# Long-Term West Texas Export Study

January 2022

# Document Revisions

| Date | Version | Description | Author(s) |
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| January 14, 2022 | 1.0 | Final | Jameson Haesler, Megan Miller, Ehsan Rehman, Priya Ramasubbu |
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# Executive Summary

Significant amounts of Inverter-Based Resources (IBR), primarily wind and solar generation, have been connected to the ERCOT system, with more than 67 GW of IBRs planned to be operational by 2023. Nearly 60%, or over 38 GW, of that IBR capacity is planned for West Texas – more than double the designed capacity for the Competitive Renewable Energy Zone (CREZ) projects.

IBRs in West Texas are far from electrical demand centers located in metropolitan areas such as Dallas-Fort Worth, Houston, Austin, and San Antonio (Figure 1). The existing transmission system may not be sufficient to accommodate large-scale, long-distance power transfers from West Texas to those electrical demand centers under high renewable output conditions. Generation curtailment has been necessary to constrain flows across the interface in real-time operations and may continue to be necessary to maintain stability and a reliable transfer level on the existing system. In October 2020, a Generic Transmission Constraint (GTC) was established in real-time operations to address wide-area instability challenges associated with large power transfers from West Texas.

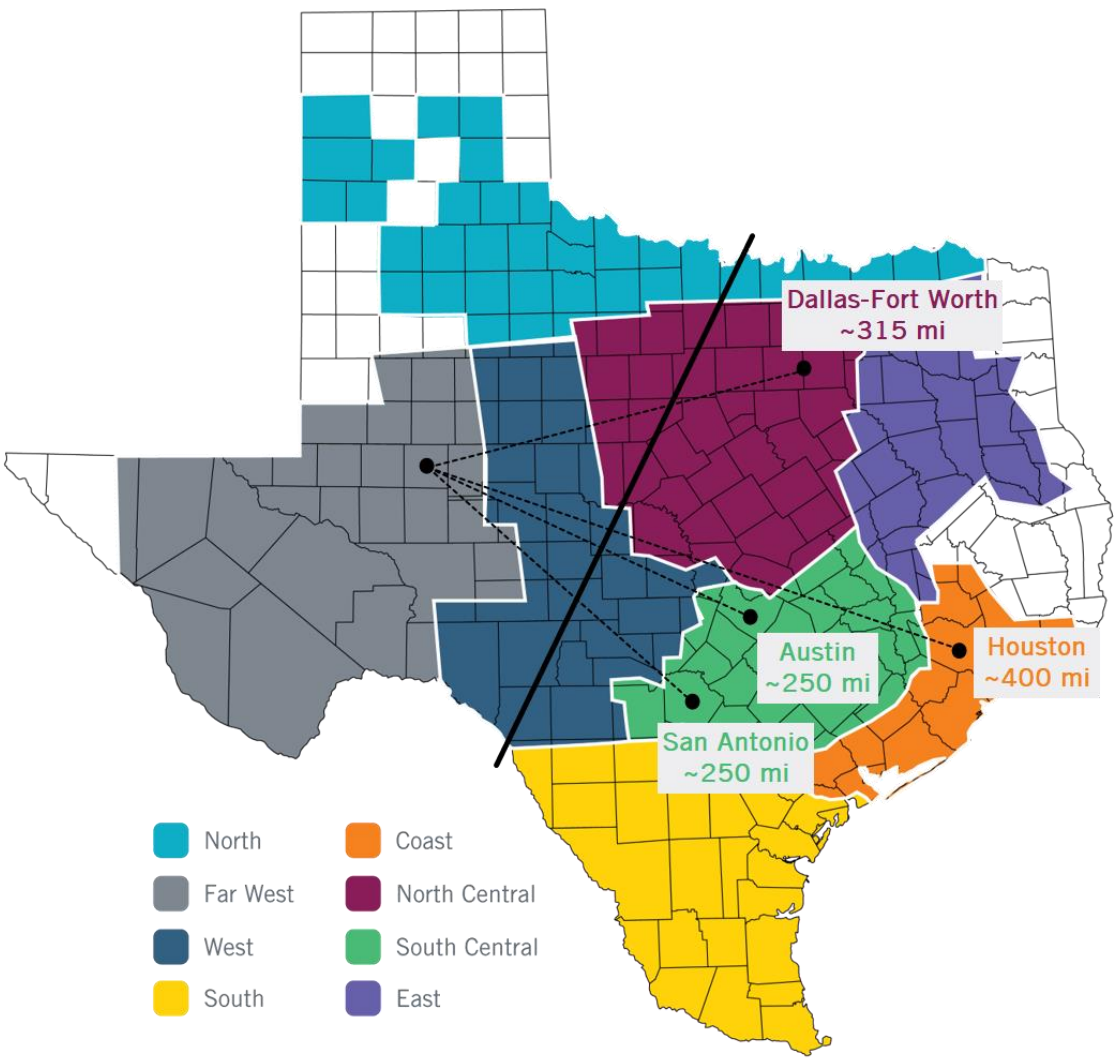


*Figure 1: Approximate Distances from West Texas to Electrical Demand Centers*

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ERCOT initiated the Long-Term West Texas Export Study in late 2020 with the following objectives:

- identify potential cost-effective long-term transmission improvement options, tailored to future system load and generation trends, that alleviate the West Texas export constraint
- maximize the realized benefits of increased transfer limits by addressing downstream constraints
- improve operational flexibility and resilience

The Long-Term West Texas Export Study represents a comprehensive, integrated transmission planning assessment incorporating parallel and iterative reliability and economic analyses to identify potential transmission improvements to alleviate the West Texas export constraint. Assumed system conditions for study years 2023 and 2030 were evaluated to identify short-term and long-term system needs. Many transmission improvement options, including various technologies and locations, were evaluated over the course of the study. ERCOT solicited stakeholder feedback throughout the study via updates provided at Regional Planning Group meetings. ERCOT also worked with relevant Transmission Service Providers (TSP) to obtain detailed feedback and cost estimates for short-listed transmission improvement options.

ERCOT identified the following key findings based on the results of the study:

1. The West Texas export interface is expected to become one of the top system constraints by 2023 as a result of continued growth of IBRs in West Texas.
2. New transfer pathways are essential to effectively improve the West Texas export transfer limit. Additional reactive support alone is not sufficient.
3. Technologies beyond typical 345-kV circuit additions are needed to effectively improve the West Texas export limit.
4. Holistic solutions addressing both the West Texas export limit and constraints closer to electrical demand centers are required to accommodate large-scale generation transfers.
5. The identified improvement options are expected to reduce curtailment but not necessarily allow full output of all IBRs under all system conditions, including peak demand months.

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Figure 2 shows two preferred, short-listed options which effectively increased the transfer across the West Texas export interface, reduced West Texas wind and solar curtailment, and delivered transferred power to electrical demand centers.

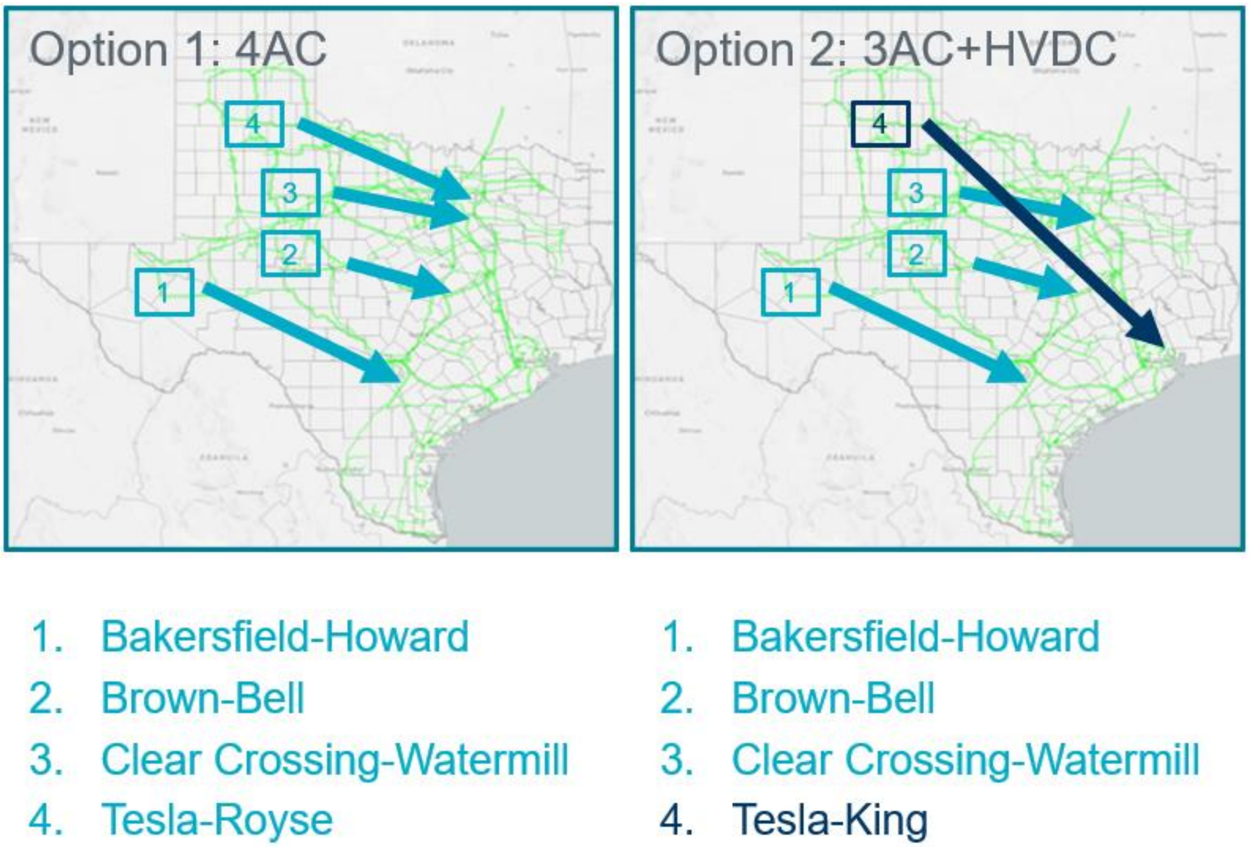


*Figure 2: Short-Listed Improvement Options*[1]

Table 1 highlights key reliability and economic results of the two short-listed options. Both options increased the calculated voltage stability limit by approximately 35%. In the 2030 study case, approximately $140M of additional production-cost savings resulted from Option 2 as compared with Option 1, highlighting the benefits of a holistic approach considering downstream constraints in tandem with the West Texas export constraint.

[1] Teal represents low-impedance 345-kV technology, while dark blue represents 1.5 GW HVDC technology.

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*Table 1: Reliability and Economic Results Summary*

| Improvement Option | Steady-State Voltage Stability Limit[2] (GW) | | Estimated New Double-Circuit Miles[3] | Production-Cost Savings ($M) | | TSP Cost Estimate ($M)[4] |
|---|---|---|---|---|---|---|
| | 2023 | 2030 | | 2023 | 2030 | |
| Base Case | 12.24 | 13.75 | - | - | - | - |
| Option 1 (4AC) | 16.46 | 18.35 | 1,009 | 135 | 642 | 2,738 |
| Option 2 (3AC+HVDC) | 16.49 | 18.78 | 1,274 | 170 | 783 | 5,203 |

Table 2 shows that while the two short-listed options do not fully resolve West Texas curtailment or the interface constraints, they are expected to provide consistent and notable system benefits. Both short-listed options resulted in significant reductions in congestion on the West Texas export interface and West Texas wind and solar generation curtailment. Option 2 also resulted in reduced congestion on the North-to-Houston interface.

