2020 Panhandle Regional Stability Study

Final Report

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Document Revisions

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Executive Summary

ERCOT completed the 2020 Panhandle Regional Stability Study to evaluate the impact of increasing amounts of Inverter-Based Resources (IBRs) connecting to the Panhandle region (behind the existing Panhandle Generic Transmission Constraint (GTC) interface) and Nearby Panhandle region (just outside the existing Panhandle GTC interface). Although the total capacity of IBRs[1] in the Panhandle region remained close to 5.2 GW, an additional ~2 GW of IBRs[1] in the Nearby Panhandle region were added since the completion of 2019 Panhandle Regional Stability Study. As a result, the total capacity of IBRs in the Nearby Panhandle region exceeds 5.3 GW, which is a 25% increase compared to 2019 Panhandle Regional Stability Study and is in line with the continuously increasing trend in this region over the past few years.

In addition, Lubbock Power and Light (LP&L) is planned to connect to the ERCOT Transmission Grid in 2021. The LP&L load close to the Panhandle region and an additional 345 kV transmission path connected to the Panhandle region from Ogallala to Long Draw and White River are expected to improve the power transfer capability from the Panhandle region.

With the rapidly increasing IBR generation capacity and transmission topology changes in the vicinity of the Panhandle region, ERCOT conducted the 2020 Panhandle Regional Stability Study. The focuses of this study are: 1) to evaluate the impact of ~2 GW of additional IBRs in the Nearby Panhandle region and LP&L integration on the system stability and 2) to review the interface definition of the existing Panhandle GTC. It should be noted that Panhandle and Nearby Panhandle output may also be impacted by other stability constraints such as a potential West Texas Export constraint. The assumptions in this study ensured that West Texas export levels remained below export limits identified in previous planning studies.

The study results showed no widespread control instabilities related to low system strength. Dynamic voltage instabilities were identified for the PH100NP100 scenario (100% dispatch of IBRs in the Panhandle and Nearby Panhandle regions). The system remained stable for the PH80NP100 scenario. Additional evaluations were conducted to determine the adequacy of a revised Panhandle interface including the following 345 kV circuits:

- Tesla – Riley and Tesla – Jim Treece (Measured at Tesla)
- Tesla – Edith Clarke double circuit (Measured at Tesla)
- White River – Cottonwood double circuit (Measured at Cottonwood)
- Ogallala – Abernathy (Measured at Abernathy)
- White River – Abernathy (Measured at Abernathy)

Determination and implementation of a GTC is subjected to further review by ERCOT Operations.

[1] IBRs that met the Planning Guide Section 6.9 Addition of Proposed Generation to the Planning Models

Findings and Recommendations:

- Planned transmission upgrades associated with LP&L integration improve the stability in the Panhandle region and are aligned with the Stage 2 upgrades as referenced in the exit strategy for the current Panhandle GTC.
    - With increasing IBR installations in the Panhandle and Nearby Panhandle regions, the proposed Panhandle GTC exit options should be re-evaluated in the future.
- With increasing IBRs in the Nearby Panhandle region, LP&L integration and the associated 345 kV transmission lines which provide an additional outlet for the Panhandle region, the system assumptions associated with calculating and applying the WSCR metric are no longer valid. Therefore, WSCR may not be a suitable metric to effectively and consistently quantify the system strength of the Panhandle region after the LP&L integration. Further review will be needed. Based on the study results, voltage stability limits are expected to be more binding than the system strength issues in the near term.
    - Potential system strength issues should still be evaluated, especially under prior outage conditions and as IBR levels continue to increase.
    - An alternative metric or methodology to properly represent the Panhandle system strength should be further investigated.
- PSS/e is still the primary dynamic simulation tool for stability studies. PSCAD study is needed to compare and verify the PSS/e study results in regions with high penetration level of IBRs like the Panhandle and Nearby Panhandle. PSCAD studies are necessary to evaluate potential control stability issues in these regions.
    - Both PSCAD and PSS/e dynamic simulations should be performed when evaluating stability in the Panhandle and Nearby Panhandle regions.
    - A larger scale PSCAD study, covering wider areas of West Texas, may be required in the future. ERCOT is collaborating with consultants, software vendors and industry partners to explore potential options to improve the simulation efficiency.
- Although PSCAD models are expected to better reflect certain performance details of IBRs that are simplified in the positive sequence model (e.g. PSS/e dynamic model), the verification of PSCAD models is imperative to ensure the model can accurately represent the dynamic response of an IBR and can be used to benchmark the positive sequence model. The model review and update process can be tedious, time consuming and often requires support from Resource Entities, manufacturers, consultants, and Transmission Service Providers (TSPs).
    - ERCOT needs to continue work with stakeholders to adopt the dynamic model validation and verification process as soon as possible to improve the accuracy and quality of dynamic models, including both PSS/e and PSCAD models, in an efficient way, such that the system stability evaluation cycle can be shortened and completed with higher fidelity.

- Numerical and solution issues were experienced while conducting PSS/e dynamic simulations. These issues appear to be prevalent when system conditions are near stability thresholds or when stressed system conditions (e.g. weak grid) are being modeled.
  - Further investigations into the tools and models are being conducted.
- Observed IBR tripping in the PSS/e simulations was primarily due to transient overvoltage which occurred right after fault clearing. The transient overvoltage issue could be further exacerbated with continuous growth of IBRs under weak grid conditions.
  - Options to mitigate the transient overvoltage includes reducing IBRs' output, adding transmission elements and adding dynamic reactive devices.
- Different types of abnormal and oscillatory responses during the post-contingency stage were observed. Such performance may be due to model issues or may be an indicator for potential control instabilities as IBR penetrations in the Panhandle and nearby Panhandle region continue to increase.
  - For identified modeling issues, ERCOT will continue to work with the Resource Entities to review model responses and obtain an updated model if necessary.

1. Introduction

The Panhandle and Nearby Panhandle regions have experienced rapid growth of Inverter Based Resources (IBRs) and changing transmission system topologies since 2013. To evaluate the potential stability issues associated with the large scale of IBRs integrated within the system, detailed PSCAD simulations have been included in the ERCOT Panhandle stability studies since 2016. The report for the 2019 Panhandle Regional Stability Study was completed in December 2019[2]. Some transmission upgrades, such as installing two synchronous condensers, were identified in previous studies and implemented based on ERCOT planning criteria to allow a higher level of IBR output in the Panhandle region.

An additional ~2 GW of planned IBRs that met the Planning Guide Section 6.9 requirements were included in the Nearby Panhandle region (just outside the existing Panhandle GTC interface). As a result, the total capacity of IBRs in the Nearby Panhandle region exceeds 5.3 GW, which is a 25% increase compared to 2019 Panhandle Regional Stability Study and is in line with the continuously increasing trend in this region over the past few years. As shown in Figure 1, the cumulative IBRs in the Panhandle and Nearby Panhandle has increased rapidly since 2013 and this trend is more prominent in the Nearby Panhandle region recently.

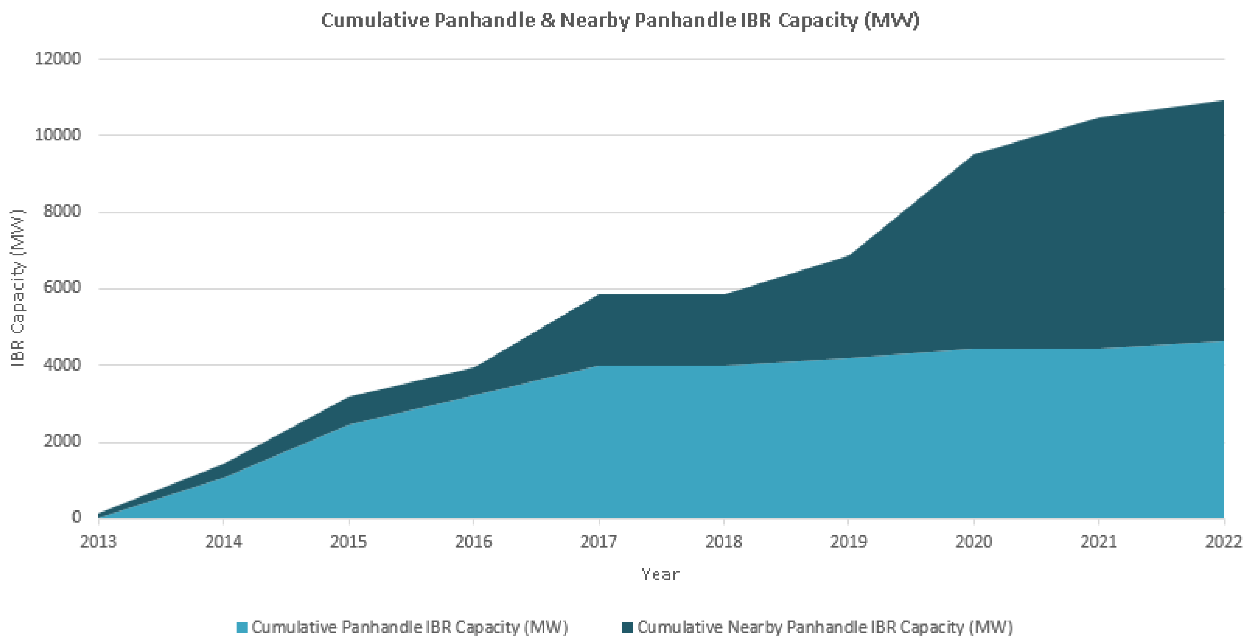


Figure 1. Cumulative Panhandle and Nearby Panhandle IBR capacity (MW). (Based on the ERCOT GIS data as of second quarter of 2020)

LP&L is planned to connect to the ERCOT grid in 2021. The LP&L load can improve stability in the region by providing a more localized sink for the IBR generation in the Panhandle region, although the load is relatively small compared to the amount of IBR generation in the region. Associated with the

[2] http://www.ercot.com/content/wcm/lists/197392/2019_PanhandleStudy_public_V1_final.pdf

integration of LP&L load, there will be an additional 345 kV transmission path connected to the Panhandle region from Ogallala to Long Draw and White River, as shown in Figure 2. With this additional path, the Panhandle export capability is expected to be improved.

