ERCOT System Planning:

Study of the Integration of the Lubbock Power & Light System into the ERCOT System

Version 1.0

Document Revisions

Date	Version	Description	Author(s)
06/09/2016	1.0	Final	A. Benjamin Richardson, Yang Zhang, Ying Li, Jeff Billo
		Reviewed by	Prabhu Gnanam, Fred Huang, Warren Lasher, Nathan Bigbee

Table of Contents

1. Executive Summary

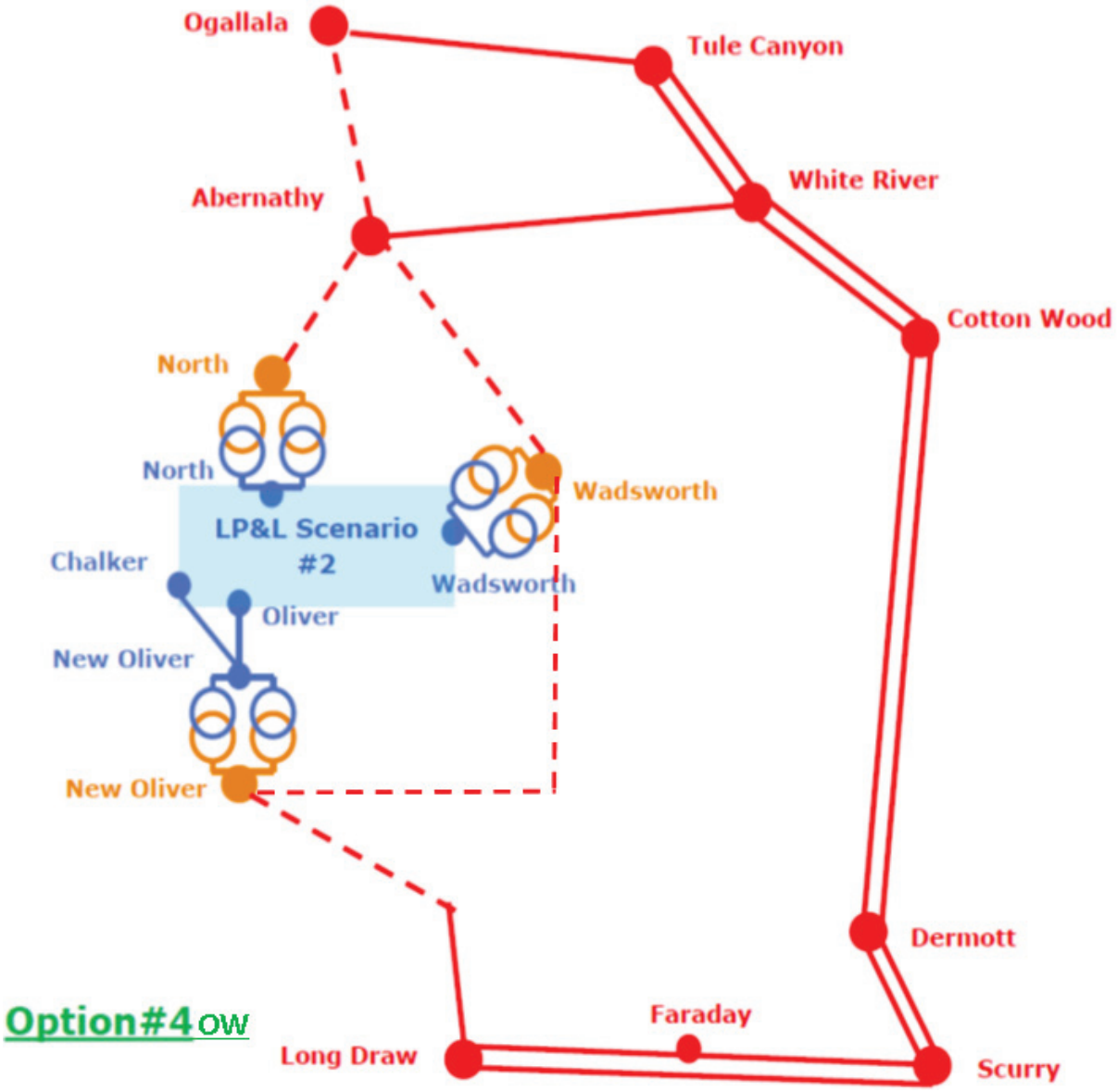
On September 24, 2015, the Public Utility Commission of Texas (PUCT) asked ERCOT to perform a study to identify the transmission system improvements needed to integrate the Lubbock Power & Light (LP&L) system into the ERCOT system. LP&L is a municipally owned electric utility company located in Lubbock County, Texas, currently integrated into the Eastern Interconnection. LP&L anticipates that a peak customer demand ranging from 466 (Megawatts) MW to 593 MW would initially be included in the transition to ERCOT as early as June 2019, along with three generation plants providing a combined generating capacity of approximately 130 MW. The objective of the ERCOT study is to identify the most cost-effective set of new transmission facilities that would be required to integrate the LP&L load and transmission network into the ERCOT System consistent with ERCOT and NERC Transmission Planning reliability criteria. ERCOT evaluated over forty transmission integration alternatives and systematically narrowed down the options.

The results of this analysis showed that a minimum of three independent connections to the existing ERCOT System were required to serve the LP&L system within the applicable reliability criteria, and that each of the options with three new connections provided sufficient margin for future load growth. Therefore, the selection of a preferred option was based on cost-effectiveness. Using the lowest capital cost option (LPL Option 1) as a reference, ERCOT performed system production cost simulations to determine if the additional capital cost of any of the higher cost options could be economically justified per ERCOT Protocols Section 3.11.2(5). In addition, the viable alternatives were compared to results of previous studies of the long-term ERCOT transmission needs in the area.

The production cost simulation results showed that two options (LPL Option 4ow and LPL Option 8B) resulted in annual production cost savings sufficient to justify the increase in capital cost compared to the lowest cost option. The primary reason for the annual production cost savings observed with these options was an increase in the export capability from the Panhandle region, which would facilitate greater use of wind generation in that area. Based on these results, LPL Option 4ow, illustrated in Figure ES-1, has the lowest societal cost when considering both capital costs and annual production cost. This option has an estimated capital cost of $364 million.