*Table 2: Additional 2030 Results Summary*

| Improvement Option | West Texas Wind and Solar Curtailment (%) | West Texas Interface % of Year Binding | North-to-Houston Interface % of Year Binding |
|---|---|---|---|
| Base Case | 28.4 | 52.4 | 74.5 |
| Option 1 (4AC) | 19.3 | 43.5 | 76.8 |
| Option 2 (3AC+HVDC) | 18.7 | 40.0 | 59.9 |

Moving forward, ERCOT will continue to evaluate system needs associated with the West Texas export constraint and coordinate with TSPs to identify transmission improvements following applicable planning criteria, including new and updated criteria resulting from ongoing discussions at the Public Utility Commission of Texas (PUCT) and ERCOT stakeholder groups. Ongoing evaluation will include continued consideration of new transmission technologies and endpoints for potential transmission improvements to determine the most effective approach for maximizing system benefits.

[2] Limits used in economic analysis were 90% of calculated stability limits to be consistent with the ERCOT Transmission and Security Operating Procedure.

[3] A mileage adder of 30% was applied to each circuit's straight-line distance.

[4] The HVDC cost estimate portion of Option 2 is for monopole, 525-kV technology.

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# 1. Introduction

Significant amounts of Inverter-Based Resources (IBR), primarily wind and solar generation, have been connected to the ERCOT system. Continued robust growth of IBRs is expected based on interconnection requests in the ERCOT region[5]. As of December 2021, more than 67 GW of IBRs are planned to be operational on the ERCOT system by 2023. Of that 67 GW, nearly 60%, or over 38 GW are planned for West Texas – more than double the designed capacity for the Competitive Renewable Energy Zone (CREZ) projects. IBRs in West Texas are far from electrical demand centers located in metropolitan areas such as Dallas-Fort Worth, Houston, Austin, and San Antonio.

In October 2020, a Generic Transmission Constraint (GTC) was established in real-time operations to address wide-area instability challenges associated with large power transfers from West Texas. The West Texas Export (WTX) GTC (illustrated by the orange line in Figure 3) is used to monitor flows on the sixteen existing major West Texas export 345-kV circuits that define the West Texas export interface and control those flows using market-based mechanisms to maintain stability in real-time operations. The West Texas export interface consists of:

- Riley – Krum West Switch 345-kV Double-Circuit Line
- Jacksboro Switching – Willow Creek Switch and Jacksboro Switching – Henderson Ranch Switch 345-kV Double-Circuit Line
- Graham SES – Parker Switch 345-kV Double-Circuit Line
- Clear Crossing – Willow Creek Switch 345-kV Double-Circuit Line
- West Shackelford Station – Sam Switch and West Shackelford Station – Navarro 345-kV Double-Circuit Line
- Brown Switch – Killeen Switch 345-kV Double-Circuit Line
- Big Hill – Kendall 345-kV Double-Circuit Line
- Jacksboro Switching – Krum West Switch 345-kV Single-Circuit Line
- Comanche Switch – Comanche Peak SES 345-kV Single-Circuit Line

[5] Monthly Generator Interconnection Status Reports can be found at https://www.ercot.com/gridinfo/resource.

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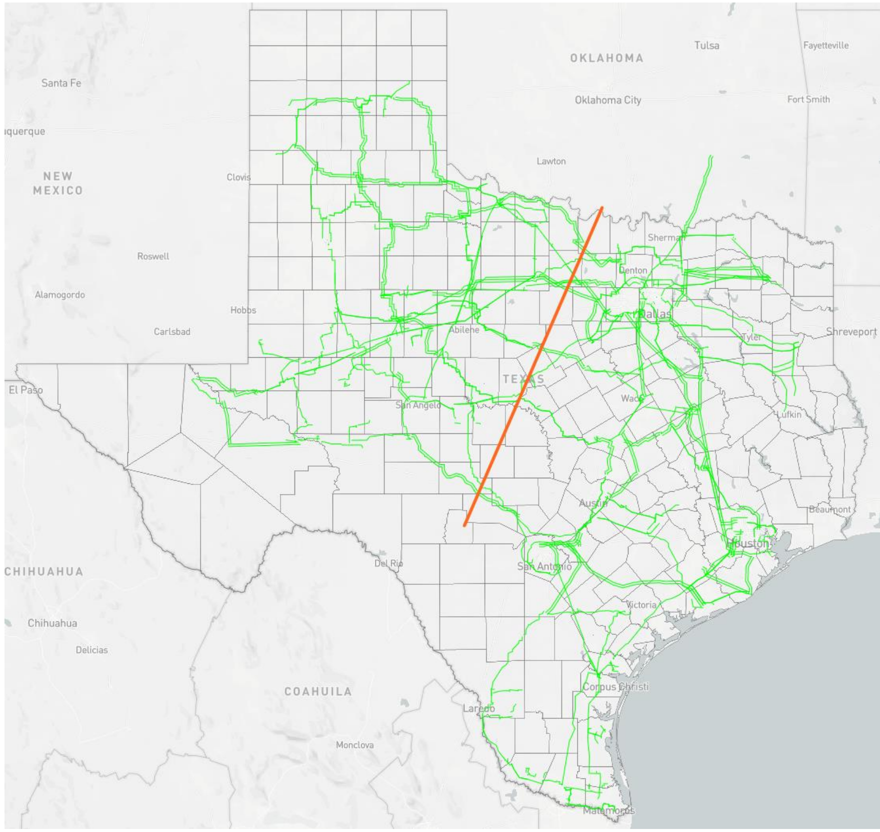


*Figure 3: Approximate West Texas Export Interface (for Illustrative Purposes Only)*

With further growth of IBRs in West Texas, the West Texas export stability constraint is projected to be one of the top constraints on the ERCOT system and could lead to significant amounts of generation curtailment and high transmission congestion in real-time operations. The existing transmission system may not be sufficient to accommodate large-scale, long-distance power transfers from West Texas to those electrical demand centers under high renewable output conditions. Generation curtailment has been necessary to constrain flows across the interface in real-time operations and may continue to be necessary to maintain stability and a reliable transfer level on the existing system.

ERCOT initiated the Long-Term West Texas Export Study in late 2020 with the following objectives:

- identify potential cost-effective long-term transmission improvement options, tailored to future system load and generation trends, that alleviate the West Texas export constraint
- maximize the realized benefits of increased transfer limits by addressing downstream constraints
- improve operational flexibility and resilience

The Long-Term West Texas Export Study represents a comprehensive, integrated transmission planning assessment incorporating parallel and iterative reliability and economic analyses to identify potential transmission improvements to alleviate the West Texas export constraint. Assumed system conditions for study years 2023 and 2030 were evaluated to identify short-term and long-term system needs. Many transmission improvement options, including various technologies and locations, were evaluated over the course of the study. ERCOT solicited stakeholder feedback throughout the study

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via updates provided at Regional Planning Group (RPG) meetings. ERCOT also worked with relevant Transmission Service Providers (TSP) to obtain detailed feedback and cost estimates for short-listed transmission improvement options.

This report summarizes the key findings, next steps, study assumptions, methodology, and reliability and economic results of ERCOT's study. The findings identified in this study are intended to provide a better understanding of system needs that can be incorporated into future planning studies following applicable planning criteria, including new and updated criteria resulting from ongoing discussions at the Public Utility Commission of Texas (PUCT) and ERCOT stakeholder groups.

## 2. Key Findings

ERCOT identified the following key findings based on the results of the analyses that went into this study:

1. The West Texas export interface is expected to become one of the top system constraints by 2023 as a result of continued growth of IBRs in West Texas.
2. New transfer pathways are essential to effectively improve the West Texas export transfer limit. Additional reactive support alone is not sufficient.
3. Technologies beyond typical 345-kV circuit additions are needed to effectively improve the West Texas export limit.
4. Holistic solutions addressing both the West Texas export limit and constraints closer to electrical demand centers are required to accommodate large-scale generation transfers.
5. The identified improvement options are expected to reduce curtailment but not necessarily allow full output of all IBRs under all system conditions, including peak demand months.

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### Key Finding 1: The West Texas export interface is expected to become one of the top system constraints by 2023 as a result of continued growth of IBRs in West Texas.

As shown in Figure 4, the historical flow across the West Texas export interface has increased in magnitude along with the continued growth of IBRs in West Texas. Increased frequency of high flows across the interface was observed across all months in 2021, coinciding with a 150% increase in installed solar capacity from 2020 to 2021. Significant growth is expected to continue for all IBR technology types, as illustrated in Figure 5.

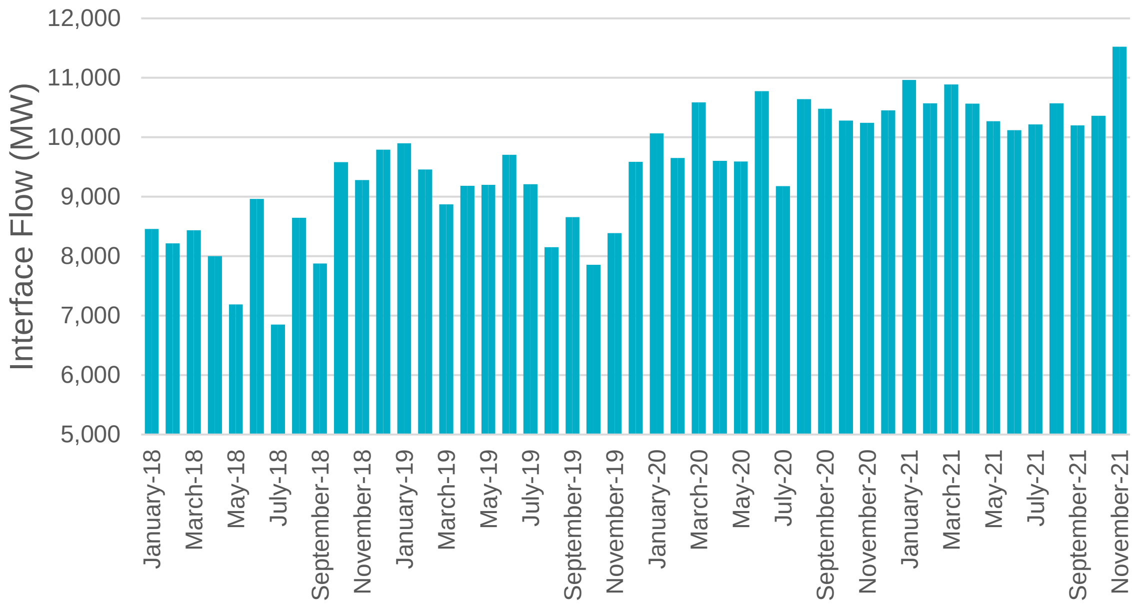


*Figure 4: Highest Monthly Flow on the West Texas Export Interface*


*Figure 5: IBR System Totals (Actual and Planned)*[6]

[6] Totals for 2022 and 2023 include projects with signed Interconnection Agreements (IA).

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Figure 6 shows additional system trends including locations of the planned IBR generation (right). While IBR interconnection requests on the east side of the West Texas export interface are increasing, the bulk of requests are still west of the interface. Additionally, retirements of older thermal generation units (center) closer to growing eastern electrical demand centers (left) are expected to continue.