This 2020 Panhandle Regional Stability Study was conducted to evaluate the impact of increasing amounts of IBRs connecting to the Panhandle and Nearby Panhandle regions and to review the adequacy of the existing Panhandle interfaces with the integration of Lubbock Power and Light (LP&L).

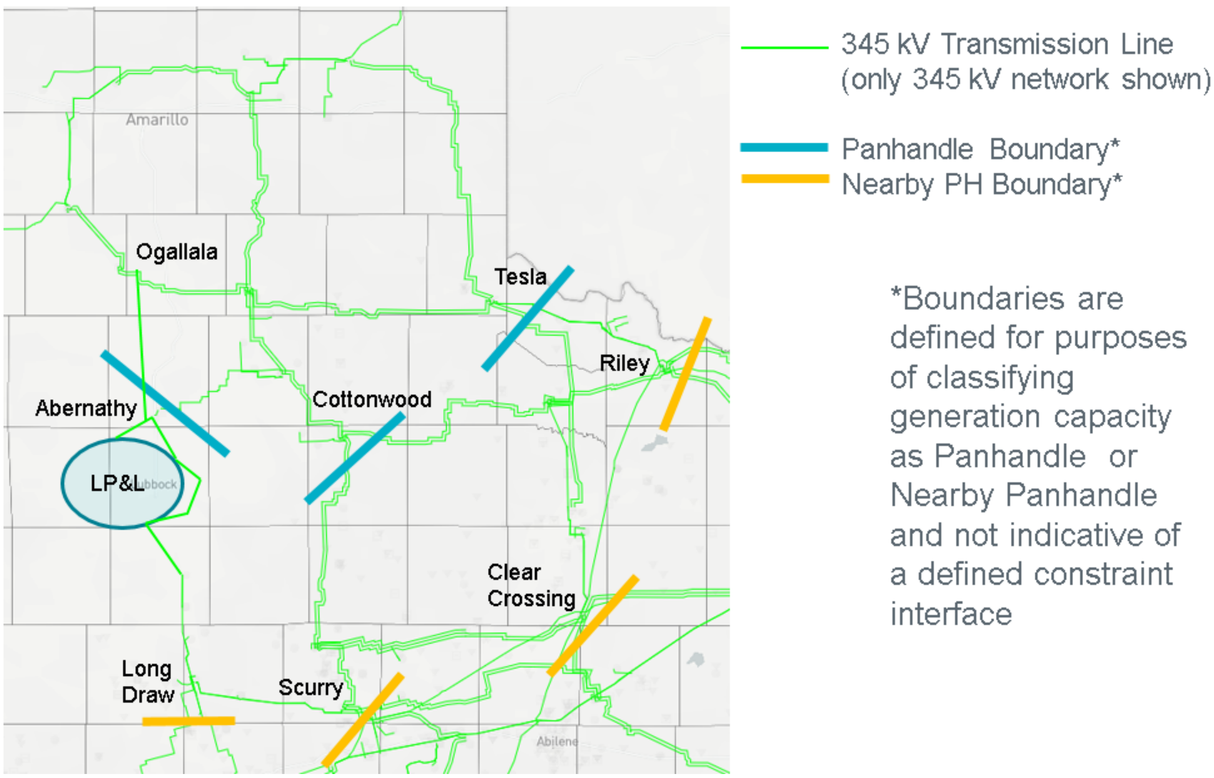


Figure 2. Illustration of the Panhandle and Nearby Panhandle boundaries

2. Study Cases and Tools Development

Study cases were developed to evaluate stability in the Panhandle and Nearby Panhandle regions using both positive sequence dynamic stability simulations in PSS/e and electromagnetic transient (EMT) stability simulations in PSCAD. The following software was used for the evaluations:

- PSS/e: version 33.12.1
- PSCAD: version 4.6.3 with IVF 12.1.4

2.1. PSS/e Case Development

The DWG 2022 High Wind Low Load (HWLL) case was used as the starting case to develop the study cases. Generation meeting Planning Guide Section 6.9 requirements in the study region were added to the base case. In addition, the following adjustments and assumptions were made in the PSS/e study case development:

- Conventional power plants in West Texas including in the Panhandle, Nearby Panhandle and LP&L regions were turned off;
- IBRs in the Panhandle and Nearby Panhandle regions were dispatched at full output;
- Two synchronous condensers in the Panhandle region were in-service;
- The LP&L low load was at 35% of its peak forecast;
- Two planned IBR projects with a total of 454 MW in the Nearby Panhandle region were represented without dynamic responses[3] due to model unavailability at the time of study;
- Based on the recent West Texas Export Stability Study[4], the total export flows on the sixteen 345 kV lines described in the study report were maintained at approximately 11.2 GW.

2.2. PSCAD Case Development

For the selected PSS/e scenarios, the corresponding PSCAD scenarios were developed to evaluate the stability issues which might not be captured by the positive sequence dynamic simulations, such as IBR control instabilities associated with low system strength. Accurate evaluation of such phenomena requires the use of detailed PSCAD models.

To have consistent system topology between PSS/e and PSCAD simulations, the PSS/e powerflow case was used and converted to a PSCAD case via ETRAN V5 software which leverages a pre-set up contingency substitution library as well as a parallel case substitution library to represent IBRs, two synchronous condensers and 2 SVCs in the study region. In addition, the following adjustments and assumptions were made in the PSCAD study case development:

- Two IBR projects with a total of 313 MW located in Nearby Panhandle region which are connected to the 138 kV system were not explicitly modeled in the PSCAD case (but were

[3] i.e. GNET or represented by a negative load.
[4] http://www.ercot.com/content/wcm/lists/197392/2020_West_Texas_Export_report_final.pdf

considered in the network equivalent), assuming the electrical distance is large enough for them to have limited impacts on the 345 kV transmission grid stability.

- Two IBR projects with a total of 454 MW that were represented without dynamic responses in the PSS/e cases (GNET) were not modeled in the PSCAD case. The conversion of GNET representation in the PSCAD case requires the use simple voltage source models. However, the use of these models could lead to optimistic system strength improvement that would not otherwise be provided if the IBRs are represented by actual PSCAD models. Therefore, these two IBR projects in the Nearby Panhandle region were not modeled in the PSCAD case.
- Four projects (930 MW) were lacking power plant controllers (PPC) models.

The PSCAD cases primarily include generators and transmission elements connected to the 345 kV transmission grid in the Panhandle and Nearby Panhandle region. The rest of the ERCOT system was represented by a multiple terminal static equivalent network beyond the Nearby Panhandle boundaries as shown in Figure 2. A total of 46 IBR projects in the study region were modeled and 43 PSCAD cases (1 master and 42 slave cases) were created for parallel simulations. The master case and slave cases were linked together following the Etran+ parallel for PSCAD simulation via TCP/IP ports during the simulation. The layout of the final PSCAD case is illustrated in Figure 3.

