LL&P), Tri-State Generation and Transmission (TSGT), and Western Area Power Administration (WAPA).

Powerflow Study Models

For this analysis, a power flow model was developed to reflect 2007 heavy summer loading conditions. Data representation in the area of study was reviewed and modified to accurately reflect the Rocky Mountain regional transmission system. Power transfers from south to north through Colorado were increased to study the regional transmission system. The Lamar DC tie was modeled at its maximum rating of 210 MW east to west.

The 69 MW wind farm was modeled as a conventional generator with a 0.95 per unit (p.u.) lagging power factor (overexcited) and a 0.90 p.u. leading power factor (under-excited) capability to simulate the VAR requirements of the generators, which the Customer indicated as GE 1.5 MW DFIG turbines.

The proposed project was connected to the Lamar Substation 230 kV bus, via a single 17-mile 230 kV line, according to Customer provided data. For the study, the project generation was scheduled to the northern PSCo system by reducing generation in that area.

Study Results

Power Flow Analysis

This study determined the network upgrades that would be required to accept the full 69 MW from the proposed wind farm on a firm basis for the conditions studied. At 69 MW of generation, several contingencies near Lamar caused solution problems in the powerflow analysis. In order to eliminate the contingency problems, a new (second) 99-mile 230 kV line from Lamar to Boone was modeled. In addition to a second Boone – Lamar 230kV line, a new 43-mile 230kV transmission line between Boone and Midway is required to mitigate contingency overloads west of Boone.

This request was also evaluated taking into consideration the relevant projects ahead in the queue. Sensitivity studies evaluated what transmission upgrades would be required if both GI-2004-2 and GI-2004-11 were implemented. GI-2004-2 is a request for a 238 MW expansion of the existing Colorado Green wind project with an in-service date of December 2005. Studies indicated that if the network upgrades for delivery for GI-2004-2 were in place, then no additional network upgrades would be required to deliver the 69 MW from GI-2004-11 on a firm basis. However, interconnection costs of $1.4 million would still be required. Study reports for GI-2004-2 can be seen on the RMAO web page at www.rmao.com.

Short Circuit Analysis

The short circuit analysis from previous studies, as shown below, consisted of calculating fault levels for the buses in the region of study. The results indicated that there are not any major increases in fault currents, and that current breaker ratings are sufficient to integrate this project into the PSCo system.

The short circuit analysis consisted three-phase and phase to ground faults at the Lamar, Boone, and Colorado Green 230kV buses with. The short circuit analysis performed for request (GI-2004-2) will also apply for this request when considered a stand-alone project. The results show that this 69 MW Signal Hill Wind Farm GI-2004-11 and its associated transmission line would not adversely impact the ratings of any existing equipment on the PSCo transmission system. The results are described in the following tables.

Table 1 Short Circuit Results (kA) for a stand-alone project

Fault	Fault Description	Fault Current @ 6 Cycles (kA, RMS)	CO GRN 1	DC Link
1	LLLG at Lamar 230 kV	1.45	Trip	Blocked
2	LLLG at Boone 230 kV	7.25	Trip	0 power
3	LLLG at CO Grin 230 kV	1.23	Trip	0 power
4	LLLG at Lamar 115 kV	2.5	Trip	0 power
5	LLLG at Boone 230 kV	7.6	Trip	Voltage Control (High Q)
6	SLG at Lamar 230 kV	2.7	Delayed Trip	Low PQ
7	SLG at Boone 230 kV	7.1	No Trip	Voltage Control (High Q)
8	SLG at Co Grn 230 kV	1.52	No Trip	Voltage Control (High Q)
9	SLG at Lamar 115 kV	4.1	No Trip	Voltage Control (High Q)
10	SLG at Boone 230 kV	7.1	No Trip	Voltage Control (High Q)