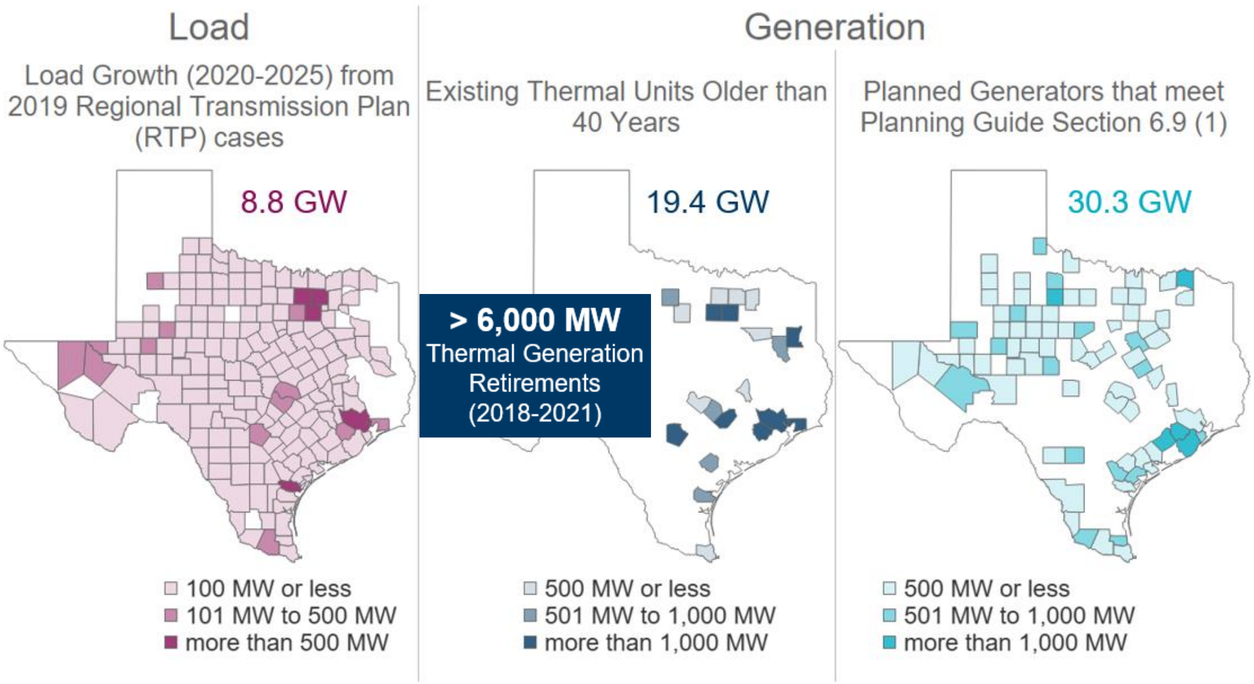


*Figure 6: ERCOT System Load and Generation Trends*[7]

As an increasing portion of system demand is served by western renewables, the West Texas export interface is expected to be more constrained. Figure 7 shows the annual loading of the interface observed for the 2023 and 2030 base cases. The aforementioned system trends resulted in the West Texas export interface binding approximately 20% of the time in study year 2023 and 50% of the time in study year 2030. East-to-west flow across the interface was observed approximately 10% and 2% of the time in the 2023 and 2030 study years, respectively. This flow generally occurs during off-peak hours (i.e., hours with little or no solar generation output) to serve industrial and oil and gas loads in Far West Texas. The decrease in reverse flow observed for the 2030 study year compared to the 2023 study year is attributable to the large increase in wind units included in the 2030 base case. Wind units in the Far West region typically reach maximum output in off-peak timeframes and therefore increase the number of hours that load is served by local generation.

[7] Existing thermal unit capacities are from the final Fall 2021 Seasonal Assessment of Resource Adequacy (SARA) report, and planned generation capacities are from the August 2021 Generation Interconnection Status (GIS) report.

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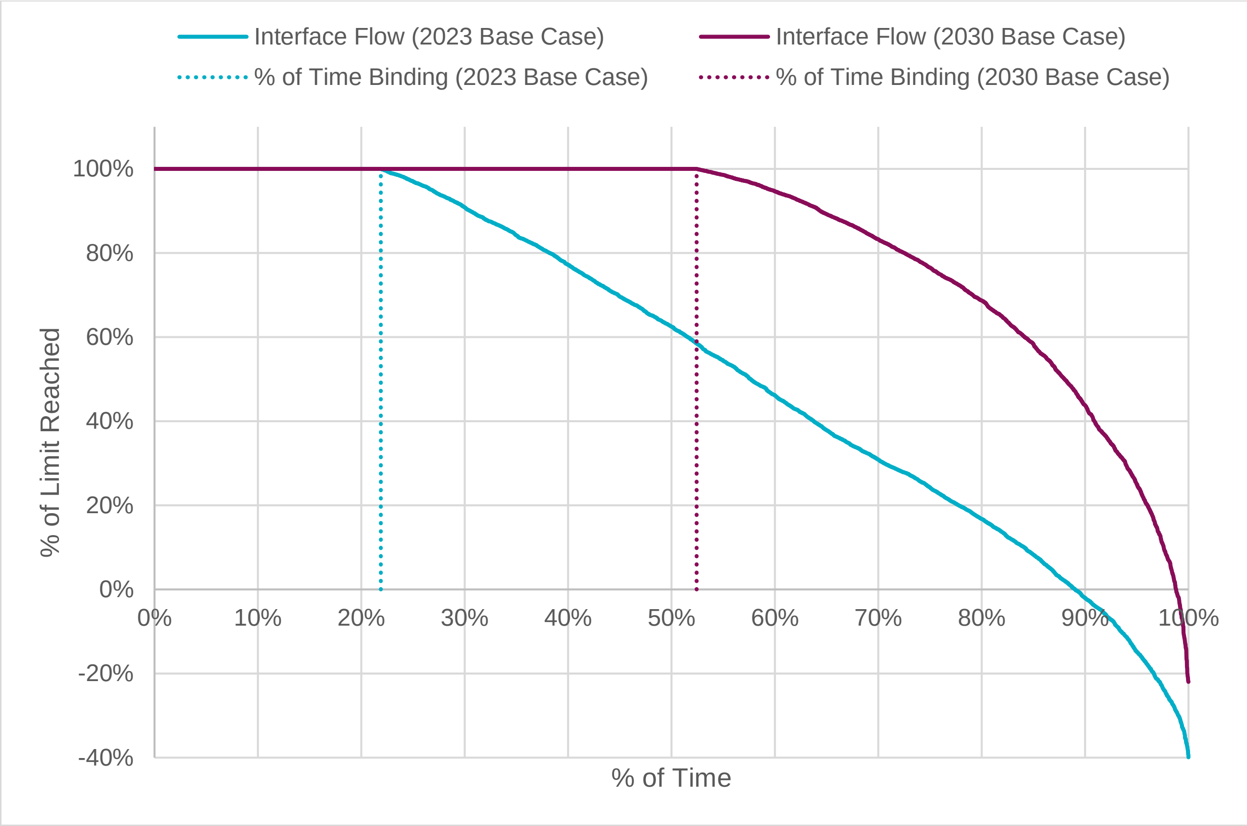


*Figure 7: West Texas Export Interface Flow-Duration Curves*[8,9,10]

When the interface binds, generation behind it is curtailed. Figure 8 shows annual, aggregated West Texas curtailment in the 2030 base case compared to the 2023 base case. The 2023 base case resulted in approximately 6,700 GWh of wind and solar curtailment behind the West Texas export interface, while 2030 resulted in ten times the amount of curtailment, or approximately 67,000 GWh.

[8] All flow duration curves in this report use data from the UPLAN economic study cases. The limits used in UPLAN were 90% of calculated stability limits, consistent with the ERCOT Transmission and Security Operating Procedure.

[9] Negative values represent reverse flow (east-to-west) across the interface.

[10] All study results are based on the assumed system conditions in the study base cases. Actual congestion and generation curtailment will be subject to system conditions and generation additions that may differ from the assumptions used for this study.

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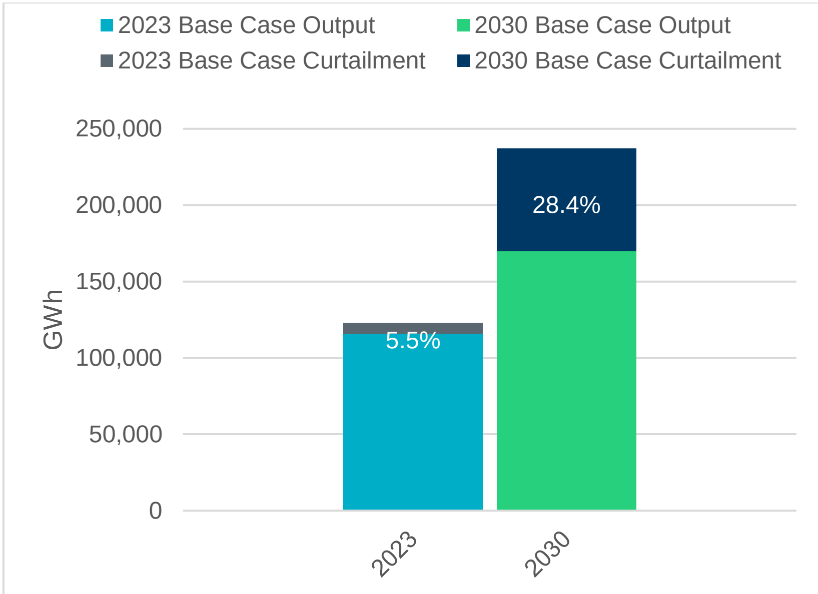


*Figure 8: Annual Wind and Solar Output and Curtailment in West Texas*

Figure 9 shows the resulting curtailment, by county, for study years 2023 (left) and 2030 (right). In the 2023 base case, 18 West Texas counties experienced at least 100,000 MWh of annual curtailed wind and solar generation, with a maximum annual curtailment amount of just over 1,000,000 MWh in Pecos County. Curtailment increased in both magnitude and scope in the 2030 base case with 49 West Texas counties experiencing at least 100,000 MWh of annual curtailed wind and solar generation, with a maximum annual curtailment of just over 9,000,000 MWh in Wilbarger county.

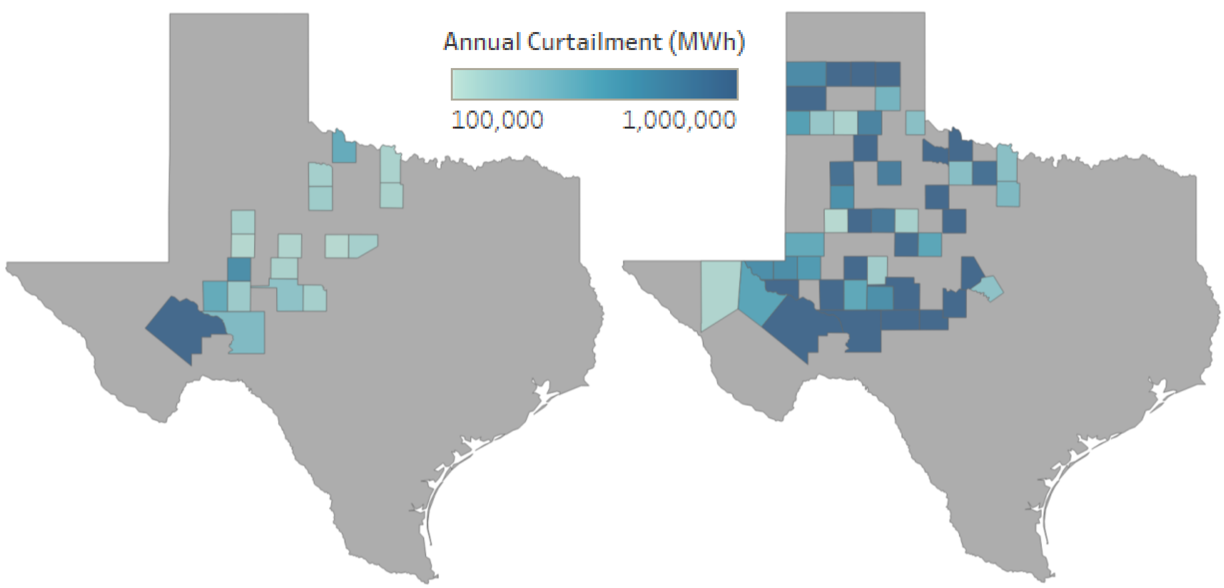


*Figure 9: Counties with at Least 100,000 MWh of Annual Curtailed Wind and Solar Generation in 2023 (Left) and 2030 (Right)*

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## Key Finding 2: New transfer pathways are essential to effectively improve the West Texas export transfer limit. Additional reactive support alone is not sufficient.

The primary reliability challenges associated with large power transfers across the West Texas export interface are a significant increase in reactive power consumption and angle separation under both normal and post-contingency conditions, as illustrated in Figure 10. These challenges are a product of the long distances and high impedance associated with the existing export corridors and resulted in the West Texas export interface reaching a stability limit prior to the thermal limits of the 345-kV lines that comprise the interface being exceeded.