In April 2014 ERCOT published a report describing a potential roadmap of future transmission system improvements to increase the export capability from the Panhandle as wind generation is developed in the area. The first stage of transmission improvements from that roadmap is being developed. The second stage of potential improvements included a new 345 kV transmission line from Ogallala to Long Draw; LPL Option 4ow would create an electrically similar path through a series of intermediary substations. The economic benefits noted in production cost simulations are an indication of this similarity – LPL Option 4ow is consistent with long-term transmission plans developed to increase access to Panhandle generation.

Figure ES-1: LPL Option 4ow



ERCOT also found that the LPL Option 4ow would provide two feasible alternatives for future expansion to increase the export capability from the Panhandle. Both of these future expansion alternatives for LPL Option 4ow met the economic criteria described in ERCOT Protocols Section 3.11.2(5). ERCOT has not included these additional facilities related to future expansion in this assessment because they are not essential to the interconnection of the LPL system to ERCOT. If the Commission authorizes the interconnection of the LPL system to ERCOT under option 4ow, these economic upgrades can be reviewed and compared with other possible options through the Regional Planning Group process at the appropriate time.

Based on the analysis detailed in this report, ERCOT prefers LPL Option 4ow for integrating the LP&L System into ERCOT for the following reasons:

- It meets applicable reliability criteria with significant margin for future load growth and/or local generation retirement;
- The additional cost compared to the lowest cost option is economically justified;
- It has the lowest societal cost when considering both capital and annual system production costs;
- It provides the largest increase to the Panhandle export capability compared with the other final short-listed options;
- It aligns with a recent roadmap of future Panhandle upgrades; and
- It provides opportunities for future expansion.

2. Introduction

Lubbock Power and Light (LP&L) is a municipally owned electric utility company located in Lubbock County, Texas. While LP&L is currently integrated into the Eastern Interconnection, the utility is contemplating integrating a majority of its transmission and distribution network assets into the ERCOT Interconnection as early as 2019. LP&L anticipates that a peak customer demand ranging from 466 MW to 593 MW would initially be included in the transition to ERCOT along with three generation plants providing a combined generating capacity of approximately 130 MW. On September 24, 2015, the Public Utility Commission of Texas (PUCT) asked ERCOT to study the impact of integrating LP&L into the ERCOT grid.

The objective of the current study was to identify the most cost-effective set of transmission facilities required to integrate the LP&L transmission network, resources and customer demand into the ERCOT grid while satisfying ERCOT and NERC Transmission Planning reliability standards.

This study scope was not designed to produce a determinative recommendation as to whether the PUCT should or should not approve the LP&L request to integrate assets into ERCOT. Instead the scope is based on the assumption that the specified assets must be integrated into ERCOT.

The study scope and approach was presented to the ERCOT Regional Planning Group (RPG) at the December 2015 meeting for stakeholder comment and review. ERCOT also considered transmission solutions proposed in the Lubbock Power & Light ERCOT Integration Plan issued on September 24, 2014 by Sharyland Utilities, transmission interconnection options detailed within the Lubbock Power & Light ERCOT Integration Study issued on December 9, 2015 by LP&L, and the findings of previous studies published by ERCOT, including the Panhandle Renewable Energy Zone Study Report issued in April 2014 and ERCOT Long-Term System Assessment (LTSA) reports.

3. Assumptions, Criteria and Methodology

ERCOT performed studies under various assumed system conditions to evaluate reliability requirements and to find a robust and cost-effective transmission expansion option to integrate LP&L into the ERCOT System. The assumptions, methodology, and criteria for this study are described in this section and are consistent with the ERCOT Planning Guide, ERCOT Protocols, and NERC Reliability Standards.

3.1. Assumptions

This study was performed using existing ERCOT models plus additions and/or modifications and cost estimates provided by relevant Transmission Service Providers (TSPs) and/or owners of generating units. The final models and cost estimates were reviewed, modified if necessary, and then adopted by ERCOT.

3.1.1. Background

The 2021 study year was selected to account for the current expected timeline for integration of LP&L into the ERCOT region with the potential for schedule delays and resulting growth in customer demand. LP&L provided two peak customer demand forecasts for the portion of the LP&L load that is being considered for integration into the ERCOT System: a “Business as Usual (BAU)” peak load forecast of 466 MW and a “High Growth” peak load forecast of 593.5 MW. LP&L currently has two separate distribution systems serving the residents of Lubbock. Only one of these two systems is being considered for integration into ERCOT. As such, there is an additional 170 MW of peak load served by LP&L that is not included in this analysis.

To be consistent with the ERCOT Integration Study published by LP&L in December 2015, this study assumes that a portion of the 69 kV LP&L transmission network will be converted to 115 kV leaving only 200 MW of load served by the existing 69 kV LP&L network.

3.1.2. Steady-State

There were two study cases created for the steady-state portion of this study. The first was created from the 2015 Regional Transmission Planning (RTP) 2021 Summer Peak base West Far-West case (15RTP_2021_SUM1_WFW_11092015). The second was created from the 2015 RTP 2018 High Wind Low Load (HWLL) base case (15RTP_2018_HWLL_11092015). The 2018 HWLL case was selected since it was the most recently updated HWLL case and represented a year nearest the year LP&L could be integrated into ERCOT. Both of the ERCOT 2015 RTP base cases were constructed according to the 2015 RTP Study Scope and Process.[1]

Lubbock provided two base cases for this study. The first represented a 2021 High Load Scenario (LPL_System_Scenario2_High-Load) and contained a total LP&L load of 593.5 MW along with 130 MW of internal Lubbock generation. The second represented a 2021 Low Load Scenario (LPL_System_Scenario2_Low-Load) and contained a total LP&L load of 399 MW along with 130 MW of internal Lubbock generation. Lubbock also provided a list of relevant contingencies for these cases consistent with contingency definitions in NERC TPL-001-4.