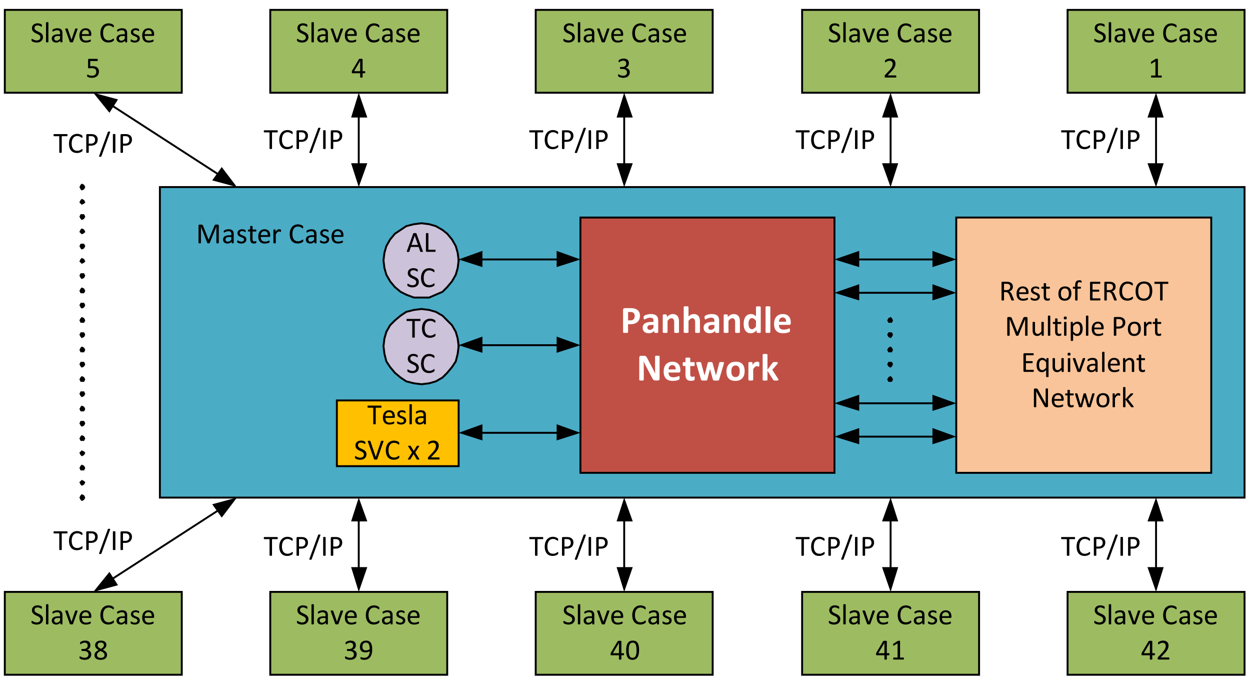


Figure 3. Illustration of PSCAD parallel case set up

Table 1 shows the model summary of the IBRs in Panhandle and Nearby Panhandle.

Table 1. Model Summary in 2020 Panhandle Stability Study

	Panhandle		Nearby Panhandle	
	# of Projects	Capacity (MW)	# of Projects	Capacity (MW)
Total IBR Projects	26	5,223	24	5,304
Projects with PSS/e Dynamic Models	26	5,223	22 (and 2 GNET)	4,850
Projects with PSCAD Dynamic Models	26	5,223	20 (4 not included)	4,537

2.3. Contingency Descriptions

With the assumption that the faults applied on either end of a transmission line have a similar effect, a set of 36 contingencies covering most 345 kV circuits in the Panhandle and Nearby Panhandle region were tested in both PSS/e and PSCAD simulations. Both three-phase fault with a 4-cycle clearing time and no fault were considered in the tested contingencies.

2.4. Study Methodology and Criteria

The methodology adopted in the PSS/e studies is described below:

- All IBRs in the Panhandle and Nearby Panhandle regions were initially dispatched at full output which was named PH100NP100;
- Conducted contingency studies of PH100NP100 case to evaluate the stability within the study region;
- Adjusted IBR the dispatch level within the study region to evaluate the stability of different scenarios, such as PH80NP100, etc. The total export flows on the sixteen 345kV lines referenced in the section 2.1 above were maintained at approximately 11.2 GW;
- Revised the Panhandle interfaces, and evaluated the stability of the tested scenarios;

Prior to performing PSCAD simulations, selected PSCAD models were reviewed and Resource Entities were informed to update the models as necessary. The PH100NP100 scenario was evaluated with PSCAD simulations. Additional scenarios were selected for evaluation with PSCAD based on PSS/e simulation results.

In the PSS/e simulations, selected ERCOT 345 kV transmission buses in the study region were monitored for frequency and voltage deviations in the simulations. Real and reactive output for all generating units were monitored. 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, IBRs tripped by voltage protection relays, etc.).

In the PSCAD simulations, channels including the following quantities for each IBR were recorded: real and reactive outputs, the RMS and instantaneous voltage at each point of interconnection (POI), trip signals if available. For transmission lines, the power flowing through each line and the voltages at both terminals were recorded. Quantities associated with SVCs and synchronous condensers were also monitored for performance review.

2.5. PSCAD Study Automation Tool Development

A PSCAD Auto Run (PCAR) tool was developed in this study to facilitate the model quality review and to facilitate the PSCAD parallel simulations. PCAR is a Python based tool utilizing the PSCAD automation library. PCAR supports multiple runs and reduces the manual simulation processes. Overall, PCAR reduces the PSCAD case building time and allows the engineer to focus on the system study and results analysis.

The PCAR tool currently includes 7 modules for PSCAD model quality review and one module for PSCAD parallel simulation.

- VUP (Voltage step up test)
- VDW (Voltage step down test)
- LVRT (Low voltage ride through test)
- HVRT (High voltage ride through test)
- AUP (Phase angle step up test)
- ADW (Phase angle step down test)
- SCR (Short circuit ratio/System strength test)
- PRLLe (Parallel simulation for Etran+)

3. Study Results

3.1. PSS/e Simulation Results

The PH100NP100 scenario was initially tested and dynamic voltage instability was identified. The plots of several 345 kV bus voltages in the study region are shown in Figure 4 for one of the tested three phase fault contingencies. Instability was also observed in some of the tested no-fault contingencies and an example of this instability is shown in Figure 5 which features plots for voltages at the same buses as Figure 4.

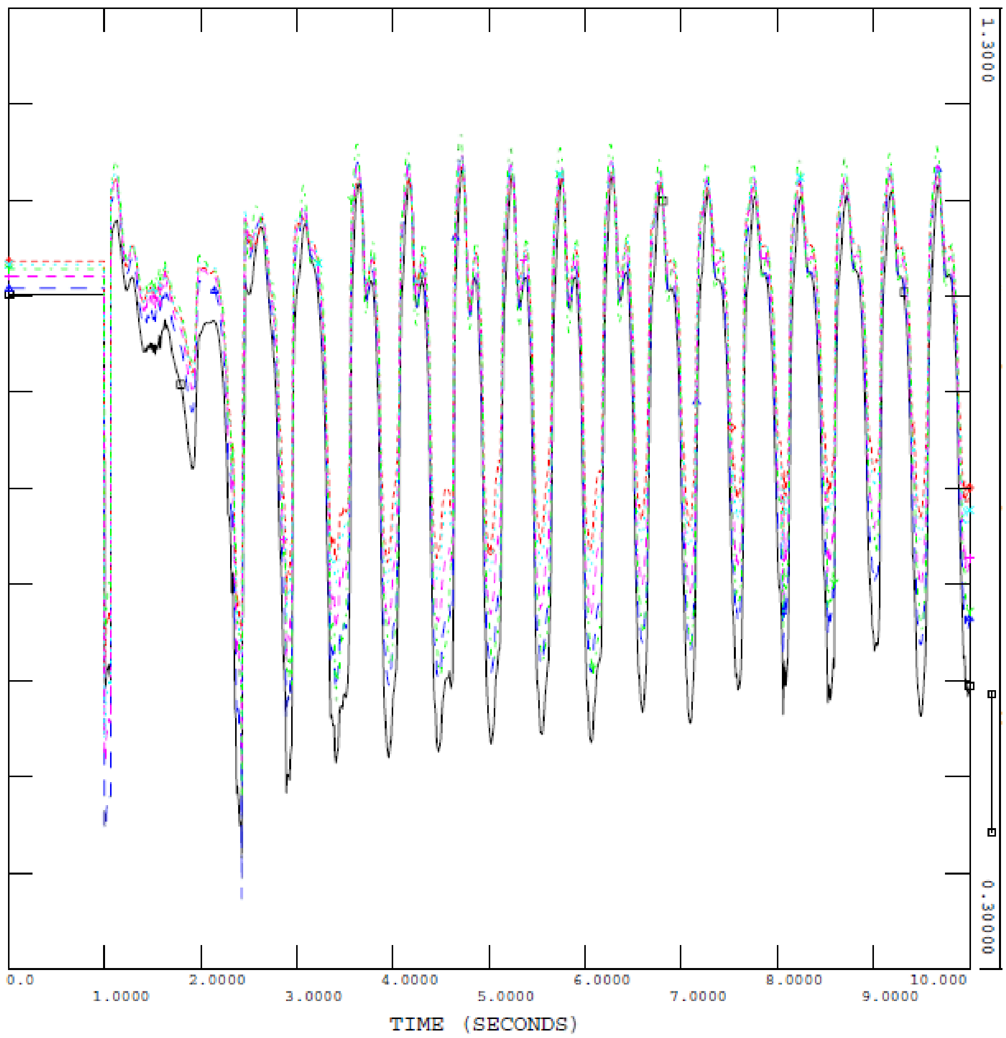


Figure 4. Dynamic voltage instability for PH100NP100 faulted scenario.