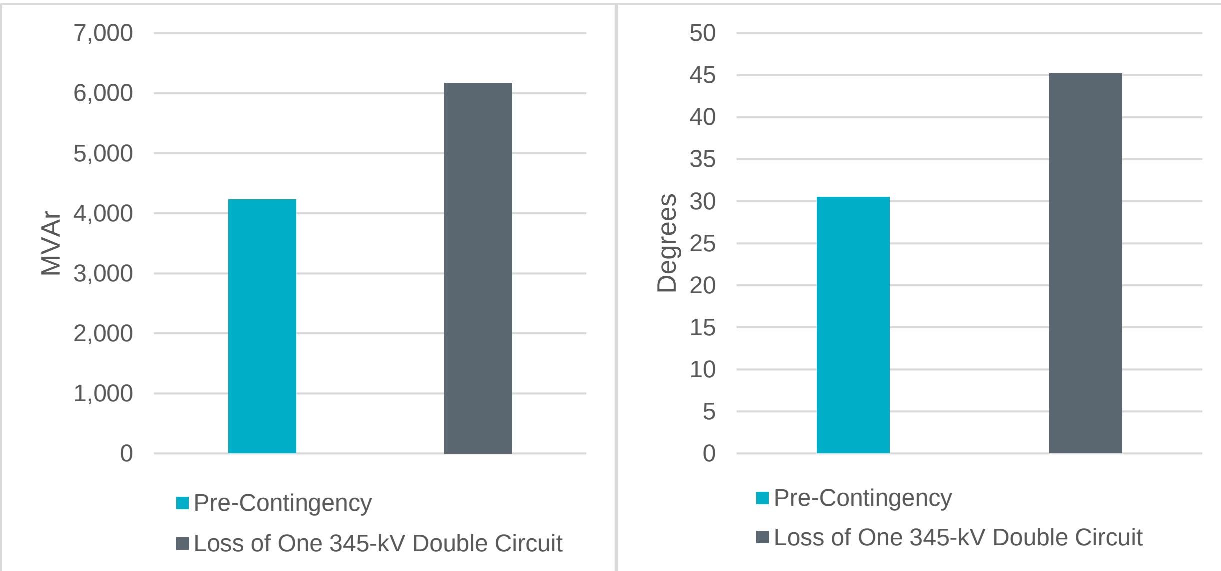


*Figure 10: Total MVAr Losses (Left) and Angle Separation (Right) Observed on a West Texas Export Interface Circuit*

New transfer paths parallel to the existing export corridors will effectively reduce the impedance and reactive losses. Improving the West Texas export transfer limit solely using additional reactive support is not an effective option primarily because it does not address the high impedance challenge, thereby imposing additional operational risk.

As illustrated in Figure 11, the options involving additional reactive support only – shown as gray and green lines – resulted in voltage collapse points – identified with red circles – being raised to within the range of normal system operating voltages. Voltage collapse points within the range of normal system operating voltages reduce operational awareness of potential instability and, thereby, reduce operators' capability to implement mitigation necessary to prevent voltage collapse effectively and in a timely fashion.

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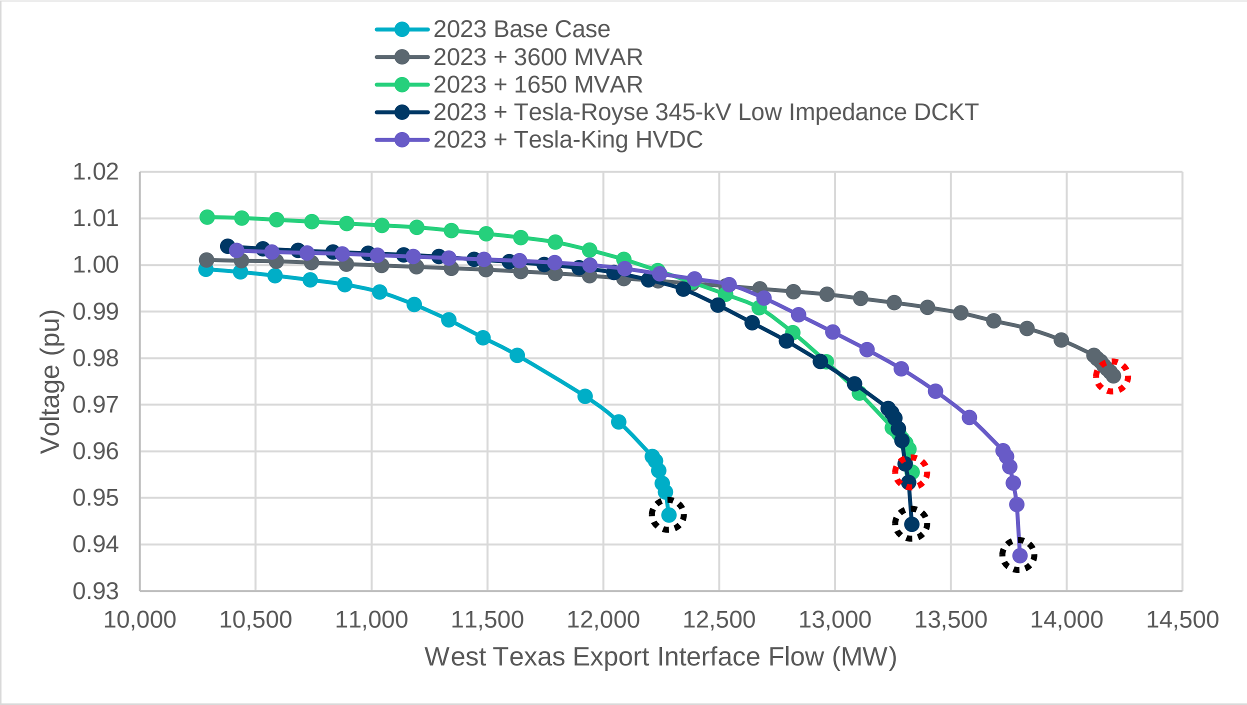


*Figure 11: Post-Contingency Voltages with Different Technology Types Added (2023 Study Case)*

In contrast, the options involving the addition of a new circuit – shown as dark blue and purple lines – can effectively improve the transfer limit without imposing additional operational risk and are considered viable options to effectively improve the West Texas export limit.

Reactive support alone is also inferior compared to the addition of new transfer pathways in improving angle separation across the interface. Figure 12 compares angle separation on one of the 345-kV double-circuit West Texas export pathways following a critical contingency for three different 2030 scenarios: base case (dark blue), base case with 300 MVAr of additional reactive support (gray), and base case with one low-impedance 345-kV new transfer pathway (light blue). The reactive support only option shows no angle separation improvement compared to the base case, whereas the option with a new transfer pathway effectively reduces the post-contingency angle separation by 15 degrees.

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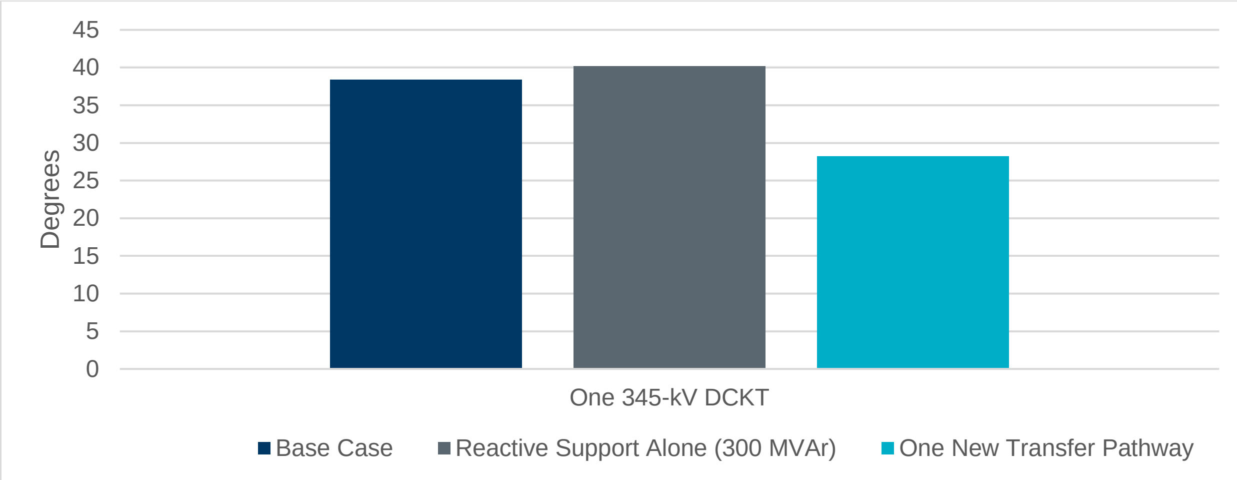


*Figure 12: Post Critical Contingency Angle Separation for a 345-kV Double-Circuit in the West Texas Export Interface*

Another challenge associated with using reactive support alone is the cost inefficiency of such options. Though adding reactive support increases transfer limits, reactive losses increase exponentially with increased power transfer. As shown in Figure 13, the exponential nature of reactive power losses leads to a high ratio of additional reactive support to the corresponding improvement in transfer limit. In addition to the operational risks, improving the West Texas export transfer limit using reactive support alone would only provide marginal benefit.

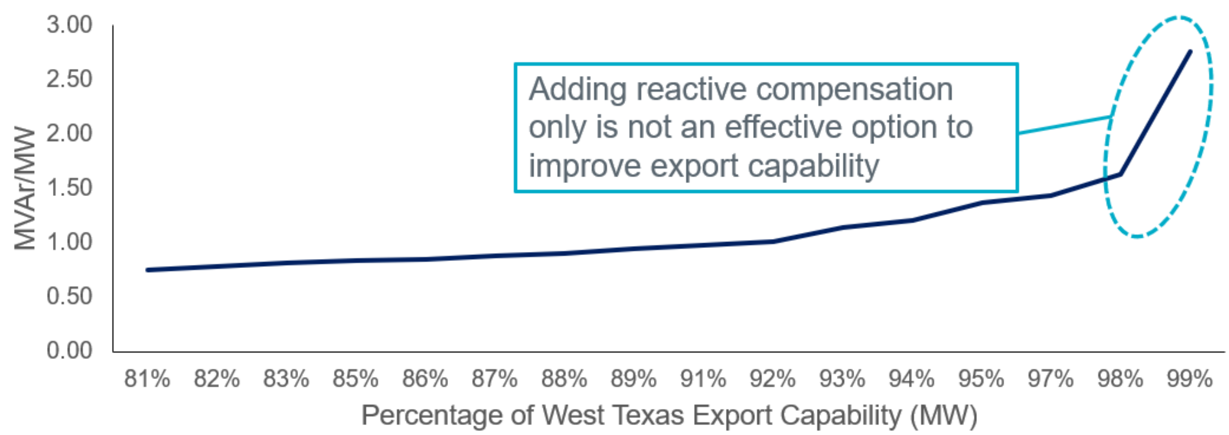


*Figure 13: Reactive Compensation Requirement for West Texas Export*

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**Key Finding 3: Technologies beyond typical 345-kV circuit additions are needed to effectively improve the West Texas export limit.**

The system load and generation trends discussed in Key Finding 1 highlight the need for long-distance power transfer from resource-rich generation centers in West Texas to electrical demand centers (i.e., major urban areas) further east. Figure 14 shows the North, West, and Far West weather zone wind and solar generation capacities included in the 2023 base case and approximate distances from a centralized West Texas location to electrical demand centers. It should be noted that the actual transmission circuit distances between IBRs in West Texas and the listed major electrical demand centers are expected to be higher than the ones shown in Figure 14 once routing is accounted for.