Table 2 Short Circuit Results (kA) with consideration of 2004-02

Fault	Fault Description	Fault Current @ 6 Cycles (kA, RMS)	CO GRN 1	CO GRN 2	DC Link
1	LLLG at Lamar 230 kV	1.45	Trip	No Trip	Blocked
2	LLLG at Boone 230 kV	7.25	Trip	No Trip	0 power
3	LLLG at CoGrn 230 kV	1.23	Trip	No Trip	Low Power, Voltage Control
4	LLLG at Lamar 115 kV	2.5	Trip	No Trip	Low Power, Voltage Control
5	LLLG at Boone 230 kV	7.6	Trip	No Trip	Voltage Control (High Q)
6	SLG at Lamar 230 kV	2.7	Trip	No Trip	Low Power
7	SLG at Boone 230 kV	7.1	Trip	No Trip	Low Power
8	SLG at Co Grn 230 kV	1.52	Trip	No Trip	Voltage Control (High Q)
9	SLG at Lamar 115 kV	4.1	No Trip	No Trip	Voltage Control (High Q)
10	SLG at Boone 230 kV	7.1	No Trip	No Trip	Voltage Control (High Q)

As shown in the tables, the Colorado Green Wind Farm will contribute minimal current to the total fault current at Lamar and will not exceed any of the 40 kA circuit breaker fault duty interrupting capabilities.

Stability Analysis

Transient stability analyses of the Lamar area were performed by modeling three-phase faults and single line to ground fault contingencies in the region of study. Dynamic models for the proposed project were prepared using Customer supplied data and modeled GE 1.5 MW DFIG turbines with low voltage ride through capability of 30% of nominal voltage. If turbines with different characteristics are used for this project, additional studies may be required. The stability analysis indicated that the existing regional system is at risk of transient and voltage instability due to the relatively weak transmission system east of Boone. The most critical disturbances are those that result in the loss of the Boone – Lamar 230kV line. The benchmark results are shown in Table 3. System instability was evident for three of the disturbances modeled due to the weakness of the 115 kV system between Lamar and Boone. Studies indicated that the addition of a second Boone-Lamar 230kV line alleviates stability problems in the region. Therefore, that line is listed as a requirement for firm delivery of the project. The last column of Table 3 shows that the system stability is acceptable with the project and associated upgrades for delivery implemented.

Stability studies for request GI-2004-4 indicate that if appropriate transmission upgrades are implemented to accommodate over 500 MW of new wind generation at Lamar that the system will remain stable.

The models for these studies do not contain enough detail to analyze the interactions of the power electronics of the Signal Hill generator with those of the Colorado Green generators or the Lamar HVDC Tie. This interaction study will need to be performed during the Facilities Study and will have to be addressed during LGIA discussions.

Before the interaction studies can take place, the Customer will have to provide a detailed PSCAD model of their facilities.

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Table 3 - Transient Stability Results – Comparison of Existing System (Benchmark Results) to GI-2004-11 with and without Network Upgrades. Lamar DC tie is scheduled at 210 MW East to West.