To create the 2021 Summer Peak Lubbock Load Integration Study Case (2021 Summer Peak Study Case), the 2015 RTP 2021 Summer Peak WFW Base Case was combined with the LP&L 2021 High Load Scenario Case.

[1] https://mis.ercot.com/pps/tibco/mis/Pages/Reports/PlanningReports

To create the 2021 High Wind Low Load Lubbock Load Integration Study Case (2021 HWLL Study Case), the 2015 RTP 2018 High Wind Low Load (HWLL) base case was combined with the LP&L 2021 Low Load Scenario. The Panhandle Loop project endorsed by the ERCOT Board of Directors on December 8, 2015 was added to both of these study cases, including the second 345 kV circuit on the Alibates to Tule Canyon 345 kV loop, one 150 MVar synchronous condenser at Alibates, and one 150 MVar synchronous condenser at Tule Canyon.

In the modeling analysis, the ERCOT and LP&L grids were connected using 345/115 kV transformers and various 345 kV transmission tie line options. Impedances for the 345/115 kV transformers and all transmission facilities internal to Lubbock were provided by LP&L. The 345 kV transmission line impedances, ratings, and capital cost assumptions were based on the recently completed White River to Abernathy 345 kV transmission line due to its close proximity to the City of Lubbock. In most cases, ERCOT adopted 345 kV line length estimates presented in the LP&L ERCOT Integration Study for proposed 345 kV ERCOT-LP&L tie lines.

The list of future generating units included in the Study Cases was updated in accordance with the model building requirements in ERCOT Planning Guide Section 6.9. The maximum dispatch for individual renewable generators was restricted per Section 3.2 and 3.4 of the 2015 RTP Study Scope and Process. Table 3.1 shows the list of proposed generators that were added to the study cases as a result.

Table 3.1: Generating Units Added to Study Region

GINR Reference Number	Project Name	County	Fuel	MW For Grid
12INR0059b	Barilla Solar 1B	Pecos	SOLAR	7
15INR0036	Downie Ranch Solar	Uvalde	SOLAR	95
11INR0079a	Shannon Wind	Clay	WIND	200
13INR0028	Antelope & Elk 1	Hale	GAS	369
15INR0032	Elk 2	Hale	GAS	202
15INR0033	Elk 3	Hale	GAS	202
14INR0025b	South Plains II Phase a	Floyd	WIND	152
14INR0025c	South Plains II Phase b	Floyd	WIND	148
14INR0066	Lamar Power Upgrade	Lamar	GAS	130
16INR0048	RE Roserock Solar	Pecos	SOLAR	160
08INR0018	Gunsight Mt W	Howard	WIND	120
15INR0074	Happy Whiteface W	Deaf Smith	WIND	157
16INR0052	Solara Solar	Haskell	SOLAR	110
14INR0047	Wake Wind	Dickens	WIND	300
15INR0070_1	West Texas Solar	Pecos	SOLAR	110
16INR0062	Electra Wind	Wilbarger	WIND	360
15INR0045	Riggins Solar	Pecos	SOLAR	150
13INR0010b	Mariah Del Norte	Parmer	WIND	230
11INR0082a	Val Verde Wind	Val Verde	WIND	180
16INR0037	Blanco Canyon Wind 1	Floyd	WIND	50
16INR0037b	Blanco Canyon Wind 2	Floyd	WIND	150
13INR0005b	Colbeck's Corner W	Carson	WIND	200
16INR0073	East Pecos Solar	Pecos	SOLAR	100
13INR0005c	Grandview W 3	Carson	WIND	188
14INR0023b	Longhorn South	Briscoe	WIND	160
16INR0087	RTS Wind	McCulloch	WIND	200
14INR0062	Salt Fork 1 Wind	Gray	WIND	200
16INR0065	SP-TX-12	Upton	SOLAR	180
13INR0038	Swisher Wind	Swisher	WIND	300
13INR0010a	Mariah Del Este	Parmer	WIND	139
13INR0010c	Mariah Del Sur	Parmer	WIND	230
15INR0059	Pecos Solar I	Pecos	SOLAR	108

3.1.3. Weighted Short-Circuit Ratio

Maintaining a Weighted Short-Circuit Ratio (WSCR) greater than or equal to 1.5 under normal system conditions is recommended for Panhandle system strength and stability based on previous detailed studies of the region.

The WSCR is an index based on short circuit levels for the strength of a cluster of buses. If generation output in the Panhandle were to be sufficiently high such that the WSCR were to fall below 1.5, it could lead to control system instability in the Panhandle region under contingency conditions. WSCR is defined as:

$$WSCR = \frac{\sum_{i}^{N}(S_{SCMVAi} * P_{RMWi})}{(\sum_{i}^{N} P_{RMWi})^2}$$

Where S_{SCMVAi} is the short circuit capacity at bus *i* before the connection of wind plants. P_{RMWi} is the MW dispatch of wind plant connected to bus *i*. and *N* is the number of buses of a cluster.

The substations in the Panhandle and associated wind generation capacities included in the WSCR calculation are summarized in Table 3.2.

Table 3.2: Panhandle Wind Generation by Transmission Station

Panhandle Transmission Station	Wind Generation Capacity (MW)
Cottonwood	299.25
White River	701.60
Tule Canyon	509.85
Ogallala	299.48
Windmill	1256.00
AJ Swope	354.95
Alibates	751.44
Railhead	400.00
Gray	488.60
Total	**5061.17**

The following assumptions were used in the WSCR calculation:

- Conventional generating units in Lubbock and West Texas were de-committed to simulate the most stressed system condition from a voltage stability and system strength perspective
- All existing series capacitors in West Texas were modeled as in-service
- The Panhandle output limit based on the WSCR calculation was determined by proportionally reducing the output with respect to the capacity of all Panhandle wind generating units

3.1.4. Economic

Total capital costs and annual production costs were estimated for various interconnection options based on the assumptions described in this section.

3.1.4.1. Capital Costs

Total capital costs for the transmission elements were based on estimates shown in Table 3.3.