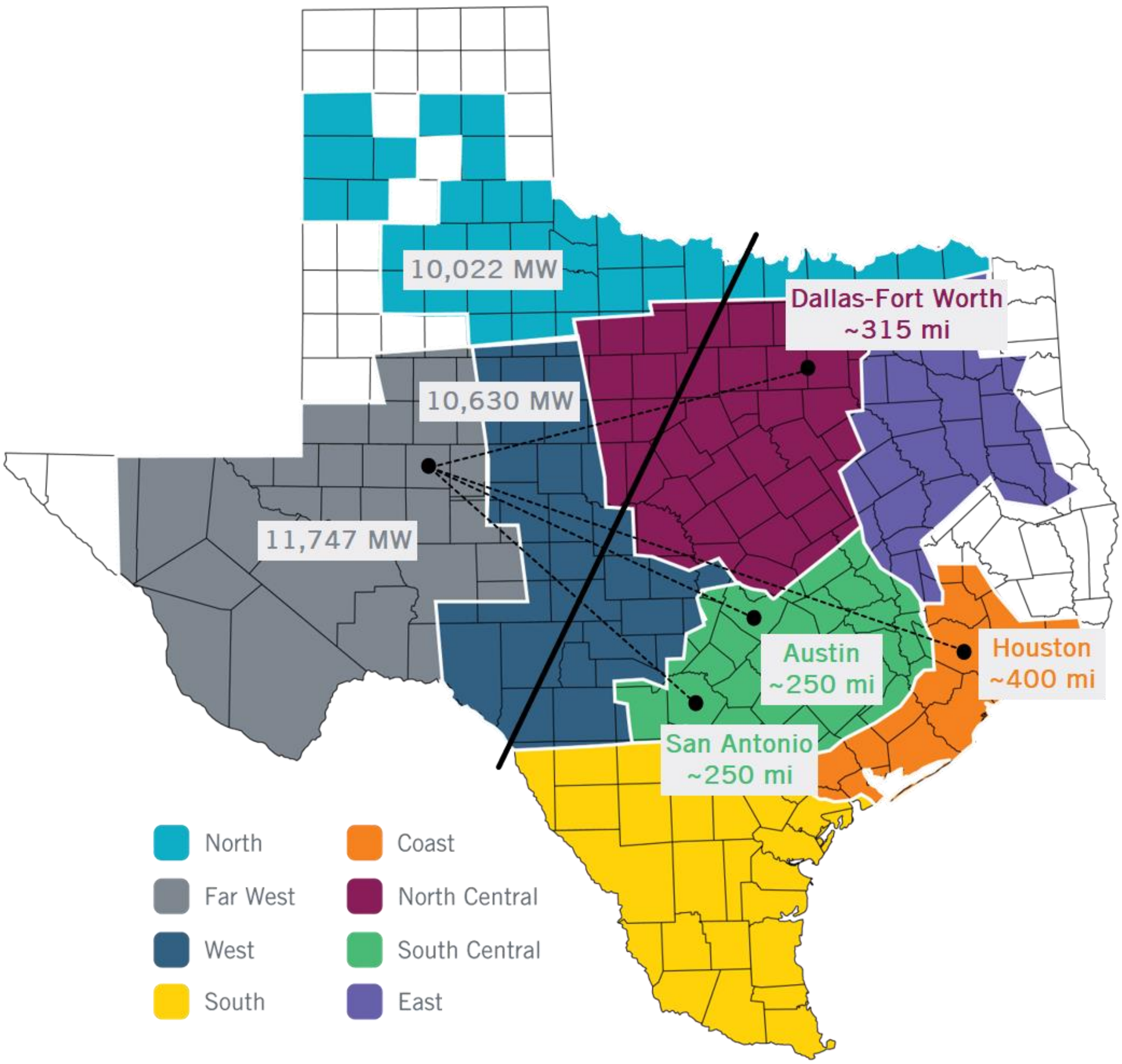


*Figure 14: Approximate Distances from West Texas to Electrical Demand Centers*

Like the existing transmission circuits that comprise the West Texas export interface, new long-distance transmission pathways across the interface using typical 345-kV technology would result in

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similarly high impedances and correspondingly high additional reactive losses. Significant reactive power compensation would be required to support the high long-distance power transfers over typical 345-kV circuits unless series capacitors, or similar technologies, were used to reduce the impedance. Series-compensated 345-kV lines are not a preferred solution due to complex subsynchronous resonance (SSR) issues, and the potential to affect the operation of generating units, that can arise from their use.

Furthermore, the additional reactive support needed for a typical 345-kV circuit would require additional coordination for those large reactive devices. These inherent obstacles make alternative technologies, such as low-impedance 345-kV circuits, voltage levels above 345 kV, or high-voltage direct current (HVDC) lines more effective to achieve the desired improvement in West Texas export transfer capability.

ERCOT studied multiple technology types and their potential impact to the West Texas export capability as summarized in Table 3.

*Table 3: Technology Types Considered*

| Option | Estimated Power Transfer Improvement | Estimated Cost | Notes |
|---|---|---|---|
| Typical 345-kV double-circuit line | < 1 GW | $$ | • Not effective for long-distance transfer<br>• Complex SSR issues need to be addressed if adding series capacitors |
| Low impedance 345-kV double-circuit line | ~1-1.2 GW | $$ | • Suitable for long-distance power transfer<br>• Not widely implemented |
| Typical 500-kV double-circuit line | ~1.3-1.6 GW | $$$ | • Suitable for very long-distance power transfer<br>• Additional transformers are needed to connect to the existing system (~4 transformers per circuit) |
| VSC-HVDC line | ~1.5-2 GW | $$$ | • Suitable for very long-distance power transfer<br>• Further discussion on system and market operation required |
| Reactive Devices | ~2-4 MVAr/MW | $ | • Additional reactive devices alone could increase the operational risk of voltage instability near nominal voltage<br>• Cost inefficient |

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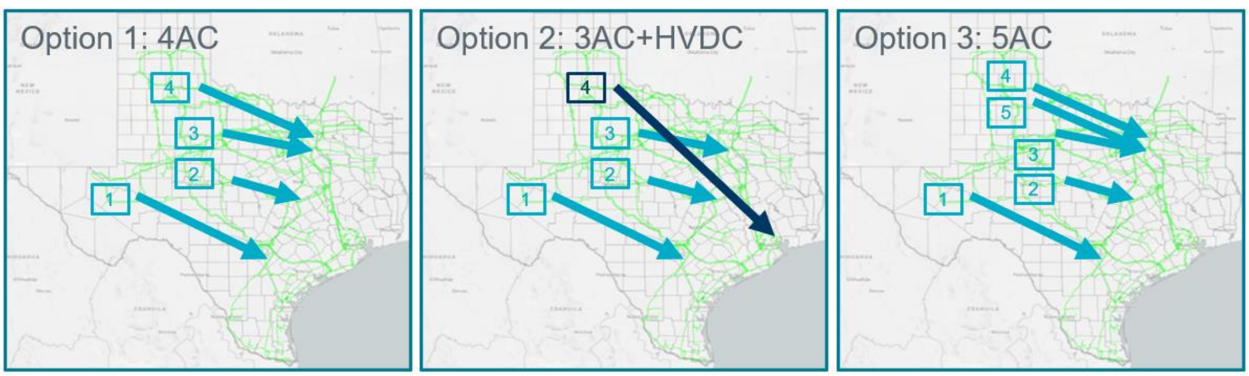
Results from this study indicate that technology beyond typical 345-kV equipment will be necessary to effectively improve transfer capability across the West Texas export interface. Further analysis is needed to determine which technology is optimal, and TSP cost estimates for additional technology options should also be developed. The most effective technology will be determined in future planning assessments considering both reliability and economic criteria.

***Short-Listed Options***

An extensive variety of potential transmission improvement options were considered to effectively increase the transfer across the West Texas export interface, reduce West Texas wind and solar curtailment, and deliver transferred power to electrical demand centers. Figure 15 shows three improvement options[11,12] selected from the initial results for more detailed analysis, including full dynamic stability analysis. Additionally, cost estimates were requested from TSPs for these options. Options 1 and 2 are considered short-listed improvement options based on this study's results; however, Option 3 details are included in this report in order to contextualize the results of Options 1 and 2 presented in Key Findings 4 and 5.




Option 1: 4AC
1. Bakersfield-Howard
2. Brown-Bell
3. Clear Crossing-Watermill
4. Tesla-Royse

Option 2: 3AC+HVDC
1. Bakersfield-Howard
2. Brown-Bell
3. Clear Crossing-Watermill
4. Tesla-King

Option 3: 5AC
1. Bakersfield-Howard
2. Brown-Bell
3. Clear Crossing-Watermill
4. Tesla-Royse
5. Edith-Clarke-Graham-Watermill

*Figure 15: Improvement Options Selected for Detailed Analysis*[13]

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[11] AC technology was modeled as low-impedance 345-kV with assumed circuit impedance (pu/mile) of R = $2.79\times10^{-5}$, X = 0.0003513, and B = 0.012051, normal rating of 1606 MVA, and emergency rating of 1784 MVA.

[12] The VSC-HVDC technology tested was monopole with a nominal kV of 585 and a voltage setpoint of 500-kV.

[13] Teal represents low-impedance 345-kV technology, while dark blue represents 1.5 GW HVDC technology.

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**Key Finding 4: Holistic solutions addressing both the West Texas export limit and constraints closer to electrical demand centers are required to accommodate large-scale generation transfers.**

As discussed in Key Finding 3, technology better suited for long-distance high-power transfers helps improve the West Texas export transfer capability. However, another key component to effectively improve congestion and generation curtailment in West Texas is addressing constraints closer to electrical demand centers in tandem with the West Texas export constraint. Increased transfer limits may not be fully utilized without also addressing constraints near electrical demand centers that result in curtailment behind the West Texas export interface. Table 4 summarizes reliability and economic assessment results for the three options included in Figure 15.

*Table 4: Reliability and Economic Results Summary*

| Improvement Option | Steady-State Voltage Stability Limit[14] (GW) | | Estimated New Double-Circuit Miles[15] | Production-Cost Savings ($M) | | TSP Cost Estimate ($M)[16] |
|---|---|---|---|---|---|---|
| | 2023 | 2030 | | 2023 | 2030 | |
| Base Case | 12.24 | 13.75 | - | - | - | - |
| Option 1 (4AC) | 16.46 | 18.35 | 1,009 | 135 | 642 | 2,738 |
| Option 2 (3AC+HVDC) | 16.49 | 18.78 | 1,274 | 170 | 783 | 5,203 |
| Option 3 (5AC) | 17.45 | 19.16 | 1,248 | 150 | 742 | 3,459 |

Higher transfer limits generally correlate to higher production-cost savings. However, that correlation only held while the West Texas export limit was the leading constraint resulting in curtailment behind the interface. Once the interface constraint was relieved to the point where it was no longer the primary cause of curtailment, additional increases in the transfer limit were not utilized until the new leading constraint was addressed.Als

A comparison of Option 2 and Option 3 illustrates this point. Option 3 had a higher transfer limit than Option 2 due to an additional transfer path across the interface, but Option 3 resulted in lower production-cost savings than Option 2. This is because Option 2 also alleviated the North-to-Houston stability constraint, which was the second-leading constraint resulting in West Texas generation curtailment, whereas Option 3 did not. As a result, Option 2 was selected over Option 3 as one of the two short-listed options that are considered to effectively improve West Texas export limits and reduce

[14] Limits used in economic analysis were 90% of calculated stability limits to be consistent with the ERCOT Transmission and Security Operating Procedure.

[15] A mileage adder of 30% was applied to each circuit's straight-line distance.

[16] The HVDC cost estimate portion of Option 2 is for 525-kV monopole technology.

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generation curtailment. The other short-listed option, Option 1, provides less improvement compared to Option 2, but at a lower cost.

The 2023 and 2030 annual flow duration curves for the North-to-Houston stability constraint shown in Figure 16 and Figure 17, respectively, show the underlying system behavior driving the interplay between the West Texas export limit and resulting production-cost savings.