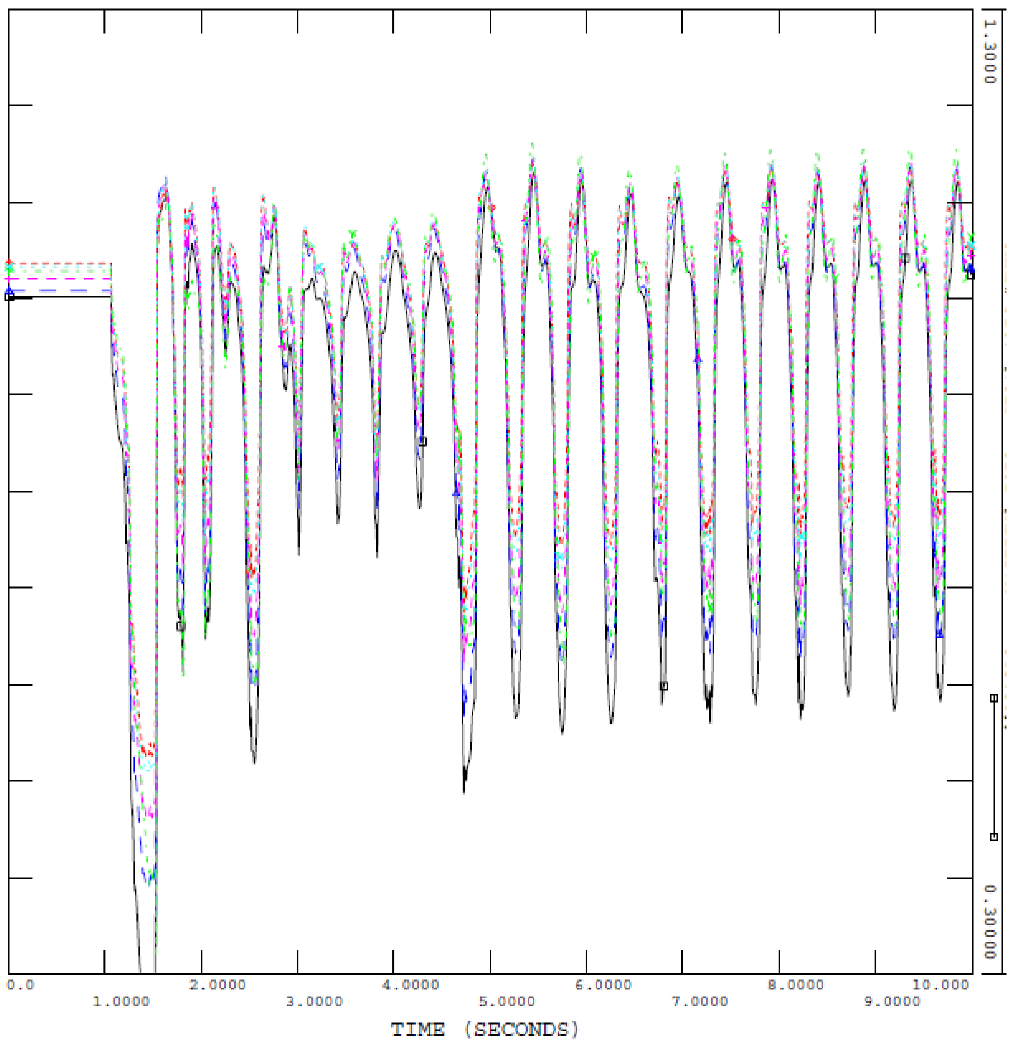


Figure 5. Dynamic voltage instability for PH100NP100 no-fault scenario.

In order to obtain acceptable responses, the Panhandle and Nearby Panhandle generation dispatch was reduced to 80% (PH80NP80). For a sensitivity study, the Panhandle dispatch was reduced to 80% while the Nearby Panhandle generation dispatch was kept at full output (PH80NP100). Acceptable responses were also obtained for the PH80NP100 scenario, therefore, additional curtailment in the Nearby Panhandle region did not improve stability performance and does not appear to be warranted at this time. Another sensitivity study was conducted to examine the effects of the reverse assumption, meaning that the IBRs in the Nearby Panhandle region were curtailed rather than keeping those in the Panhandle region curtailed (PH100NP80). For the PH100NP80 dispatch case, dynamic voltage stability issues were identified.

The reactive power losses on the 345 kV transmission lines within the study region were calculated for PH80NP100 and PH100NP80 scenarios and are tabulated in Table 2. It is apparent from Table 2 that the total active power generation in the Panhandle and Nearby Panhandle regions are comparable in both cases. This is due to the fact that in this study, the IBR capacity in the Panhandle and Nearby Panhandle regions are nearly the same. However, it is observed that the reactive power losses can be reduced by more than 27% if the IBR units located in the Panhandle region are curtailed rather than those in the Nearby Panhandle. Considering the situation that voltage stability and reactive support are critical for dynamic stability in the Panhandle and Nearby Panhandle regions, it is deemed that controlling the Panhandle generation output is a proper approach in order to maintain the system stability in this region at this time.

Table 2. Reactive Power Losses in the Study Region

	Total Dispatch (MW)	Reactive Power Losses (MVAr)
PH80NP100	9,023	2,051
PH100NP80	9,095	2,827

With transmission upgrades associated with the LP&L integration providing an additional transfer path out of the Panhandle region, a sensitivity test was also conducted to determine the proper interface to manage the stability in the Panhandle region. The interface was determined based on the following considerations:

- The major flow paths for the Panhandle export
- The critical contingencies and location of instability
- Effectively managing the Panhandle generation output

Since the analysis results for the PH80NP80, PH100NP80 and PH80NP100 scenarios do not indicate benefits for expanding the area behind the interface, it was deemed appropriate to monitor flows into Abernathy from White River and Ogallala as part of the interface definition after the integration of LP&L. Additional modifications to the interface involved considering flows into Cottonwood from White River instead of flows out of Cottonwood to Edith Clarke and Dermott and considering flows into Riley from Jim Treece and Tesla instead of the flows out of Tesla to Jim Treece and Riley. Simulation results showed no significant difference in stability performance when considering the interface modifications described above. Therefore, the following interface is proposed:

- Tesla – Riley and Tesla – Jim Treece (Measured at Tesla)
- Tesla – Edith Clarke double circuit (Measured at Tesla)
- White River – Cottonwood double circuit (Measured at Cottonwood)
- Ogallala – Abernathy (Measured at Abernathy)
- White River – Abernathy (Measured at Abernathy)

The proposed new Panhandle interface is illustrated in Figure 6 and will require further review. As summarized in Table 3, the proposed interface allows a slight increase to the overall Panhandle and Nearby Panhandle generation while not significantly impacting stability performance.

Table 3. Comparison of MW Output and Stability Performance with New Interface

	PH80NP100 Original Interface	PH80NP100 New Interface
Total Panhandle and Nearby Panhandle Output (MW)	9,023	9,071
Stable	Yes	Yes

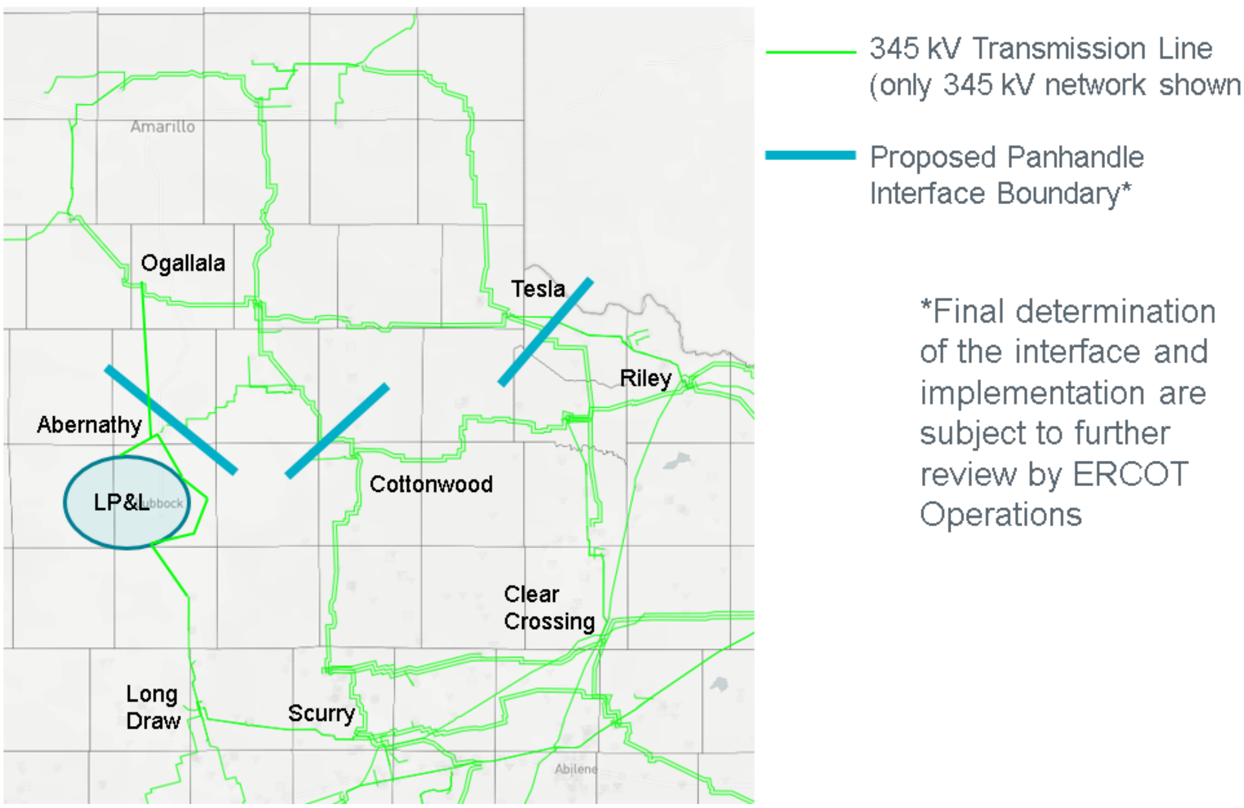


Figure 6. Illustration of the proposed Panhandle interface after LP&L integration

3.2. PSCAD Simulation Results

PSCAD runs were conducted based on selected PSS/e scenarios. The increasing number of transmission elements and generation projects modeled in the PSCAD cases has significantly increased the complexity of PSCAD case development and computation time. Each PSCAD run in this study required 43 CPU threads (1 master case and 42 slave cases as shown in Figure 3) for the parallel processing. For a single contingency test with a 30-second run, it took around 2.5 hours and produced approximately 3.4 GB of simulation result data. To run multiple scenarios and contingencies, the PCAR tool developed in ERCOT was used to help facilitate the study process and review the large amount of simulation results.