Table 3.3: Capital Cost Assumptions

Item	Cost	Unit
345 kV Double Line on Double Ckt Structure	$ 1,840,000	$/mi
345 kV Single Line on Double Ckt Structure	$ 1,660,000	$/mi
345 kV Add 2nd Line to Double Ckt Structure	$ 350,000	$/mi
345/115 kV 350 MVA Autotransformer	$ 6,000,000	1 Unit
115 kV Line	$ 1,600,000	$/mi
Land Acquisition new 345/115 kV Substation	$ 500,000	1 Unit
345 kV Substation - ring bus 6 - line terminals	$ 15,940,000	1 Unit
115 kV Substation - ring bus 6 - line terminals	$ 9,050,000	1 Unit
Cottonwood/LongDraw 1 345 kV terminal	$ 4,000,000	1 Unit
Cottonwood/LongDraw 2 345 kV terminals	$ 5,000,000	2 Units
Abernathy Expansion 1 345 kV terminal	$ 2,900,000	1 Unit
Abernathy Expansion 2 345 kV terminals	$ 4,600,000	2 Units
Abernathy Expansion 3 345 kV terminals	$ 10,700,000	3 Units
Ogallala Expansion 1 345 kV terminal	$ 1,800,000	1 Unit
Ogallala Expansion 2 345 kV terminals	$ 3,600,000	2 Units
White River Expansion 1 345 kV terminal	$ 1,800,000	1 Unit
Vealmoor Expansion 1 345 kV terminal	$ 3,800,000	1 Unit
Dermott Expansion 1 345 kV terminal	$ 700,000	1 Unit

3.1.4.2. Production Cost

The 2021 economic case built for the 2015 Regional Transmission Plan (RTP) was modified to create the study cases by including the LP&L system.

Generating units were added to match ERCOT's steady-state models (see Table 3.1). Economic data for LP&L units were provide by LP&L. The transmission topology for the production-cost modeling in and around LP&L was also modified to match the corresponding ERCOT steady-state cases.

3.1.5. Stability

The ERCOT Dynamic Working Group (DWG) Future Year 2018 High Wind Low Load dynamic dataset was used as the start case to develop the stability study case. The stability cases contained all existing and planned facilities in the study region, including reactive resources and control equipment. The automatic operation of these facilities designed to provide dynamic control of electrical system quantities were simulated in the study.

The following changes were made to the start case to create the study cases:

- Addition of the second circuit on the Panhandle loop: Alibates – AJ Swope – Windmill – Ogallala – Tule Canyon 345kV line
- Addition of 150 MVA of synchronous condensers connected at 345 kV at Alibates and Tule Canyon
- Addition of the LP&L transmission system consistent with the steady-state cases; LP&L system load modeled at approximately 593 MW to represent the high load growth scenario
- Wind generating units in the Panhandle and West Texas that meet Planning Guide Section 6.9 requirements were modeled in the study case
- Wind generating units in the Panhandle were dispatched at a uniform percentage of their capacity while maintaining a WSCR of 1.5 in the Panhandle
- Conventional generating units in West Texas and Panhandle were turned off

The total capacity of Panhandle wind generating units modeled in the stability study case was 5,061 MW. The total capacity of wind generating units modeled was 18,570 MW. The dynamic modeling parameters for both LP&L system generating units and load were provided by LP&L

3.2. Study Criteria

This section provides detail on the NERC and ERCOT Steady-State and Dynamics reliability criteria that were used to identify potential reliability violations for the various transmission interconnection options that were tested. It also describes how the ERCOT economic criteria were used to compare the options.

3.2.1. Steady-State Criteria

For the reliability analysis, the following thermal and voltage limits were enforced:

- Rate A under pre-contingency conditions for 60 kV and above transmission lines and for transformers with a low side voltage of 60 kV and above
- Rate B under post-contingency conditions for 60 kV and above transmission lines and for transformers with a low side voltage of 60 kV and above
- 0.95 p.u. voltage under pre-contingency conditions for 100 kV and above transmission lines and for transformers with a low side voltage of 100 kV and above
- 0.90 p.u. voltage under post-contingency conditions for 100 kV and above transmission lines and for transformers with a low side voltage of 100 kV and above

- 1.05 p.u. voltage under pre- and post-contingency conditions for 100 kV and above transmission lines and for transformers with a low side voltage of 100 kV and above

The Study Region monitored for this study was the combined ERCOT North, West and Far-West weather zones along with the LP&L network and all facilities proposed to interconnect LP&L with ERCOT. Certain thermal and voltage violations within the Study Region that were physically and electrically remote from the proposed 345 kV facilities to interconnect LP&L with ERCOT were deemed unrelated and ignored.

The following contingencies were simulated based on NERC TPL-001-4 and ERCOT Planning Criteria[2]:

- P0
- P1 and P7
- P3: G-1+N-1 only
- P6: X-1+N-1 and selected N-1-1 only
- P2, P4, and P5

For the G-1+N-1 contingencies, each generator within the study region was turned off (including applicable combined-cycle trains) followed by each N-1 contingency per ERCOT Planning Guide Section 4.1.1.1.

For the X-1+N-1 contingencies each 345/138 kV and 345/115 kV transformer within the Study Region was taken out of service followed by each N-1 contingency per ERCOT Planning Guide Section 4.1.1.1.

Selected N-1-1 contingencies were evaluated inside the Study Region.

3.2.2. Economic Criteria

The transmission interconnection option with the lowest total capital cost was identified and the incremental capital costs to construct each of the other options were calculated based on the difference between those options and the lowest capital cost option.

The first year annual revenue requirements for the higher cost options were estimated based on the incremental capital cost of each of those options and the most recent analysis of revenue requirements costs posted on the ERCOT Market Information System (MIS). The current 2016 financial assumptions indicate that the first year annual revenue requirement for a project is approximately 15% of the project capital cost.

The total annual system production cost of the transmission interconnection option with the lowest total capital cost was determined using a security-constrained economic dispatch hourly production cost model (UPlan). The relative annual production cost savings of each of the other options were calculated based on the difference between the total annual production cost of the lowest capital cost option and the total annual production cost of each of the higher capital cost options.

[2] http://www.ercot.com/content/wcm/current_guides/53526/04_050115.doc

If the relative annual production cost savings for a higher capital cost option exceeded the first year annual revenue requirement for that incremental cost, then that option was identified as having met the necessary economic criteria per ERCOT Protocols Section 3.11.2(5).