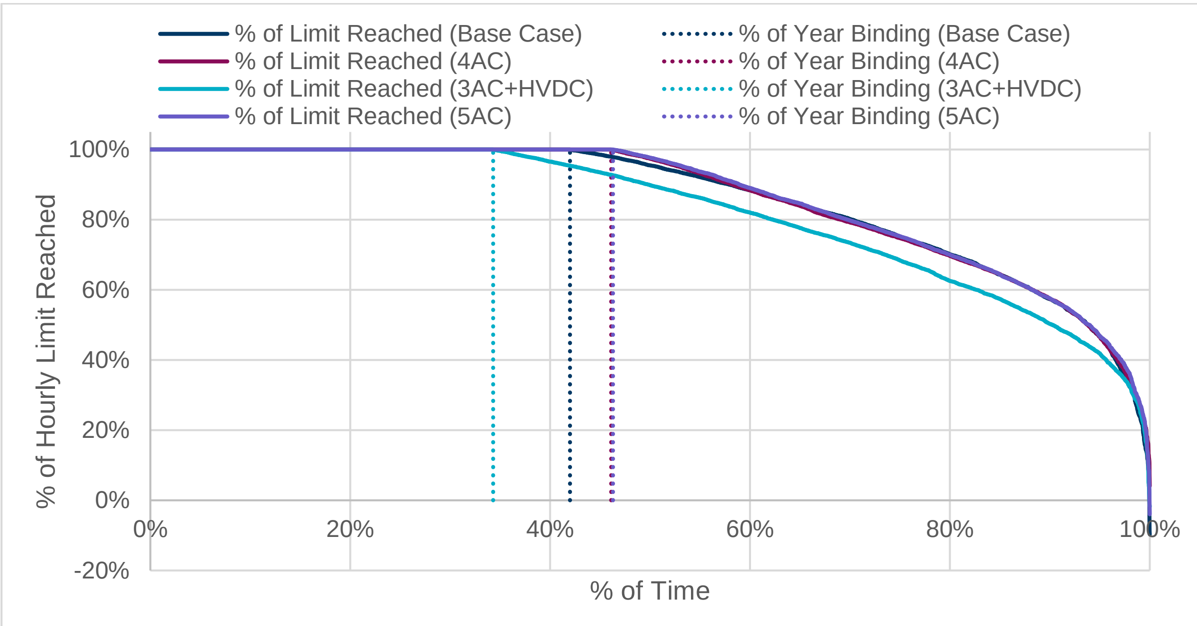


*Figure 16: Annual Flow Duration Curves for the North-to-Houston Stability Constraint in the 2023 Study Year*

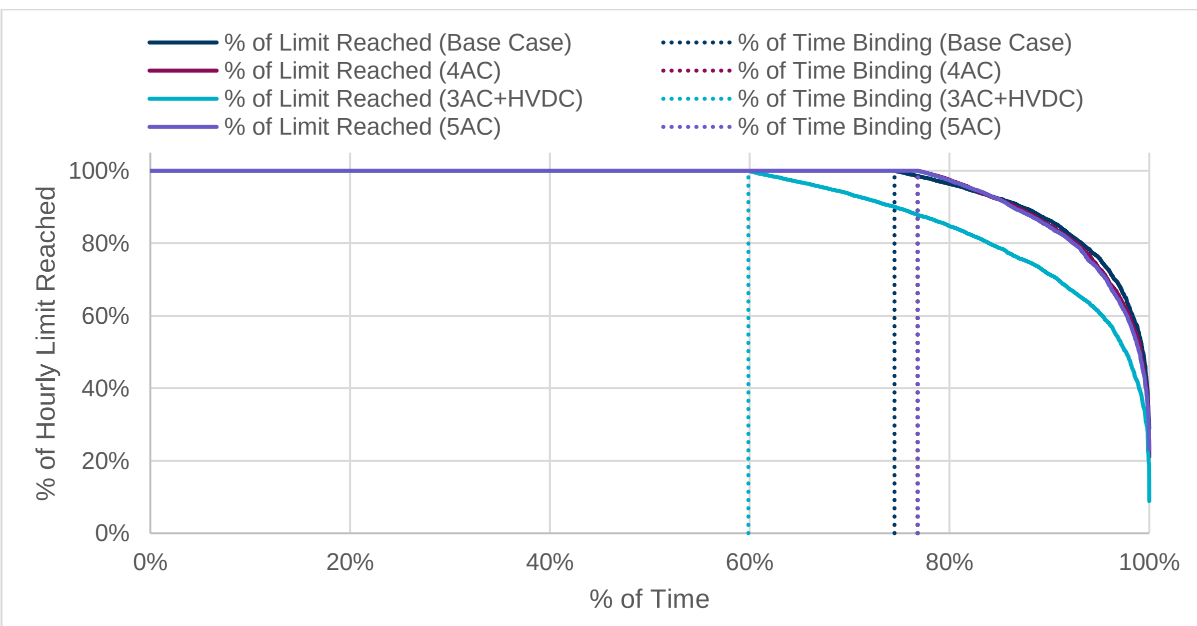


*Figure 17: Annual Flow Duration Curves for the North-to-Houston Stability Constraint in the 2030 Study Year*

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Figure 16 compares the annual flow duration curves for the North-to-Houston stability constraint for the base case against those of the three selected improvement options for study year 2023. Options 1 and 3 increased congestion on the North-to-Houston interface from 42% of the year to 46% of the year. This is due to the North-to-Houston stability constraint preventing increased IBR output from West Texas from serving electrical demand in Houston. Alternatively, Option 2 not only improves the West Texas export limit but the Tesla-to-King VSC-HVDC line also alleviates the North-to-Houston constraint. The interface was binding approximately 34% of the year with Option 2 in place. Figure 17 shows the trend observed in the 2023 study case continuing in the 2030 study case. Increased demand in the Houston area resulted in additional congestion on the North-to-Houston stability interface in the 2030 study case.

These results underscore the importance of integrated planning processes. If these options had been evaluated through a single lens, for example from a voltage stability limit perspective, Option 3 would have appeared more effective, as it resulted in the highest West Texas export limit in the 2030 study case. However, integrating economic analysis with the stability analysis demonstrated that the effectiveness of increased transfer limits can be diminished by other constraints. The production-cost savings results highlight the fact that the higher transfer limit associated with Option 3 was underutilized compared to the improved transfer limit resulting from Option 2. Integrated planning processes incorporating steady-state, stability, and economic analyses are fundamental to identifying holistic solutions that maximize the benefits of transmission improvements.

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### Key Finding 5: The identified improvement options are expected to reduce curtailment but not necessarily allow full output of all IBRs under all system conditions, including peak demand months.

Figure 18 illustrates the improvement each of the three selected options provided to the West Texas export constraint for study year 2030. All three improvement options decreased how often the interface was binding. However, the West Texas export constraint was still binding a significant portion of time under all three options. It should be noted that renewable generation behind the West Texas export interface was approximately 75% higher in study year 2030 compared to study year 2023 (see Appendix I for details) and that future congestion is subject to the amount and location of generation added to the system.

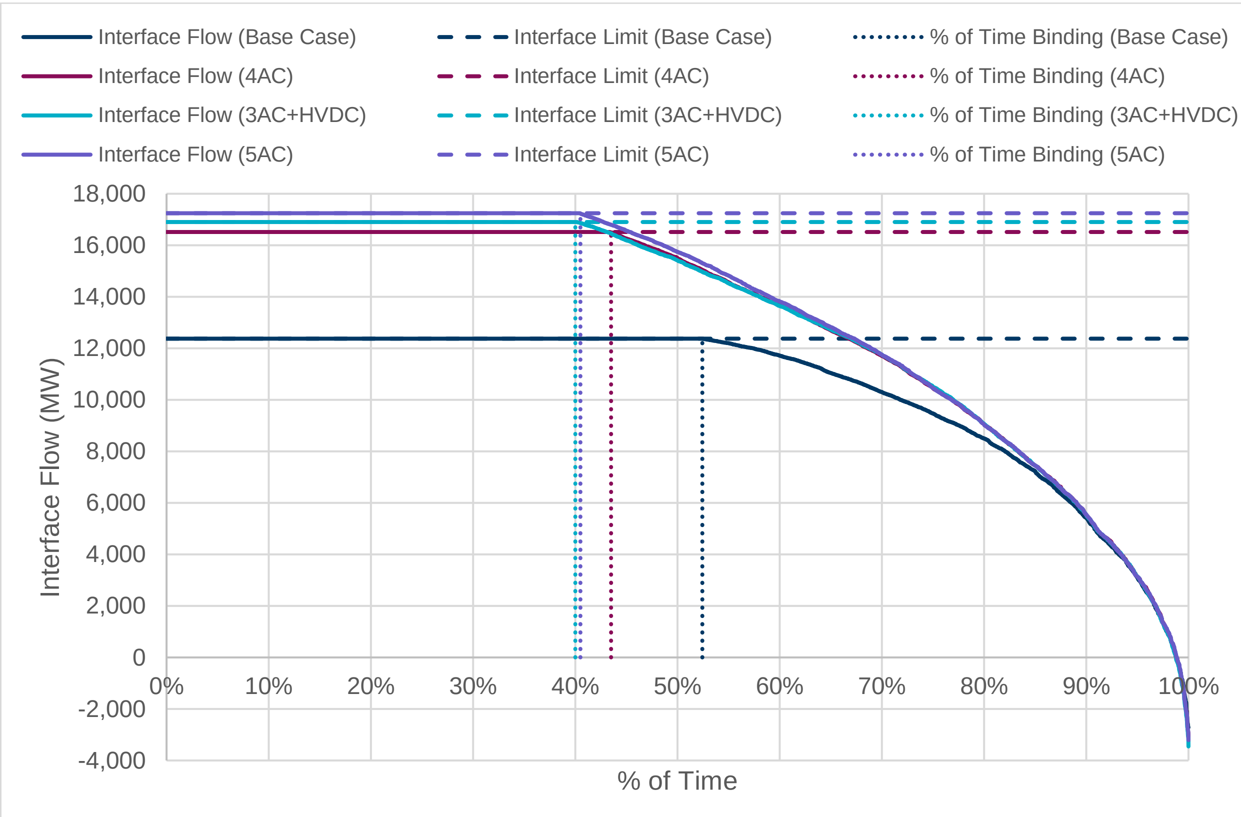


*Figure 18*: Annual Flow Duration Curves for the West Texas Export Constraint in the 2030 Study Year

Figure 19 shows 2030 annual wind and solar energy production and curtailment numbers from the base case and each of the improvement options. Each of the improvement options decreased annual West Texas generation curtailment, but no option fully resolved all curtailment.

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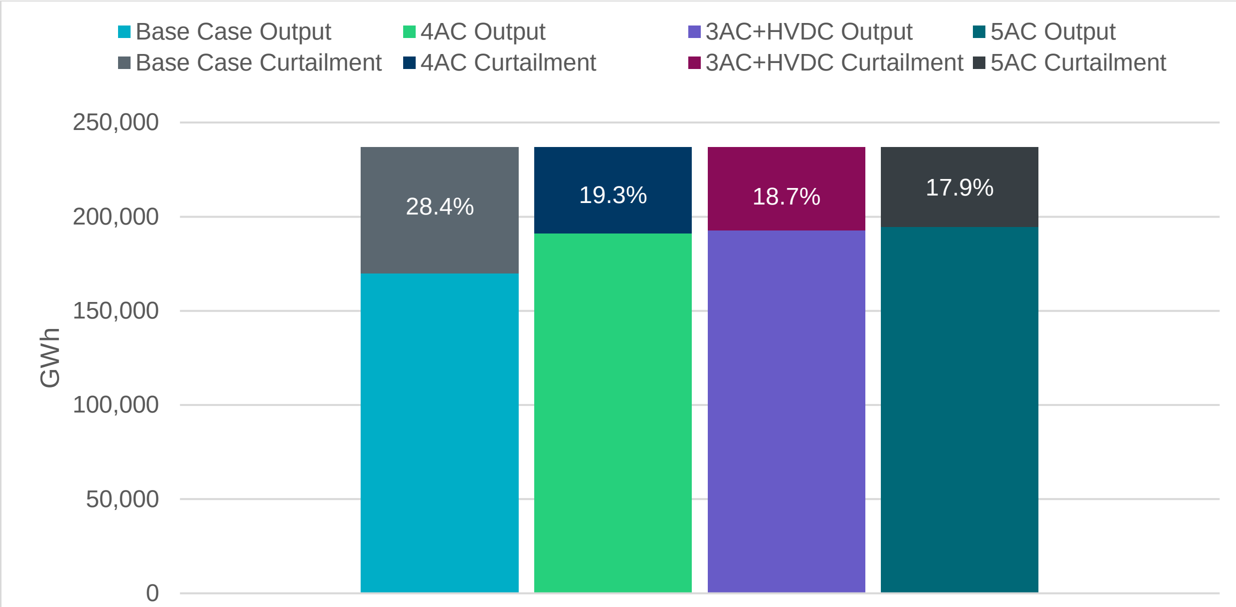


*Figure 19: Annual Wind and Solar Energy Production and Curtailment in the 2030 Study Year*

### *Curtailment During Peak Demand Months*

Figure 20 shows monthly curtailment in the 2023 base case. West Texas wind and solar curtailment in the peak summer demand months of July, August, and September averaged just under 2%, for a monthly curtailment average of approximately 150 GWh. Lower curtailment in summer months is attributable to limited solar generation in West Texas in the 2023 study case and the fact that West Texas wind units tend to have lower outputs during that timeframe.