The PSCAD simulation results showed no system wide instability issues. Due to the model availability and assumptions made in the PSCAD cases, as listed in Table 1, only 85% of IBRs in the Nearby Panhandle region were explicitly represented with PSCAD models. Therefore, PSCAD results that show better dynamic performance could be due to less total generation output. Even though no instability was observed, multiple IBRs were observed to trip in the simulations. The largest trip amounts were less than 1 GW and didn't lead to voltage collapse or cascading. There was no significant tripping amount variations between the PH100NP100 and PH80NP100 scenarios. This result is because there were fewer IBRs modeled in the PSCAD case, as listed in Table 1, which reduced the system stress within the PSCAD study case.

3.3. Performance Comparison between PSS/e and PSCAD Results

For the stable scenarios, the overall performances from PSCAD simulations were consistent with that from PSS/e simulations. A typical pair of plots from PSCAD and PSS/e simulations for the same contingency is shown in Figure 7. It is noted that the generation difference over the pre-contingency duration was due to the fewer IBRs with PSCAD models as listed in Table 1. The post-contingency total power difference also reveals that there was some difference in IBR tripping amount. This is due to the different modelling approaches adopted in PSS/e and PSCAD. Other than these static differences, the overall dynamic performances between the two platforms matched well to each other.

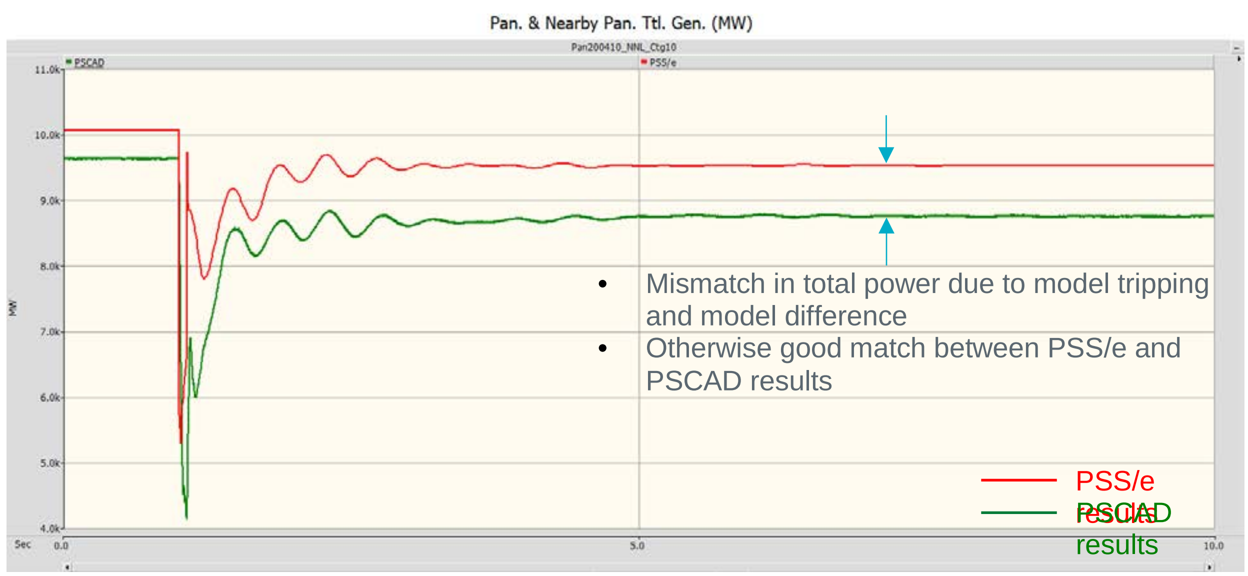
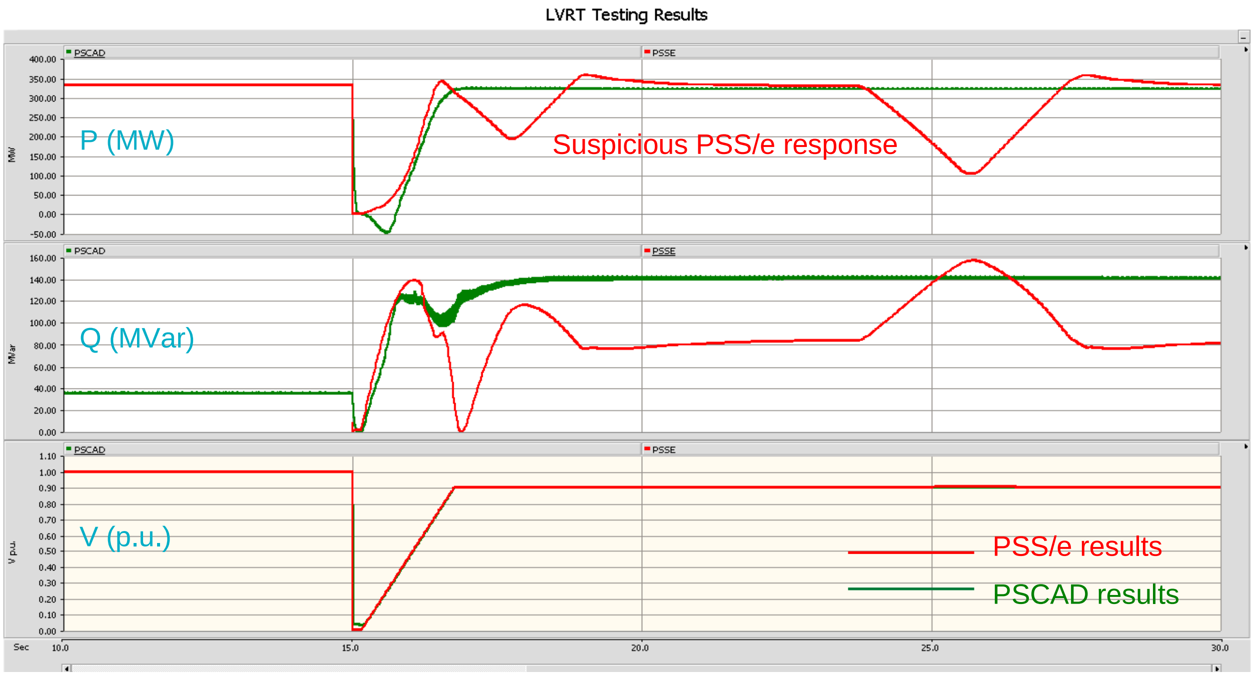


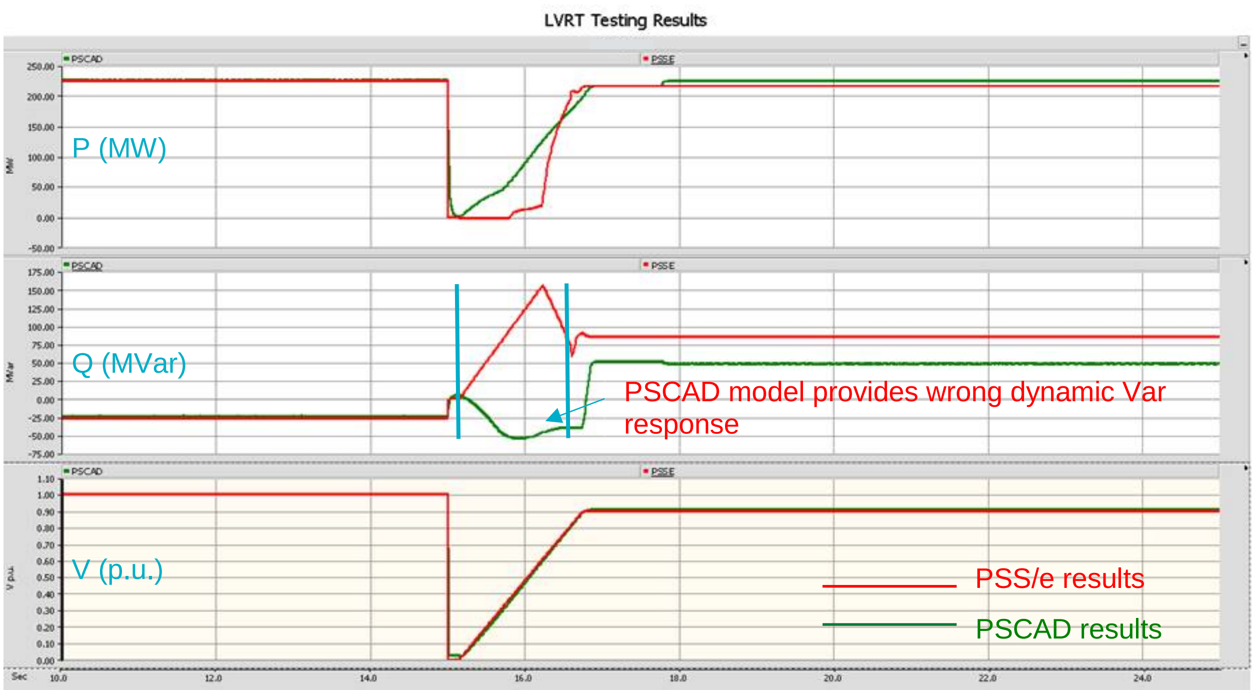
Figure 7. Simulation results comparison between PSS/e and PSCAD of the total generation in Panhandle and Nearby Panhandle regions (for PH100NP100 scenario, Ctg. #10)