	Fault Location	Action	Benchmark	Signal Hill 69 MW without Network Upgrades	Signal Hill 69 MW and Network Upgrades
1	3PH at Lamar 230 kV bus, 4 cycles	Trip Boone-Lamar 230 kV line, ckt 1 or 2	Colorado Green Trips System Unstable	Colorado Green Wind Tripped, Signal Hill Wind Tripped System Unstable	Colorado Green Trips, Signal Hill Trips System Stable No criteria violations
2	3PH at Boone 230 kV bus, 6 cycles	Trip Boone-Lamar 230 kV line, ckt 1 or 2	Colorado Green Trips System Unstable	Colorado Green Wind Tripped, Signal Hill Wind Tripped System Unstable	Colorado Green Trips, Signal Hill Trips System Stable No new violations
3	3PH at Lamar 115 kV bus; 6 cycles	Trip Lamar 230-115 kV transformer	Colorado Green Tripped System Stable Post-transient voltage deviations	Colorado Green Wind Tripped, Signal Hill Wind Tripped System Stable Post-transient voltage deviations	Colorado Green Trips, Signal Hill Trips System Stable No new post transient violations.
4	3PH at Colorado Green 230 kV bus; 4 cycles	Trip Lamar-Colorado Green 230 kV line	Colorado Green Trips System Stable	Colorado Green Wind Tripped System Stable	Colorado Green Trips System Stable
5	3PH at Signal Hill 230 kV bus; 6 cycles	Trip Signal Hill-Lamar 230 kV line	Colorado Green Trips System Stable	Colorado Green Wind Tripped, Signal Hill Wind Tripped System Stable	Colorado Green Trips, Signal Hill Trips System Stable
6	3PH at Midway 230 kV bus; 6 cycles	Trip Boone-Midway 230 kV line, ckt 1 or 2	Colorado Green Trips System Stable Frequency Violations	Colorado Green Wind Tripped, Signal Hill Wind Tripped System Stable No New Violations	Colorado Green Trips, Signal Hill Trips System Stable
7	3PH at Comanche Station 230 kV bus; 6 cycles	Trip Comanche Unit 1	Colorado Green Trips System Stable	Colorado Green Wind Tripped, Signal Hill Wind Tripped System Stable	Colorado Green Trips, Signal Hill Trips System Stable
8	SLG at Boone 230 kV bus; 20 cycles	Trip Boone-Lamar 230 kV line, ckt 1 or 2	Colorado Green Trips, Lamar DC Tie Trips System Stable Post-transient voltage deviations	Colorado Green Wind Tripped, Signal Hill Wind Tripped, Lamar DC Tie Trips System Stable Post-transient voltage deviations	Colorado Green Trips, Signal Hill Trips System Stable
9	SLG at Comanche Station 230 kV bus; 20 cycles	Trip Comanche Unit 1	System Stable	System Stable	System Stable
10	SLG at Midway 230 kV bus; 20 cycles	Trip Boone-Midway 230 kV line, ckt 1 or 2	System Stable	System Stable	System Stable

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	Fault Location	Action	Benchmark	Signal Hill 69 MW without Network Upgrades	Signal Hill 69 MW and Network Upgrades
					No criteria violations
11	SLG at Lamar 230 kV bus; 20 cycles	Trip Boone-Lamar 230 kV line, ckt 1 or 2	Colorado Green Trips, Lamar DC Tie Trips System Stable Voltage Violations	Colorado Green Wind Tripped, Signal Hill Wind Tripped, Lamar DC Tie Trips System Stable Voltage Violations	Colorado Green Trips, Signal Hill Trips System Stable No criteria violations
12	3PH at Boone 230 kV bus; 6 cycles	Trip Boone 230-115 kV transformer	Colorado Green Trips System Unstable	Colorado Green Wind Tripped; Signal Hill Wind Tripped System Unstable	Colorado Green Trips, Signal Hill Trips System Stable No New Violations

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Cost Estimates and Assumptions

The estimated total cost for the upgrades required for interconnection and delivery is **$68.19 Million.**

The estimated costs shown are "indicative" (+/-30%) preliminary budgetary costs in 2006 dollars and are 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. The estimates do not include any costs for any Customer-owned, supplied, and installed equipment and associated design and engineering, other than the transmission line between the generation and Lamar. This estimate also does not include any costs that may, or may not be required for other entities' systems. The cost responsibilities associated with these facilities shall be handled as per current FERC guidelines

Based upon the System Impact Study performed here, in order for PSCo to provide an interconnection for the Customer, facilities must be constructed at the PSCo Lamar Substation.

PSCo Network Upgrades for Interconnection:
Table 4 and Table 5 describe the costs associated with providing an interconnection and network upgrades to PSCo's system for interconnection. This does not include all of the costs required for full delivery of the generation.