3.2.3. Dynamics Criteria

The following system performance requirements were utilized to assess the dynamic performance of the preferred option:

- NERC TPL-001-4 Requirements
- ERCOT Planning Criteria

Selected ERCOT transmission buses were monitored in dynamic simulations for frequency and voltage deviations. All generating units were monitored for angular separation. Relay actions recorded in the simulation log files were processed to summarize the operation of any relays that were included in the model (i.e. synchronous generators that were tripped due to machine angle swings in excess of 180 degrees, wind turbines tripped by voltage protection relays, etc.).

3.3. Study Methodology

The inputs described in the introduction to this study were reviewed as a first step to identifying transmission options to integrate LP&L. To meet the study objective, ERCOT elected to:

- Perform reliability assessments on selected options proposed by stakeholders
- Modify, simulate and assess other options proposed by stakeholders
- Evaluate the feasibility of ERCOT tie points that were not proposed by stakeholders
- Eliminate certain options proposed by stakeholders based on study criteria

3.3.1. Initial Considerations and Narrowing

A proposal to serve LP&L through an additional DC tie between ERCOT and SPP was deemed outside the scope of this study since the PUCT directed ERCOT to study the impacts of interconnecting LP&L into the ERCOT System.

Due to voltage stability and system strength issues in the Panhandle, ERCOT decided not to consider expanding the ERCOT network to reach the LP&L network with transmission voltages less than 345 kV. Only 345 kV tie points within ERCOT were considered in this analysis.

To minimize the risk of isolating the entire LP&L grid during maintenance outages followed by the next N-1 contingency, ERCOT decided to consider only those options that would integrate LP&L into the ERCOT System using three or more independent Rights-of-Way. This decision was also influenced by the magnitude of the imbalance between internal LP&L generation capacity and the projected peak LP&L load.

Previous ERCOT-LP&L integration studies included a sufficiently thorough examination of ERCOT 345 kV connection points located to the north, east and south of LP&L. Other ERCOT 345 kV

connection points to the northwest and southwest of those that had already been considered (including Spinning Spur, Windmill, Andrews or Midland) were deemed to be too distant from Lubbock to warrant further evaluation.

Transmission options proposed by stakeholders were grouped and compared to identify the simplest option within each grouping (typically the option that contained the least number of additional 345 kV lines). ERCOT also performed simulations to determine the minimum number of 345/115 kV transformers that would be necessary for each given option. Other options proposed by stakeholders were retained for reliability analysis based on their potential to both integrate LP&L into ERCOT as well as increase Panhandle export capability.

Some options proposed by stakeholders were based on outdated versions of the LP&L internal transmission expansion plan (one that included a 230 kV internal LP&L loop rather than a 115 kV loop). Those options were modified to be consistent with the most recent LP&L transmission expansion plan.

3.3.2. Modeling and Narrowing

Once a reduced set of transmission expansion options had been selected for further consideration, the options were modeled, evaluated and narrowed down further. The methodology included both reliability and economic assessments. The following is a high-level description of these steps.

1. The generation dispatch for each option was set by Security Constrained Optimal Power Flow
2. Each option was tested for compliance with P0, P1, P3, P6, and P7 ERCOT and NERC Steady-State reliability criteria
3. LP&L load serving capability was determined for each option
4. The WSCR Panhandle export limit was determined for each option
5. Total ERCOT annual production cost was determined for each option
6. The capital cost of each option was calculated
7. Options were narrowed further based on capital cost, production cost and ERCOT economic criteria
8. Each remaining option was tested for P2, P4 and P5 ERCOT and NERC steady-state reliability criteria
9. Final LP&L load serving capability was determined for the remaining options
10. An N-X system topology screening was performed to assess SSR Risk for the final options
11. Dynamic stability analysis was performed for the final option with ERCOT and NERC dynamic reliability criteria

4. Options Evaluation

The inputs described in the introduction to this study were reviewed as a first step to identifying transmission options to integrate LP&L into ERCOT. The initial considerations described in the Methodology section of this report were used to narrow options.

4.1. Initial Steady-State Results

As the studied options were either the same as options described in the LP&L Load Integration studies performed by LP&L or Sharyland or derived from those options, ERCOT retained the names that were originally assigned to those options but added either an “LPL” or “SHY” prefix to indicate the original option was included in the LP&L Study or the Sharyland Study. The results of the steady-state reliability analyses are provided in Appendix A, along with an explanation for any options that were not included in this analysis. The options are illustrated in the “Panhandle Interface and Limits” document attached in Appendix B.

4.2. Optimizing Options

For the options that met the initial steady-state reliability criteria, Panhandle export limits were calculated based on a WSCR criteria. Production cost models were also constructed for the remaining options using a Panhandle export limit equal to 90% of the calculated limit to allow for operating margins. Capital costs were calculated for the options that passed the initial steady-state reliability criteria and LPL Option 1 was identified as being the lowest capital cost option.

Initial production cost simulations of LPL Option 1 and several other options indicated significant congestion on the proposed 2.7-mile McKenzie-North 115 kV line in the LP&L network due certain N-1 contingencies. Based on these initial results, the modeled capacity of this proposed circuit was increased following consultation with LP&L personnel.

Initial production cost simulations also indicated congestion on the existing 3.1-mile McKenzie-Co-Op 69 kV line and the Holly-Wadsworth 115 kV line. As a result, the ratings of these lines were also increased following consultation with LP&L personnel. Capital costs for these LP&L upgrades were not included in the capital cost estimates for the LP&L integration options studied.

4.3. Impacts on the Panhandle System Strength and Export Limits

The impact of Lubbock integration on the system strength in the Panhandle region was evaluated by calculating the WSCR for the various options. The Panhandle export limit in the initial study case without LP&L and any of the associated integration options is 3765 MW based on a WSCR of 1.5. Tables 4.1 and 4.2 summarize the WSCR calculation results for the options studied.