3.4. Individual Model Performance Comparison between PSS/e and PSCAD

Selected PSCAD models for IBRs were reviewed through model quality tests and comparison with the corresponding PSS/e models. This process was meant to assess the model performance at the beginning stage and to improve the individual model quality before they were integrated into the system cases, such that a higher fidelity of the system wide study can be achieved. Three selected test results are presented in Figure 8 to show the identified modeling inconsistency and the need to require further improvement of the dynamic models submitted by the developers and Resource Entities.



(a)



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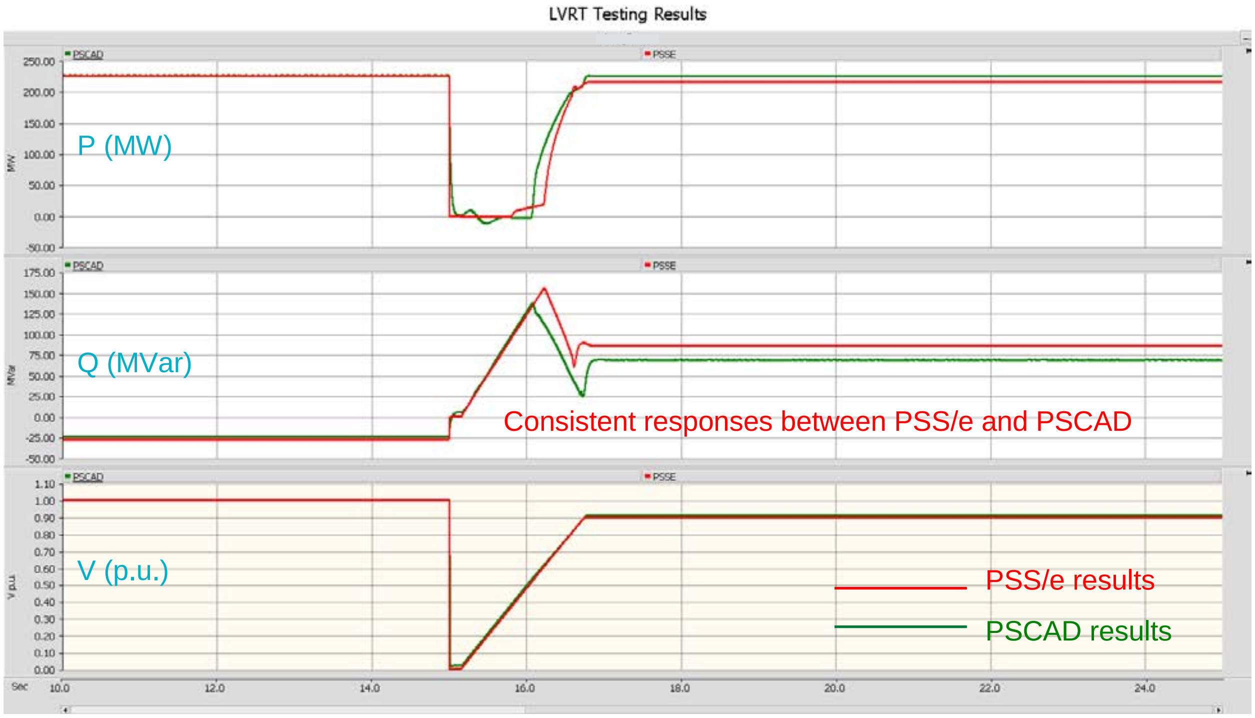


(c)

Figure 7. Individual model quality test results comparison between PSS/e and PSCAD

It can be seen from Figure 8(a) that this IBR PSS/e model showed suspicious responses (i.e., multiple real power dips during post-disturbance) while the PSCAD model showed reasonable response. In Figure 8(b), the IBR PSCAD model exhibited incorrect dynamic reactive power response during the transient period, which was absorbing reactive power rather injecting to provide voltage support. Resource Entities were notified when such model performance results were observed and requested to resolve model performance issues and inconsistencies. In this case, the Resource Entity provided revised site models which were re-tested and showed good matches between the PSS/e and PSCAD results, as shown in Figure 8(c).

4. Findings and Recommendations

This section summarizes the key findings and recommendations identified in this study.

- Instability was observed when generation in the Panhandle and Nearby Panhandle regions was at 100% of capacity. Limiting Panhandle generation to 80% of capacity was effective in mitigating the observed instability. It should be noted that Panhandle and Nearby Panhandle output may also be impacted by other stability constraints such as a potential West Texas Export constraint. The assumptions in this study ensured that West Texas export levels remained below export limits identified in previous planning studies.
- Planned transmission upgrades associated with LP&L integration improve the stability and system strength in the Panhandle region and are aligned with the Stage 2 upgrades as referenced in the exit strategy for the current Panhandle GTC. There were no widespread control instabilities related to low system strength identified in this study. Transmission upgrades associated with the LP&L integration are a key contributor to this result.
    - With increasing IBR installations in the Panhandle and Nearby Panhandle regions, the proposed GTC exit options should be re-evaluated in the future.
- Following the integration of LP&L, it is proposed that the Panhandle interface be revised to include the following 345 kV circuits:
    - Tesla – Riley and Tesla – Jim Treece (Measured at Tesla)
    - Tesla – Edith Clarke double circuit (Measured at Tesla)
    - White River – Cottonwood double circuit (Measured at Cottonwood)
    - Ogallala – Abernathy (Measured at Abernathy)
    - White River – Abernathy (Measured at Abernathy)
- The Panhandle GTC limits are currently determined by the pre-contingency weighted short circuit ratio (WSCR) threshold of 1.5, the PV voltage stability and offline dynamic voltage stability studies. With increasing Nearby Panhandle IBRs, LP&L integration and the associated 345 kV transmission lines which provide an additional outlet for the Panhandle region, the system assumptions associated with calculating and applying the WSCR metric will no longer be valid. Therefore, WSCR is considered an inadequate metric to effectively and consistently reflect the system strength in the Panhandle region after LP&L integration, but the actual implementation of its retirement will be subject to review by ERCOT Operations.
    - Potential system strength issues should still be evaluated, especially under prior outage conditions and as IRR levels continue to increase. However, voltage stability limits are expected to be more binding in the near term.
    - An alternative metric or methodology to properly represent the Panhandle system strength should be further investigated.

- PSS/e is still the primary dynamic simulation tool for stability studies. PSCAD study is needed to compare and verify the PSS/e study results in regions with a high penetration level of IBRs like the Panhandle and Nearby Panhandle. PSCAD studies are necessary to evaluate potential control stability issues in the Panhandle and Nearby Panhandle regions. To better evaluate the stability in this region, the detailed network around the study region will need to be expanded. Information highlighting the PSCAD case expansion since the 2016 study is summarized in Figure 9. The ellipses shown in Figure 9 illustrate that since the 2016 study the Nearby Panhandle boundary has expanded significantly, increasing the study region, number of IBRs, computation burden and complexity of the studies. The bar charts show the increasing trend of total IBR capacity in the Panhandle and Nearby Panhandle regions modeled in the PSCAD studies.
    - Both PSCAD and PSS/e dynamic simulations should be performed when evaluating the stability in the Panhandle region.
    - To better evaluate the Panhandle and Nearby Panhandle region stability, a detailed network around the study region might need to be expanded a few buses away from the current boundaries. This might include some downstream 138 kV system components or a hybrid simulation incorporating both PSS/e and PSCAD may become necessary.
    - A larger scale PSCAD study, covering wider areas of West Texas, may be required in the future. ERCOT is collaborating with consultants, software vendors and industry partners to explore potential options to improve the simulation efficiency.
    - The creation a model repository to archive site specific PSCAD models in a systematic way, including provision of the model information such as critical parameters, PSCAD version, compiler version, etc. should be considered.