Table 4 - Customer Interconnection Facilities

Substation	Description	Cost Est. (Millions)
Lamar (PSCo)	Interconnect Customer to tap PSCo's 230kV bus. The new equipment includes 230kV bi-directional transformer metering, relaying and associated equipment and material.	**$0.330**
	Transmission tie line into substation.	**$0.020**
	Siting and Land Rights for required easements, reports, permits and licenses.	**$0.020**
	Total Cost Estimate for Customer Interconnection Facilities	**$0.370**

Table 5 - PSCo Network Upgrades for Interconnection

Substation	Description	Cost Est. (Millions)
Lamar (PSCo)	Interconnect Customer's 230 kV line by converting the Lamar 230 kV four-breaker ring bus into a three bay, breaker-and-a-half layout. The new equipment required includes: • One 230 kV, 3000 A, 50 kA circuit breakers • Four 230 kV switches • Required electrical bus work, relaying and wiring, and steel supporting structures	**$0.807**
	Total Cost Estimate for PSCo Network Upgrades for Interconnection	**$0.807**

Table 6 describes the costs associated with providing network upgrades for delivery to PSCo Customers.

Table 6 - PSCo Network Upgrades for Delivery

Element	Description	Cost (Millions)
Lamar Substation (PSCo)	New line terminal for 230 kV circuit 2 to Boone. The new equipment required includes: • Four 230 kV, 3000 A, 50 kA circuit breaker • Five 230 kV switches	**$1.469**
Boone Substation	New line terminal for 230 kV circuit #2 to Lamar and new terminal equipment for circuit #2 to Midway. The new equipment required includes: • Five 230 kV, 3000 A, 50 kA circuit breaker • Eight 230 kV switches	**$2.674**
Midway Substation	New line terminal for 230 kV circuit 2 to Boone. The new equipment required includes: • One 230 kV, 3000 A, 50 kA circuit breaker • 230kV switches	**$0.520**
Transmission	Construct a new 99-mile, single-circuit, 230 kV line from Lamar to Boone, built to 345 kV specifications on double-circuit structures.	**$40.814**
	Construct a new 43-mile, single-circuit, 230 kV line from Boone to Midway, built to 345 kV specifications on double-circuit structures.	**$16.176**
Siting and Permitting	Obtain necessary siting, permits, and ROW as required.	**$5.364**
	Total Cost Estimate for PSCo Network Upgrades for Delivery	**$67.017**
	Total Cost of Project	**$68.190**
Time Frame		**36 Months**

Assumptions

- The cost estimates provided are “scoping estimates” with an accuracy of +/- 30%.
- Estimates are based on 2005 dollars.
- PSCo (or it’s Contractor) crews will perform all construction and wiring associated with PSCo owned and maintained facilities.

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- The estimated time for design and construction of PSCo network upgrades for interconnection at the Lamar Substation is at least **9 months**, and is completely independent of other queued projects and their respective ISD's.
- It is anticipated that in order to construct the PSCo network upgrades for delivery, a Certificate of Public Convenience and Necessity (CPCN) will be required by the Colorado Public Utilities Commission (CPUC). The application for a CPCN will not be submitted until the Interconnection Agreement is fully executed. The estimated time frame for the CPCN process, siting, permitting, easement and right-of-way acquisition, design and construction for the PSCo network upgrades is at least **36 months** from the time the Interconnection Agreement is fully executed. This time frame is also based on other identified assumptions for Siting and Land Rights, Substation Engineering and Transmission Engineering as listed below.
- The Customer will be responsible for funding and constructing the transmission line from the wind farm to the point of interconnection (Lamar Substation).
- The last span into Lamar Substation from the Customer owned 230 kV line will be a slack span between the PSCo substation dead-end and the Customer's last structure, which is assumed to be a dead-end tangent structure.
- 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.
- All necessary transmission line outages can be obtained. If not, construction duration times will be longer.
- Colorado State Land board issues will need to be addressed in future studies.