Table 4.1 Lubbock Integration Impact on System Strength in the Panhandle

Case	Panhandle Wind Generation (MW)	WSCR
Base (without LP&L)	3765	1.501
Option 1	3765	1.555
Option 4	3765	1.624
Option 4ow	3765	1.691
Option 8A	3765	1.695
Option 8B	3765	1.605
Option 11	3765	1.612
Option 12	3765	1.566
Option 12c	3765	1.557
Option 20	3765	1.628
Option 1-2a	3765	1.559
Option 1-2b	3765	1.564

Table 4.2 Lubbock Integration Impact on System Strength in the Panhandle

Case	WSCR	Panhandle Export Limit (MW)
Base (without LP&L)	1.5	3765
Option 1	1.5	3902
Option 4	1.5	4074
Option 4ow	1.5	4246
Option 8A	1.5	4256
Option 8B	1.5	4029
Option 11	1.5	4044
Option 12	1.5	3928
Option 12c	1.5	3907
Option 20	1.5	4084
Option 1-2a	1.5	3912
Option 1-2b	1.5	3928

The definition of the Panhandle interface and the heat map of relative system strength in terms of short-circuit current for each integration option are described in the “Panhandle Interface and Limits” document attached in Appendix B. It should be noted that the interface identified in this report is based on the system conditions and generation projects included in the study case. The interface may need to be revised based on future system topology and generation additions in this region.

4.4. Economic Assessment

Table 4.3 shows the results of the economic assessment of the options that passed the reliability analyses, including total capital costs and relative annual production costs compared to LPL Option 1. The relative costs are expressed as negative numbers in cases where they are lower than the annual production cost of LPL Option 1 and as positive numbers in cases where they are higher than the annual production cost of LPL Option 1.

The results for the two options highlighted in yellow were deemed adequate to meet the economic criteria described in ERCOT Protocol 3.11.2(5). Based on these results, the final short-list of options included the lowest capital cost option (LPL Option 1) along with these two options (Options 4ow and

8B). When taking into account both capital costs and annual production costs, LPL Option 4ow had the lowest total societal cost.

Table 4.3: Cost Comparison for Options Selected for Economic Assessment

Case	Capital Cost Estimate	Relative Cost ($Million)		Relative Annual Production Cost Savings as % of Relative Capital Cost
		Capital	Production (Annual)	
LPL Option 1	$311,818,800	0	0	-
LPL Option 4	$344,443,600	+$32.6	-$0.3	0.9%
LPL Option 4ow	$364,081,400	+$52.3	-$11.3	21.6%
LPL Option 8A	$426,107,200	+$114.3	-$11.5	10.1%
LPL Option 8B	$338,096,600	+$26.3	-$5.2	19.8%
LPL Option 11	$492,368,200	+$180.5	-$5.7	3.2%
LPL Option 12	$397,751,918	+$85.9	-$3.5	4.1%
LPL Option 12c	$391,751,918	+$79.9	-$0.2	0.3%
LPL Option 20	$466,552,338	+$154.7	+$1.3	-0.8%
SHY Option 1-2a	$383,800,200	+$72.0	-$0.6	0.8%
SHY Option 1-2b	$365,076,200	+$53.3	-$0.8	1.5%

4.5. Load Deliverability

Simulations were performed to calculate 2021 Summer Peak LP&L Load serving capability based on thermal limits. The optimized cases were used and the load deliverability limits were calculated by:

- Scaling LP&L load up
- Scaling all generating units that had reserve capacity and were external to LP&L up while observing unit capacity limits
- Accounting for P0, P1 and P7 NERC contingency events
- Monitoring facilities in the Study Region but excluding:
  - Branches flowing less than 3% of the transfer amount
  - Thermal violations involving bus-tie contingent and/or monitored elements

Table 4.4 shows that all of the final short listed options accommodate the 593.5 MW High Load Growth Scenario with significant margin.

Table 4.4: Thermal Load Deliverability Test Results

Case	Load Deliverability	Limiting Element	Limiting Contingency
LPL Option 1	750 MW	NORTHWEST-NORTH 115 kV	MCKENZIE-NORTH 115 kV
LPL Option 4ow	860 MW	CO-OP2-MCCULLOUGHT1 69 kV	VICKSBURGE 115/69 kV
LPL Option 8B	857 MW	CO-OP2-MCCULLOUGHT1 69 kV	VICKSBURGE 115/69 kV