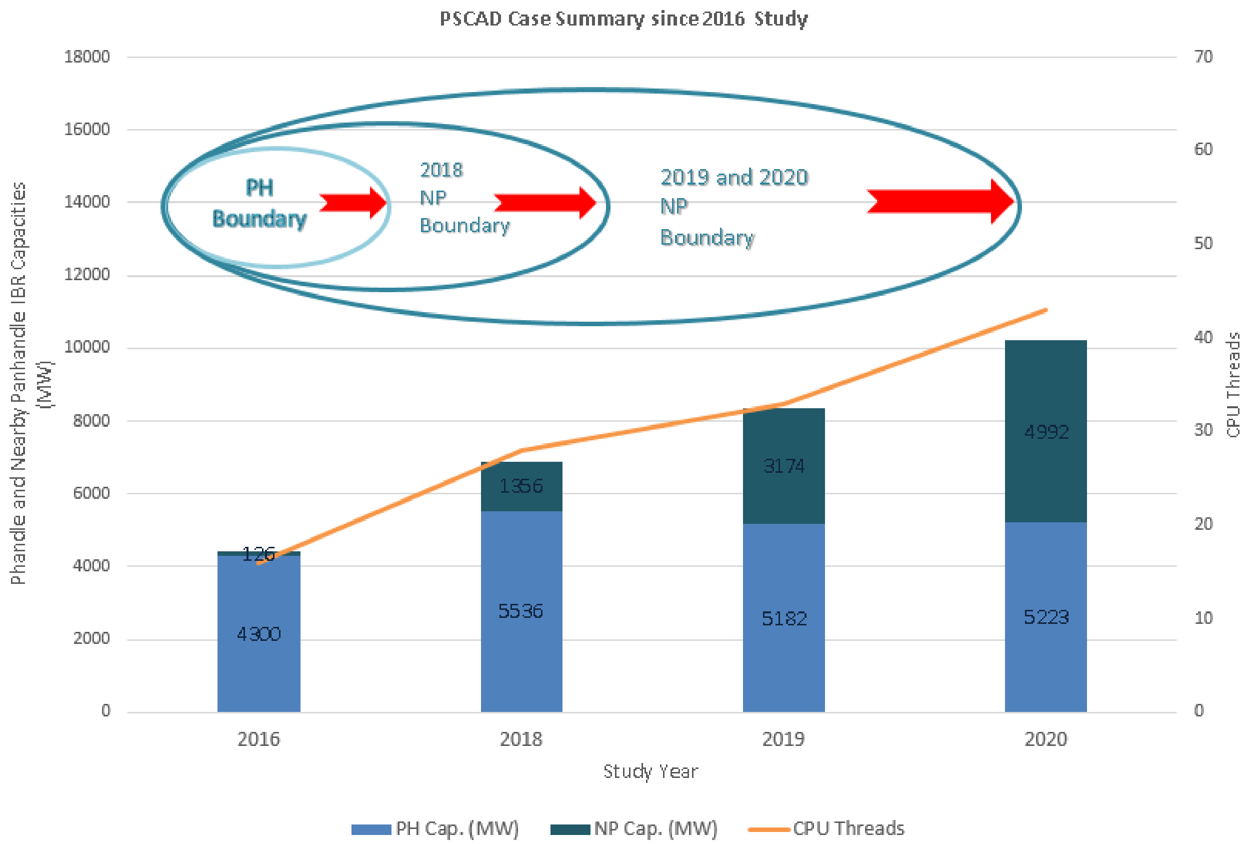


Figure 8. PSCAD case expansion since 2016 study

- Although PSCAD models are expected to better reflect certain performance details of IBRs that are either simplified or ignored in the positive sequence model (e.g. PSS/e dynamic model), the verification of PSCAD models is imperative to ensure the model can accurately represent the dynamic response of an IBR and can be used to benchmark the positive sequence model. The model review and update process can be tedious, time consuming and often requires support from Resource Entities, manufacturers, consultants, and Transmission Service Providers (TSPs). Some PSCAD model issues (e.g. suspicious trip during simulation, incorrect rated capacity in the model, inconsistent response between different PSCAD software versions and Fortran compilers) were identified and communicated to the Resource Entity during the model test stage, but not all of these issues were resolved.
    - There is a need to continue work with stakeholders to adopt the dynamic model validation and verification process as soon as possible to better address the dynamic model issues, including both PSS/e and PSCAD models, in an efficient way, such that the system wide stability evaluation cycle can be shortened with higher fidelity.

    - It is recommended that the PSCAD and IVF version information used for model development need to be included in the model documentations, such as the model manual or the ERCOT PSCAD model request form[5].

- Numerical and solution issues that caused suspicious oscillatory responses or simulation crashes were experienced while conducting PSS/e dynamic simulations. After some initial investigation into what was causing this issue, it was determined that simulation crashes could be impacted by the acceleration factor, which is a dynamic simulation parameter. Subsequent investigations and sensitivity analysis identified that decreases in this parameter value could resolve simulation issues for scenarios that previously crashed. However, this parameter adjustment also produced slightly different simulation results for other contingency scenarios. Simulation sensitivity to this acceleration factor appears to be prevalent when system conditions are near stability thresholds or when stressed system conditions (e.g. weak grid) are being modeled.
    - Further investigations into the tool and models are being conducted.
- Observed IBR tripping in the PSS/e simulations was primarily due to transient overvoltage which occurred immediately following the fault clearing. Sensitivity studies were performed by disabling the transient overvoltage protections in this study to verify that there is no incremental instability issue caused by disabling the transient overvoltage relays. The transient overvoltage issue could be further exacerbated with continuous growth of IBRs under weak grid conditions.
    - Options to mitigate the transient overvoltage includes reducing IBRs' output, adding transmission elements and dynamic reactive devices.
- Different types of poor recovery and oscillatory responses were observed during PSCAD simulations, including 1) sustained oscillatory response, 2) reverse real power flow to the project, 3) large real power dips, 4) large power swings. Such performance may be due to model issues or may be an indicator for potential control instabilities as IBR penetrations in the Panhandle and Nearby Panhandle regions continue to increase. Figure 10 shows the oscillatory responses (red color) observed for an IBR project tested in the PH100NP100 scenario and was damped out (green color) for the PH80NP100 scenario. More examples are shown in Figure 11 corresponding to different types of poor responses. It is noted that the reasons behind these performances were complex and dependent on the system operational condition and on the interactions between the IBR's control system and connected transmission grid. For example, the reverse real power shown in Figure 11(a) reveals that the control parameters inside of the IBR model may not be tuned properly to work well at this site's connection point. To fine tune the parameters would need further investigations, involving more details of the site model, which is beyond the scope of this study.

[5] http://www.ercot.com/content/wcm/lists/168307/PSCAD_Model_Guideline_Checksheet_2019.docx

- For the identified modeling issues, ERCOT will continue to work with the Resource Entities to review model responses and obtain an updated model if necessary.