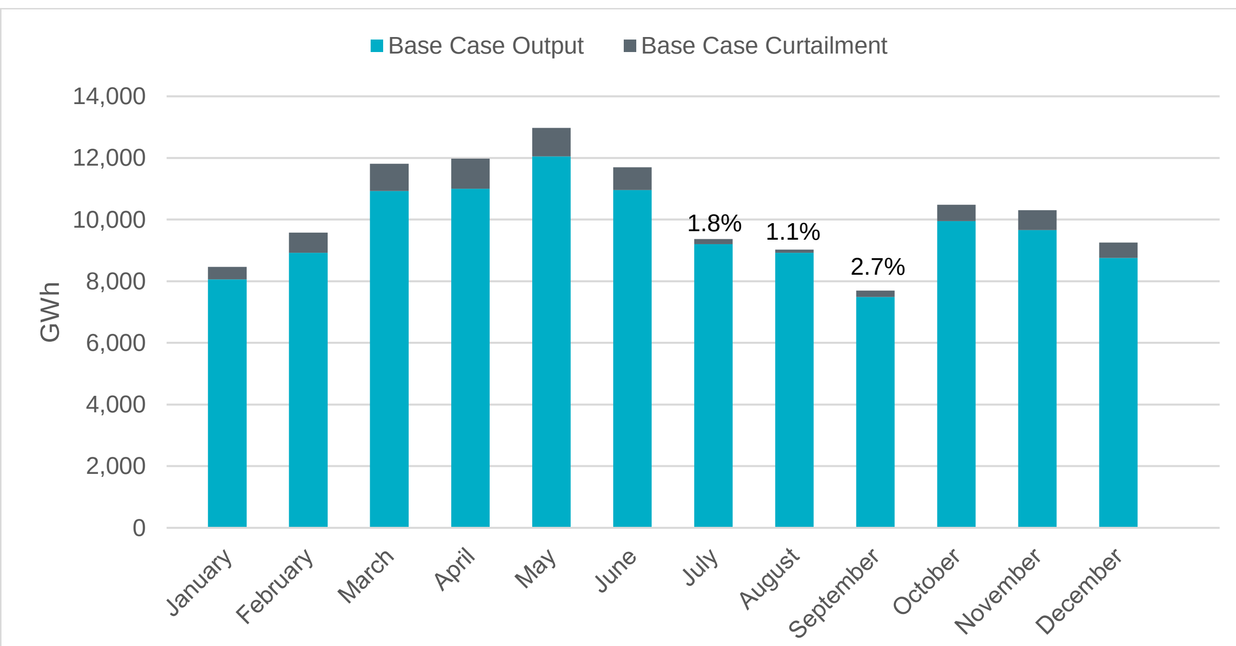


*Figure 20: Monthly West Texas Wind and Solar Curtailment in the 2023 Base Case*

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The growth in solar generation in the 2030 study case increases curtailment in 2030 peak summer demand months as shown by Figure 21. The 2030 base case resulted in an average West Texas wind and solar curtailment of 24% during the months of July, August, and September, or an average of approximately 4,200 GWh of total monthly curtailment across each of those three months.

With each of the three selected options in place, West Texas curtailment in the peak summer demand months of July, August, and September averaged approximately 15%, or 2,500-2,800 GWh across each of those months.

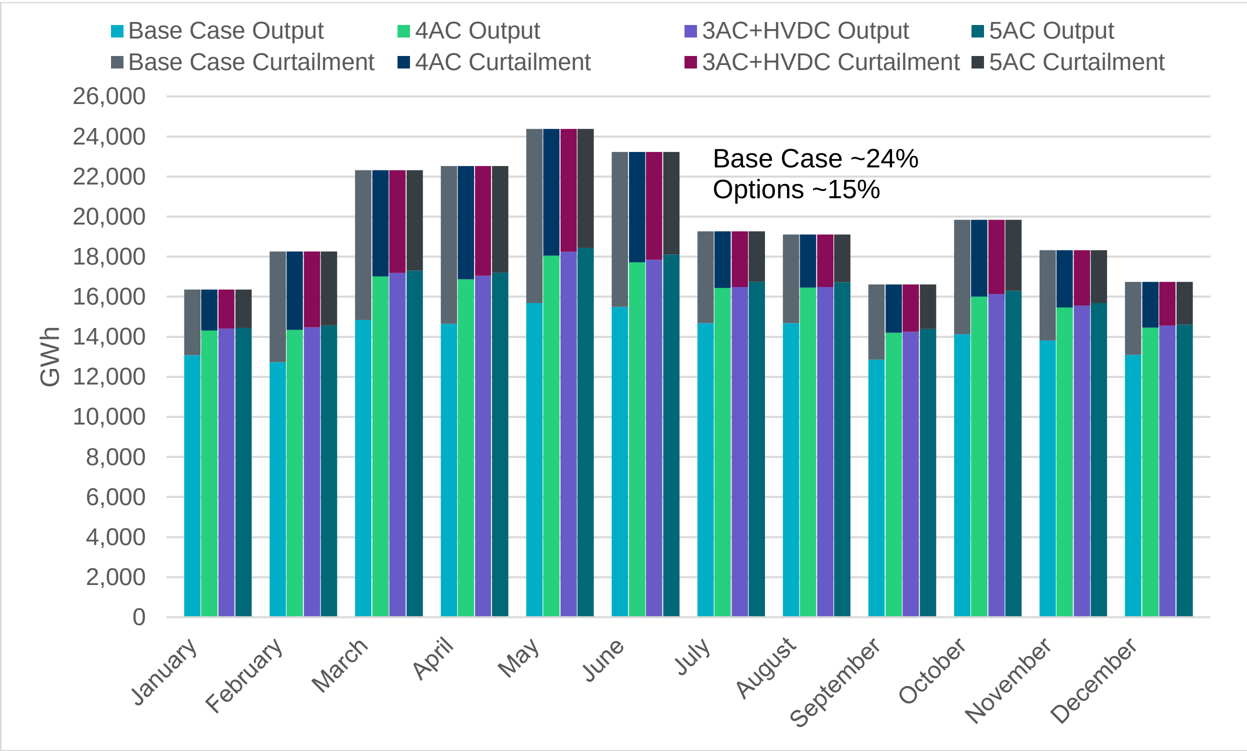


*Figure 21: Monthly West Texas Wind and Solar Curtailment in the 2030 Study Year*

While the two short-listed options do not fully resolve West Texas curtailment or the interface constraints, they are expected to provide consistent and notable system benefits. Both short-listed options resulted in significant reductions in congestion on the West Texas export interface and West Texas wind and solar generation curtailment. Option 2 also resulted in reduced congestion on the North-to-Houston interface.

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## 3. Next Steps

ERCOT will continue to evaluate system needs and coordinate with TSPs to identify transmission improvements following applicable planning criteria, including new and updated criteria resulting from ongoing discussions at the Public Utility Commission of Texas (PUCT) and ERCOT stakeholder groups.

The integrated planning process used in this study facilitated the identification of effective system improvement options to address multiple interrelated and interregional system challenges. However, utilizing this approach increased the complexity of, and therefore the resources required to complete, the study. ERCOT will, in consultation with stakeholders, continue to identify the needs to effectively perform integrated planning assessments that can identify holistic solutions to meet both near-term and long-term challenges requiring coordination between steady-state, stability, and economic analyses.

ERCOT will continue to monitor and assess emerging system trends that may impact West Texas export transfer capability and related transmission improvements. Trends in generation and demand that should be considered include:

- data centers and cryptocurrency mining facilities
- the shift in generation development from sites west of the West Texas export interface to sites east of the interface

Ongoing evaluation will include continued consideration of new transmission technologies and endpoints for potential transmission improvements to determine the most effective approach for maximizing system benefits.

With increasing system stability challenges and associated constraints that could lead to congestion and generation curtailment, adequate and accurate dynamic models are imperative to properly identify instability and develop mitigation plans and system improvements. Significant efforts were made by ERCOT with stakeholder support in recent years to improve the quality and accuracy of dynamic models provided by Resource Entities and TSPs. ERCOT will continue to review submitted dynamic models against actual performance so that accurate models are used to assess system stability. ERCOT will also coordinate with stakeholders and manufacturers to regularly review and revise the dynamic modeling requirements as the system continues to evolve toward an IBR-dominated system.

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# Appendices

## Appendix I: Study Assumptions

### *Reliability Base Case*

The 2020 Regional Transmission Plan (RTP) 2023 Minimum Load (MIN) N-1 secure case dated July 28, 2020, on ERCOT's Market Information System (MIS) was used to develop study cases for 2023 and 2030 to assess the West Texas export transfer capability in both steady-state voltage stability and dynamic stability assessment.

The 2023 MIN case was selected for transfer capability analysis due to higher renewable output resulting in larger power transfers from West Texas to electrical demand centers.

### *Transmission Topology*

Tier 1, 2, and 3 transmission projects approved by RPG from January 1, 2020, to October 31, 2020, were added to the 2023 and 2030 base cases. In addition, the STEC and LCRA TSC Bakersfield to Big Hill 345-kV Second Circuit Addition Project, approved by RPG in June 2021, was also added to the 2030 base case.

Local placeholder projects were added in the 2030 base case. These primarily included projects identified by another ERCOT planning assessment. Examples include TSP-submitted Regional Planning Group (RPG) Tier 4 projects, local projects identified by the latest Permian Basin study, and local placeholder projects identified by previous RTP studies.

### *Generation*

Planned generators identified as meeting the requirements of ERCOT Planning Guide Section 6.9(1) in the December 2020 Generator Interconnection Status (GIS) report were added to both the 2023 and 2030 study base cases. Additionally, the 2030 base case included generation resulting from the 2020 Long-Term System Assessment (LTSA) 2030 Current Trends iteration 1 capacity expansion analysis[17]. The generation resulting from capacity expansion analysis is independent of the GIS report.

Batteries were dispatched at zero megawatts but assumed to provide reactive support consistent with voltage support requirements in the ERCOT Protocols. All new wind and solar generation units added to the cases were dispatched consistent with existing units in the case. For dynamic stability analysis, in-house assumed generic models were used for assumed future IBRs or to address numerical instability.

For both 2023 and 2030, unit retirement and mothball information were maintained consistent with the 2021 RTP models. The 2030 study case utilized the results of the 2030 LTSA Current Trends iteration 1 capacity expansion analysis, which resulted in a nearly 75% system-wide IBR capacity increase. Most of that capacity increase was located behind the West Texas export interface. Table 5 shows the total system wind and solar capacity in the 2023 and 2030 study cases, while Figure 22 shows the wind and solar capacity by weather zone for 2023 and 2030, respectively.

[17] Detailed information can be found in the 2020 LTSA report posted at https://www.ercot.com/gridinfo/planning.