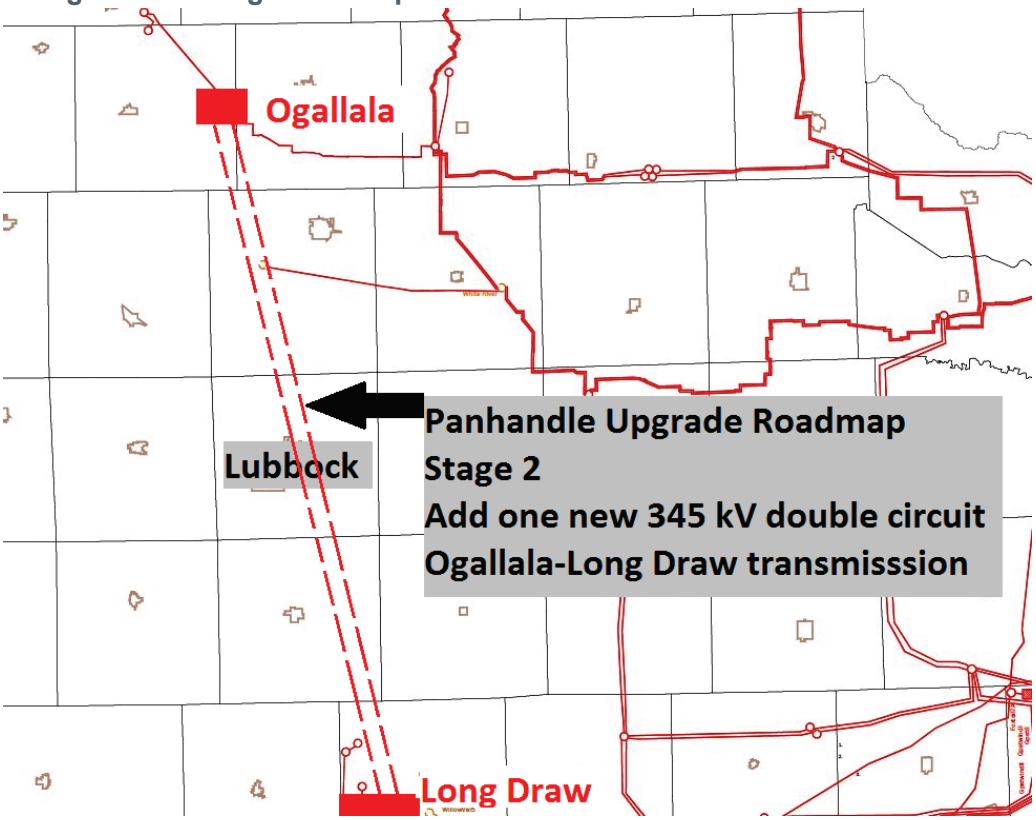
5. Selection of the Preferred Option

5.1. Alignment with 2014 Panhandle Roadmap

In April 2014, ERCOT published a report detailing a potential roadmap of future transmission system improvements to increase the export capability from the Panhandle as additional wind generation is developed in the area. Two sets of upgrades were associated with the Stage 1 improvements in that roadmap: the addition of a second circuit on the Alibates to Tule Canyon 345 kV loop; and the addition of two synchronous condensers in the Panhandle. In December 2015 the ERCOT Board of Directors endorsed the need for the addition of two synchronous condensers in the Panhandle, and Sharyland is currently pursuing regulatory approval of the Alibates to Tule Canyon 345 kV loop.

Stage 2 improvements described in the Panhandle study included additional synchronous condensers and the addition of a new 345 kV double circuit line from Ogallala to Long Draw (see Figure 5.1). Of the three final short-listed options in the current analysis, only LPL Option 4ow includes a 345 kV path that is electrically similar to what was contemplated in the Stage 2 upgrades from the April 2014 report. Specifically, LPL Option 4ow would create a 345 kV path from Ogallala to Long Draw with intervening connections at Abernathy, North, Wadsworth, and New Oliver (albeit a single-circuit connection whereas the Panhandle study indicated the likely need for a double-circuit). The alignment between LPL Option 4ow and potential future ERCOT system needs is consistent with the production cost savings noted for this option relative to LPL Option 1.

Figure 5.1: Ogallala to Long Draw Proposal



5.2. Expandability

ERCOT also considered the expandability of the final short-listed options. In alignment with the aforementioned Stage 2 upgrades from the April 2014 Panhandle report, ERCOT tested the addition of a second circuit on the newly constructed portion of the Ogallala to Long Draw 345 kV line. The addition of the second circuit increased the Panhandle export capability by 208 MW over that of LPL Option 4ow (to a limit of 4454 MW). Production cost simulation indicated that this alternative resulted in $14.3 million in annual production cost savings and was estimated to have $76.1 million in additional capital costs compared to LPL Option 1. These production cost results also indicated some congestion on the lower voltage lines internal to the LP&L System for the contingency loss of the double circuit 345 kV line between Wadsworth and New Oliver.

ERCOT also tested an expansion of LPL Option 4ow that would create a 345 kV loop around Lubbock. In this alternative, an approximately 16 mile 345 kV line was added between the North and New Oliver stations. This option was estimated to cost approximately $84.6 million more than LPL Option 1 and had a Panhandle export limit of 4413 MW. Production cost simulation results showed that this alternative would annually save $13.1 million compared to LPL Option 1. There was no congestion internal to the LP&L System observed in the simulation.

Both alternatives for expanding LPL Option 4ow meet the economic criteria in ERCOT Protocols Section 3.11.2(5). However, these expansion options can be evaluated through the Regional Planning Group review process at some future time after the Commission has decided whether to integrate the LP&L System into ERCOT. At that time, the cost-effectiveness of each of these expansion options can be compared to other system upgrade options, such as the addition of synchronous condensers in the Panhandle region. As such, ERCOT is not recommending these expanded alternatives to Option 4ow at this time.

5.3. Preferred Option

Based on the analysis detailed in this report, ERCOT prefers LPL Option 4ow for integrating the LP&L System into ERCOT for the following reasons:

- It meets applicable reliability criteria with significant margin for future load growth and/or local generation retirement;
- The additional cost compared to the lowest cost option is economically justified;
- It has the lowest societal cost when considering capital and production costs;
- It provides the largest increase in the Panhandle export capability of the final short-listed options;
- It aligns with the 2014 roadmap of future Panhandle upgrades and has identified potential expansion plans to accommodate future Panhandle generation; and
- It provides greater opportunities for future expansion.

5.4. Dynamic Stability Assessment

Dynamic stability analysis was performed to evaluate the performance of the preferred option (LPL Option 4ow) to ensure stable operation of the LP&L System and ERCOT System. The Panhandle wind generating units were dispatched to produce an aggregate 4246 MW, as shown in Table 5.1. Two system operating scenarios were evaluated to test the impact of LP&L generators, all in service or all out of service, as summarized in Table 5.1:

Table 5.1: Summary of Study Cases for Dynamic Stability Assessment

Case	LP&L generator status	LP&L loads (MW)	Panhandle Wind Output* (MW)	Panhandle Wind Dispatch Level (%)
1	offline	593	4246	83.9
2	online	593	4403	87.0

* Panhandle wind output was calculated based on the requirement of 1.5 WSCR

5.4.1. Dynamic Events

LP&L provided a list of 395 dynamic contingencies within the LP&L system. PV analysis was performed on these events to identify the most limiting events due to voltage instability or excessive low voltage conditions. Based on PV analysis results, 111 events within LP&L system were selected for dynamic simulations. In addition to events within LP&L system, 243 dynamic events outside of the LP&L system were tested to evaluate the dynamic performance of the ERCOT system.

A total of 354 dynamic events were simulated for each scenario with the preferred integration option. These events cover the NERC Category P1 through P7 contingencies and extreme events. The dynamic event definitions included the removal of all elements that the protection system and other automatic controls are expected to disconnect for each event.