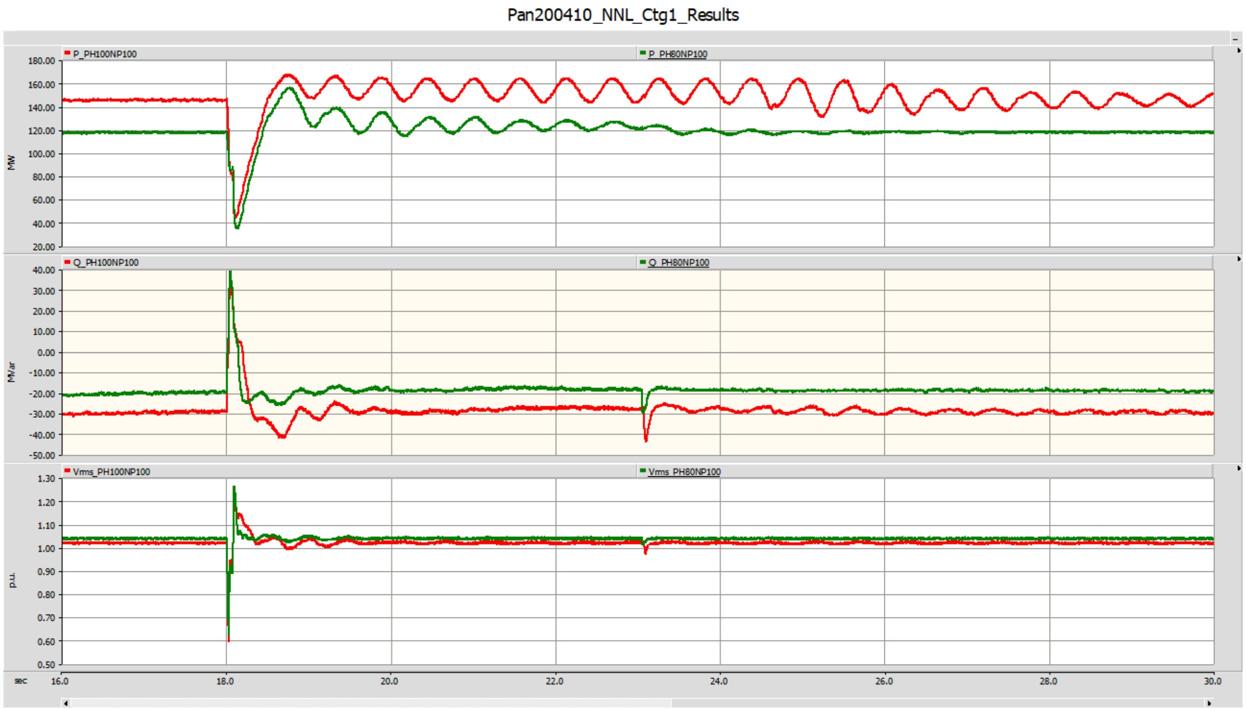
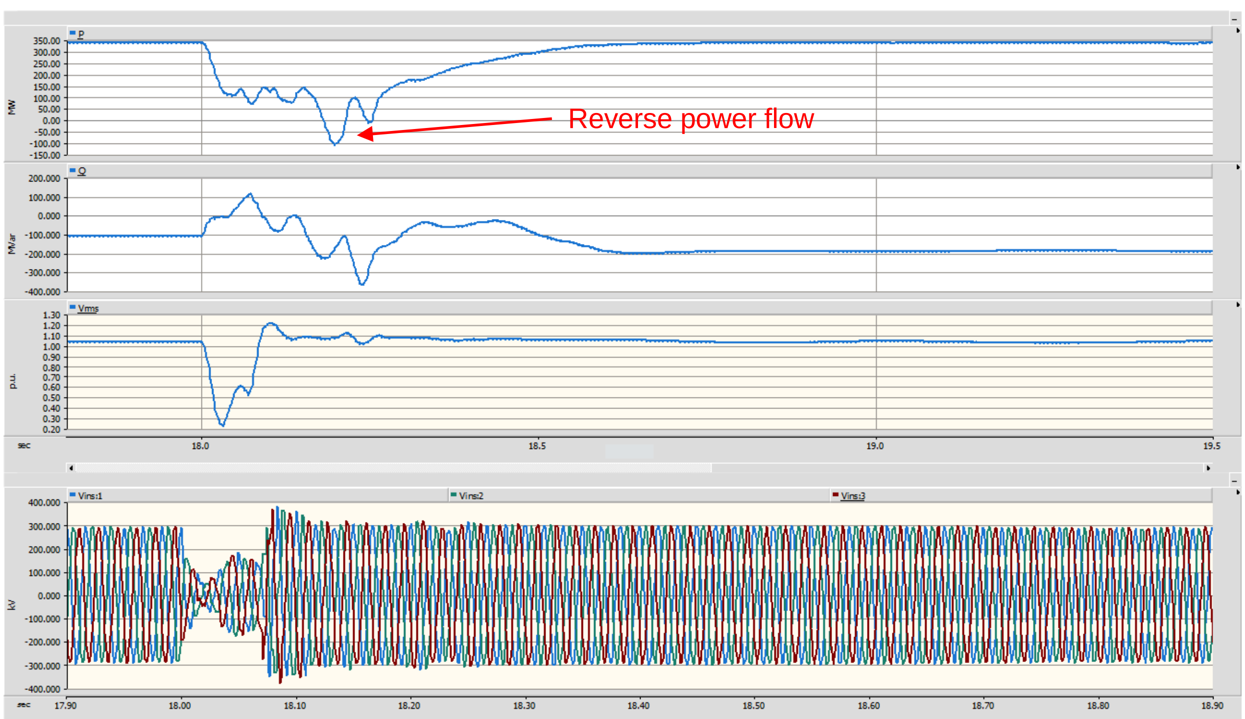
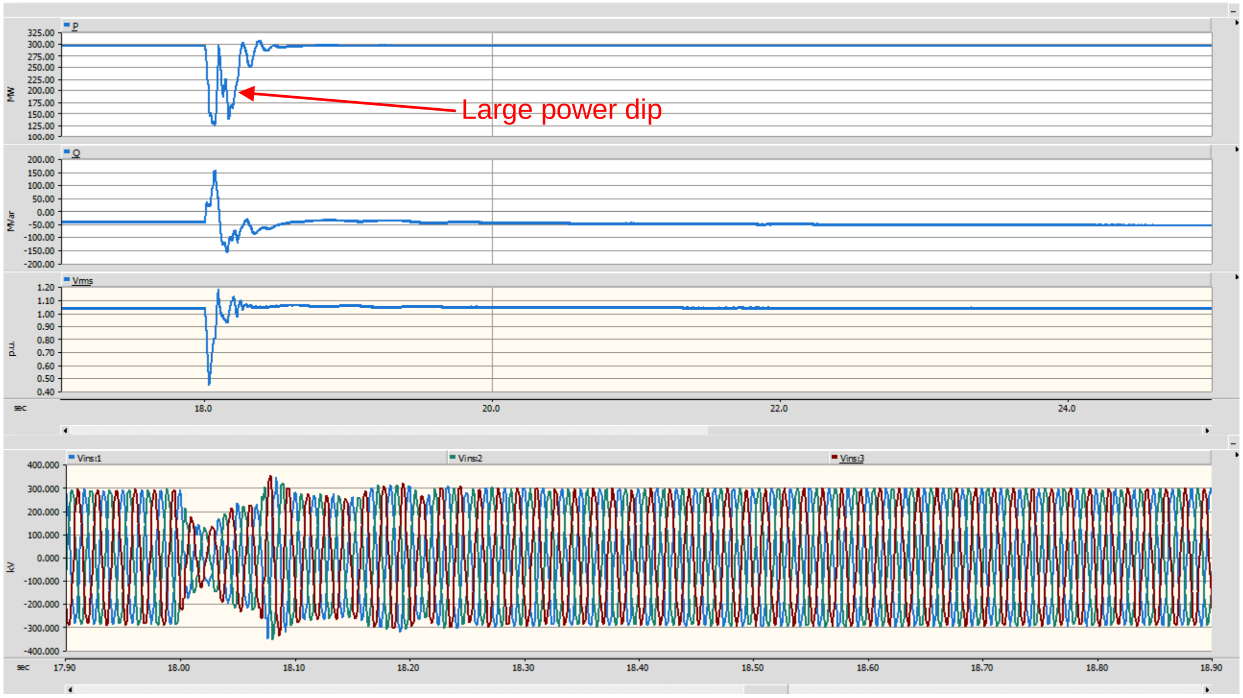


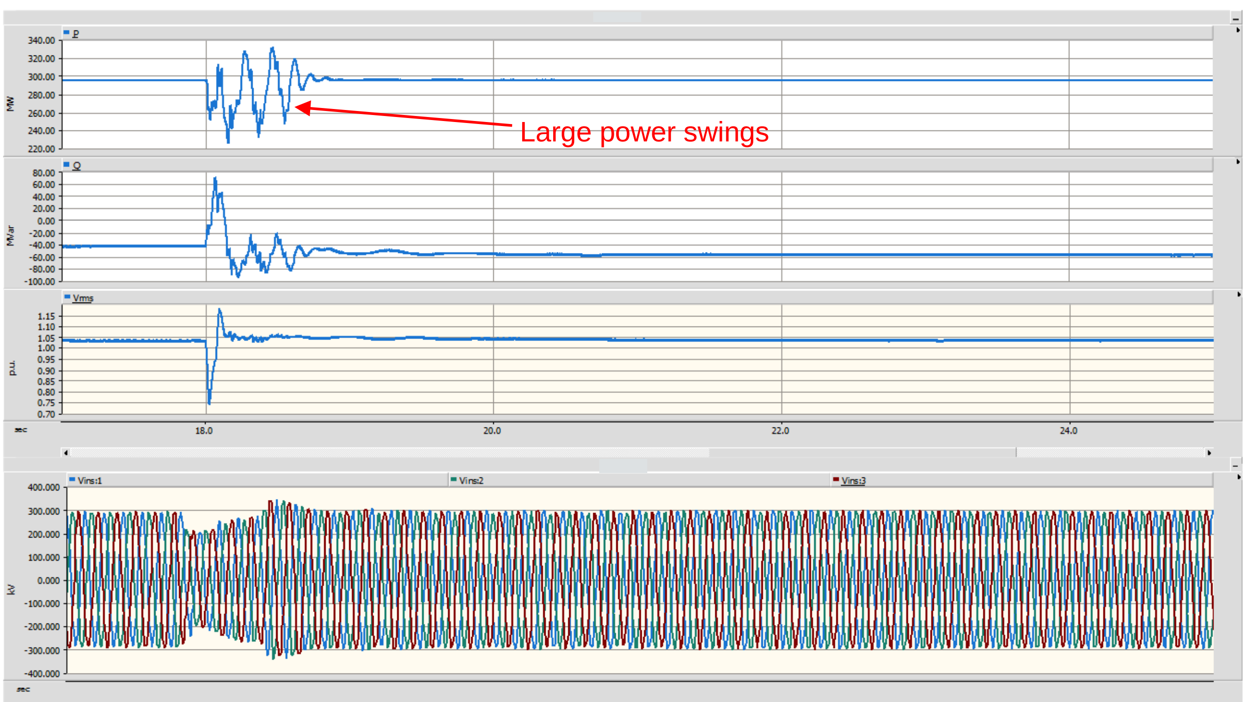
Figure 9. Sustained oscillations from one site were damped with system strength increased (for PH100NP100 and PH80NP100 scenarios, Ctg. 1)



(a) Reverse real power flow (for PH80NP100 new interface scenario, Ctg. 24).



(b) Large real power dip (for PH80NP100 new interface scenario, Ctg. 28).



(c) Large real power swings (for PH80NP100 new interface scenario, Ctg. 4).

Figure 10. Different types of poor recovery performances