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*Table 5: System IBR Capacity by Type*

| Scenario | Wind | Solar | Battery | Total IBRs |
|---|---|---|---|---|
| | Capacity (GW) | Capacity (GW) | Capacity (GW) | Capacity (GW) |
| 2023 | 36.1 | 15.2 | 1.0 | 52.3 |
| 2030 | 59.6 | 31.1 | 1.9 | 92.6 |

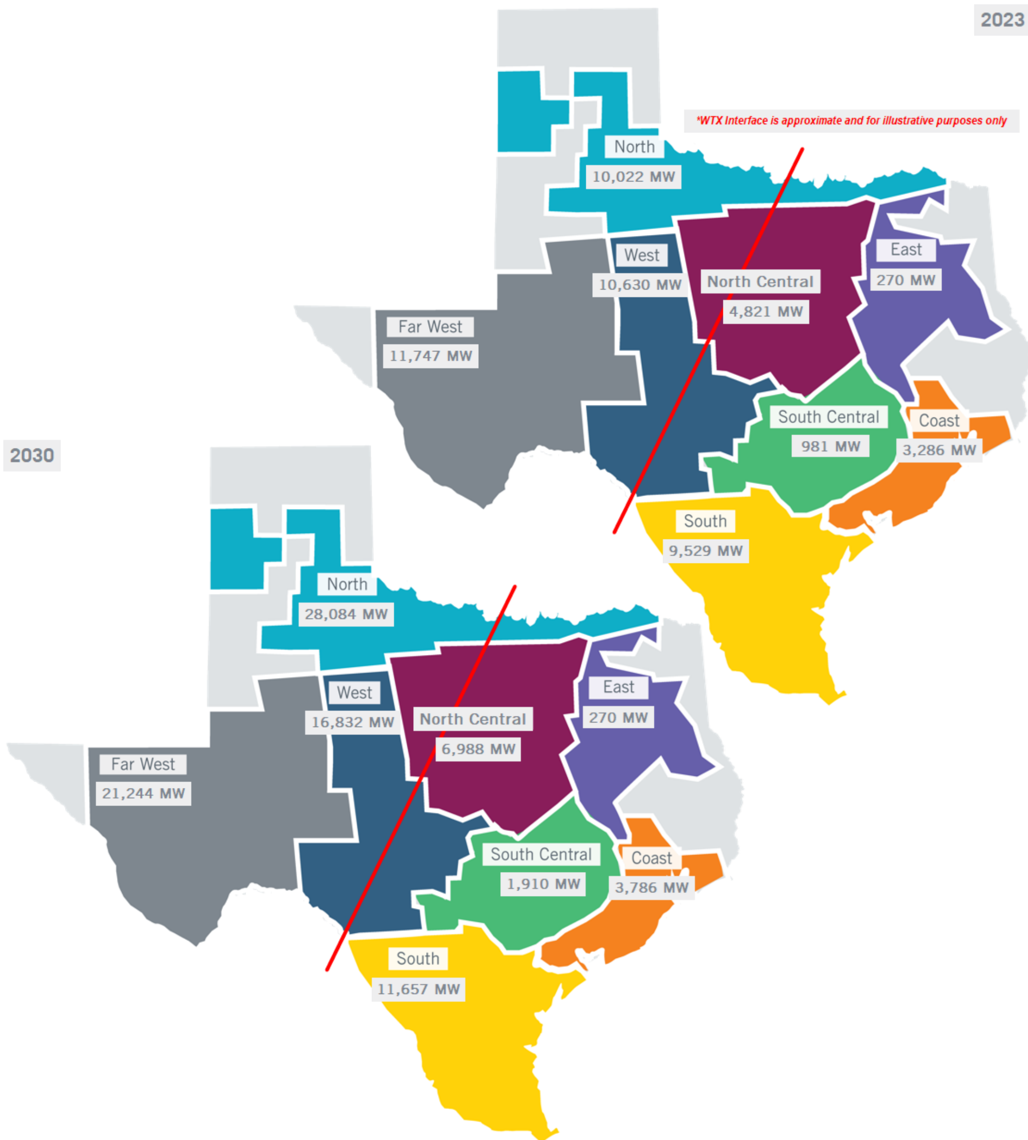


*Figure 22: 2023 and 2030 Wind and Solar Capacity by Weather Zone in Reliability and Economic Study Cases*

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### *Electrical Demand*

Table 6 shows total system electrical demand for each study year, while Figure 23 shows the weather zone demand totals for the 2023 and 2030 reliability base cases, respectively.

*Table 6: Reliability Base Case System Demand*

| Scenario | System Demand (GW) |
|---|---|
| 2023 | 42.3 |
| 2030 | 48.0 |

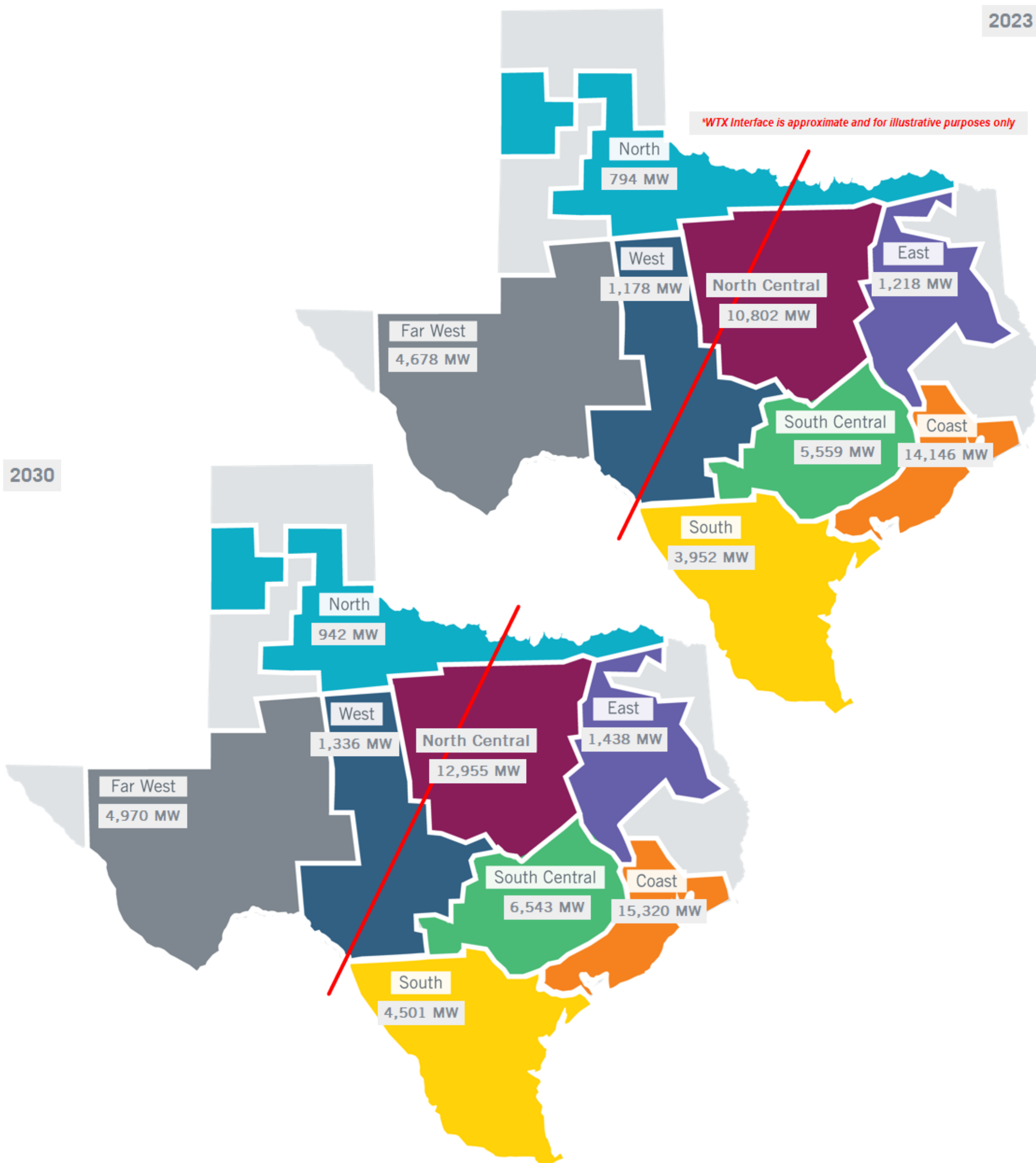


*Figure 23: Weather Zone Demand Totals for 2023 and 2030 Reliability Study Cases*

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***DC Ties***

Assumed DC tie flows were consistent with the 2021 RTP 2023 MIN case.

***Economic Base Case***

The 2023 economic base case used the system topology from the 2020 RTP 2023 MIN N-1 secure case, while all other economic data and settings were taken from the 2020 RTP economic analysis.

The 2030 economic base case used the 2020 LTSA 2030 Current Trends iteration 1 economic start case, including topology as well as supporting economic data and settings.

***Transmission Topology***

Transmission topology in the 2023 economic base case reflected that from the 2023 reliability base case.

Local placeholder projects were added in the 2030 base case. These primarily included projects identified by another ERCOT planning assessment. Examples include, the STEC and LCRA TSC Bakersfield to Big Hill 345-kV Second Circuit Addition Project, approved by RPG in June 2021, TSP-submitted RPG Tier 4 projects, local projects identified by the latest Permian Basin study, and local placeholder projects identified by previous RTP studies.

***Generation***

Generation for both the 2023 and 2030 economic base cases was consistent with the reliability base cases.

The 2023 economic base case used hourly wind and solar profiles consistent with the 2020 RTP economic analysis.

The 2030 economic base case used hourly wind and solar profiles consistent with the 2020 LTSA Current Trends iteration 1 start case.

Energy-to-power ratio and round-trip efficiency data provided by Interconnecting Entities and/or Resource Entities via ERCOT's Battery Request for Information (RFI) Template[18] were used to model batteries added to the economic base cases. An energy-to-power ratio of 2 and 86% round-trip efficiency were assumed for batteries for which ERCOT had not received an RFI at the time of case development.

***Electrical Demand***

The 2023 economic base case used the 8760-hour demand profiles for year 2023 developed for the 2020 RTP Economic Analysis.

The 2030 Economic Base Case used the 8760-hour demand profiles consistent with the 2020 LTSA Current Trends iteration 1 start case.

[18] https://www.ercot.com/files/docs/2021/02/09/Battery_RFI_Template.xlsx

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## Appendix II: Methodology

### *Reliability Analysis*

Steady-state voltage stability assessment using VSAT served as a screening tool to estimate the West Texas export limit, and the results were then applied to the economic analysis using UPLAN to develop and evaluate various system improvement options. Dynamic stability analysis using PSS/e was then used to calculate the West Texas export limit for the short-listed system improvement options.

### *Contingencies and Criteria*

N-1 contingencies, including North American Electric Reliability Corporation (NERC) P0, P1, P2-1, and P7-1 planning events were considered for this study. The performance criteria used for this study are consistent with NERC Reliability Standards and ERCOT Planning Guide requirements for the tested contingencies.

### *Economic Analysis*

The 2030 economic base case monitored and enforced both thermal and stability constraints. All NERC Bulk Electric System (BES) elements were monitored for economic analysis. Any potential issues on system elements connected below 100-kV were considered local in nature and would be expected to be resolved through near-term planning processes before 2030.

The 2023 economic base case also monitored and enforced both thermal and stability constraints. However, all elements connected to 60-kV and above were monitored and enforced, consistent with other ERCOT planning assessments conducted for the near-term planning horizon.

For economic testing, 90% of the West Texas export transfer limit that resulted from the transfer analysis in the reliability analysis was enforced in UPLAN, consistent with the ERCOT Transmission and Security Operating Procedure[19].

### *Study Tools*

ERCOT utilized the following software tools to perform this study:

- PSSE version 33.12.2 for stability analysis
- VSAT version 18 for PV (Power-Voltage) analysis
- UPLAN version 10.4.0.22733 for economic analysis

[19] ERCOT Transmission and Security Operating Procedure

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