5.4.2. Dynamic Simulation Results

Based on the performance requirements defined in NERC TPL-001-4 and the ERCOT Planning Guide, the integrated LP&L and ERCOT systems with LPL Option 4ow met the dynamic criteria for all simulated dynamic events. No cascading, voltage instability, uncontrolled islanding, or non-consequential load loss was observed for these events. LPL Option 4ow also met the ERCOT voltage recovery and power oscillation criteria for the simulated dynamic events.

Wind generation trips (less than 1000 MW) were observed in the simulations in some dynamic events. The tripped wind generation was observed outside of the Panhandle region and was caused by low voltage during and after clearing a fault.[3] For all studied events, post disturbance system frequency recovered within the range between 59.4 Hz and 60.4 Hz.

5.4.3. Sub-Synchronous Resonance (SSR) Assessment

Complete mechanical data for LP&L generators were not available at the time this study was completed; therefore, the SSR assessment was limited to a system topology check to identify the number of transmission outages required to have LP&L generators radially connect to series capacitors. With the preferred LPL Option 4ow, all LP&L units are 5 transmission circuit outages away from being fully radial to the series capacitor at Cross station on the 345 kV double circuit between

[3] ERCOT Nodal Operating Guide, section 2.9.1 Additional Voltage Ride-Through Requirements for Intermittent Renewable Resources

Tule Canyon and Tesla. Although this result indicates a potential for SSR impact to these units, LP&L has committed to implement measures (such as installation of Torsional Stress Relays or other recommended actions) to mitigate or protect these units against SSR risks if any are identified in a future SSR assessment.

5.5. Additional Requirements

5.5.1. LP&L Generation

ERCOT has determined that no generation interconnection studies will be required for the existing LP&L generating units that were included in this study if LP&L is integrated into the ERCOT region. However, the entities owning, operating and/or controlling those generating units will be required to comply with all ERCOT operating requirements for Generation Resources.

Mechanical data for LP&L generating units were not available at the time this study was completed to allow a detailed assessment of SSR risk. LP&L must submit these data to ERCOT as soon as they become available and LP&L must take sufficient measures to mitigate or protect the units against SSR risks if any are identified in a future SSR assessments.

5.5.2. Option 4ow Transmission Construction

The analysis of LPL Option 4ow presumes that the Abernathy-North and Abernathy-Wadsworth 345 kV transmission lines do not share common transmission towers. The 345 kV terminal points at Abernathy should be constructed such that no single circuit breaker failure can result in the simultaneous outage of the Abernathy-North and Abernathy-Wadsworth 345 kV transmission lines and no single circuit breaker failure can result in the simultaneous outage of the Abernathy-Ogallala and Abernathy-White River 345 kV transmission lines.

LP&L has not yet constructed the North-McKenzie 115 kV transmission line that was included in this study. The economic studies indicate that greater economic benefit will occur if this line is constructed with a higher rating than initially proposed by LP&L.

6. Conclusion and Recommendation

The results of the analysis described in this report showed that all options with at least three independent paths to serve the LP&L System meet ERCOT reliability criteria with sufficient margin for future load growth. The selection of a preferred option from among the remaining viable alternatives was based on an analysis of the relative cost-effectiveness of each option. Using the lowest capital cost option (LPL Option 1) as a reference, ERCOT performed production cost simulations to determine if the additional capital cost of higher cost options could be economically justified per ERCOT Protocols Section 3.11.2(5).

The production cost simulation results showed that two options (LPL Option 4ow and LPL Option 8B) resulted in annual production cost savings sufficient to justify the increase in capital cost compared to the lowest cost option. ERCOT observed that the primary benefit of these options compared to the lowest cost option was the production cost savings that resulted from increasing the Panhandle export capability. The selected option is electrically similar to a project identified in a previous study as a potential system upgrade in the event that wind generation continues to be developed in the Panhandle region. Of the three final options, LPL Option 4ow had the lowest societal cost when considering both capital costs and annual production cost.

ERCOT also analyzed two alternatives for the expansion of LPL Option 4ow. Although both of these alternatives meet the economic criteria in ERCOT Protocols Section 3.11.2(5), ERCOT is not recommending either alternative at this time. If the decision is made to integrate the LP&L System into the ERCOT region, these alternatives can be examined through the Regional Planning Group review process.

Throughout the study process, ERCOT staff communicated on study progress at monthly Regional Planning Group meetings. Several stakeholders at these meetings suggested that ERCOT quantify the benefits of LP&L integration to the ERCOT System. Although this report does not present a complete assessment of the system benefits, one benefit that is clear is that implementation of the selected option will increase the current export limit from the Panhandle region from 3765 MW to 4246 MW—an increase of 481 MW. At the start of this study there were 5061 MW of existing or committed wind generation in the Panhandle, and as of the date of this report, an additional 200 MW of wind generation in the Panhandle had committed to project construction.

7. Facility End Points

Table 7.1 shows new facilities required to integrate the LP&L System into ERCOT along with the owner(s) of the end point(s) of those facilities:

Table 7.1: New Facility End Points

New Facility	Owner End Point 1	Owner End Point 2
345kV Ogallala - Abernathy single circuit line	Sharyland	Sharyland
345kV Abernathy - North Station single circuit line	Sharyland	New Substation
345kV Abernathy - Wadsworth single circuit line	Sharyland	Lubbock Power & Light
345kV New Oliver - Wadsworth single circuit line	New Substation	Lubbock Power & Light
345kVSLU_Station - Oliver_New single circuit line	Sharyland	New Substation
345/115kV North Station Transformers	New Substation	New Substation
345/115kV Wadsworth Transformers	Lubbock Power & Light	Lubbock Power & Light
345/115kV Oliver_New Transformers	New Substation	New Substation
115kV Oliver_New - Oliver single circuit line	New Substation	Lubbock Power & Light
115kV Oliver_New - Chalker single circuit line	New Substation	Lubbock Power & Light

8. Appendices

Appendix A: Results from Steady-State Analysis	Steady_State_Results.xlsx
Appendix B: Panhandle Interface Limits	Panhandle Interface and Limits