Panhandle and South Texas Stability and System Strength Assessment

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Report Submitted to:
Electric Reliability Council of Texas, Inc.

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1.0 Executive Summary

1.1 Background

A detailed PSCAD analysis[1] was conducted in 2016 in the Panhandle Region evaluating the integration of a large amount of wind generation capacity. The study identified system challenges, including dynamic stability and low system strength limitations. The study also proposed some potential upgrade options and tested a new wide-area system strength metric called “Weighted Short Circuit Ratio” (WSCR). Since the completion of the 2016 study, a significant amount of new wind generation projects have satisfied ERCOT Planning Guide 6.9 requirements in both the Panhandle region and in the South region. Electranix has carried out a new analysis to validate and further explore past work under updated system conditions, as well as testing certain recommendations from the prior Electranix report.

1.2 Objectives

The objectives of this study are as follows:

a) Evaluate dynamic performance of selected planned scenarios in both the Panhandle and the South Texas systems.
b) Review the WSCR-based planning and operating thresholds proposed by ERCOT in the Panhandle, and propose adjustments if necessary.
c) Determine applicability of WSCR or similar metrics for real-time operations in the South Texas system.
d) Provide recommendations on area-wide voltage regulation strategies in the Panhandle.
e) Explore the impact of load distribution on low system strength grid issues, as well as exploring the impact the level of detail in load modelling can have on wide-area studies of this nature.
f) Transfer study tools and knowledge to ERCOT engineers.

1.3 Recommendations and Observations

The following are summaries of the recommendations and results from this analysis. Care should be taken in extrapolating these results and conclusions beyond the scope of work covered in this effort.

1.3.1 Dynamic performance in Panhandle

The cases chosen for detailed study in the Panhandle region represented transmission faults and outages during high wind scenarios, based around the WSCR metric threshold of 1.5 prior to outages occurring. In general, these cases and outages performed acceptably. However, several issues were noted, including failure of individual wind plants to recover from faults and line outages. In general these were constrained to local events, and did not result in wide-spread loss of generation. **The failure of these individual plants to ride-through close-in contingencies should be further examined and mitigated if possible.**

1.3.2 Dynamic performance in South Texas system

The cases chosen for detailed study in the South Texas network represented transmission faults and outages occurring while the network was stressed by high wind output and no thermal generation committed in the South Texas System. These cases demonstrated numerous dynamic performance issues, including the following:

- Individual wind plants failed to recover and tripped following most contingencies. The cause of tripping varies between event transients (insufficient FRT capability), control oscillations, and insufficient voltage

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[1] System Strength Assessment of the Panhandle System PSCAD Study – February 2016, Available at: http://www.ercot.com/content/news/presentations/2016/Panhandle%20System%20Strength%20Study%20Feb%2023%202016%20(Public).pdf

support. In some cases, loss of wind generation was spread across a wide region and amounted to significant portions of the total amount of South Texas generation.

- Voltage control following contingencies was poor in the region. This is due to slow or absent wind plant voltage controllers in many of the PSCAD models. Additionally, dynamic reactive device models in the region were approximated and used generic control parameters and topologies.
- The presence of series capacitors introduces risk of instability, particularly when wind plants are left radially connected through the capacitors following a fault.
- Many of the issues observed were highly dependent on model assumptions or depended on old or poor quality vendor models.

Based on this analysis the future scenarios as studied are currently prone to risk of uncontrolled tripping and unstable oscillations. Anticipating more renewable generation will be added in the South Texas region, model quality improvement are highly recommended and a follow up study should be conducted soon to verify and mitigate the issues identified in this study.

1.3.3 Weighted Short Circuit Ratio (WSCR)

The WSCR level of 1.5 in the Panhandle (representing a 70% dispatch of existing and planned resources) has been reviewed and confirmed to be acceptable. A WSCR level of 1.0 (representing 100% dispatch of planned resources) was also tested using detailed models and has been shown to provide insufficient strength for the renewable connections to operate reliably. Additional sensitivity testing was performed to evaluate several intermediate conditions (for example prior outage conditions), and these tests indicate that there may be intermediate WSCR levels (eg. 1.4) which can operate stably, although these would require further analysis to determine. It should be noted that any potential for lowering the WSCR limit (increasing Panhandle output) may be offset by wind expansion beyond the Panhandle boundary.

Prior work evaluating WSCR metrics in the Panhandle was based on a very high concentration of wind connecting to a new dedicated 345 kV transmission buildout. As heavy wind penetration continues to expand further into the main Texas network (encompassing more complex network topologies and load regions), precise definition of WSCR boundaries will become more difficult to determine. Further expansion beyond what was modeled in this study could have an impact on WSCR metrics and should be assessed for reliability impacts.

Since WSCR is based on relatively simplistic assumptions pertaining to system strength provided by conventional synchronous machines, it becomes less and less useful as the balance of generation swings towards renewables. If WSCR is no longer applicable at some future point, regular off-line PSCAD studies may be a necessity.

The WSCR metric was also evaluated in the South Texas system. It was determined that this metric has several limitations when applied in a region such as the South Texas system, including:

- Susceptibility to variations in load.
- Difficulty in defining boundaries for WSCR calculations as the wind generation disperses over a large area.
- Uncertainty in simulation due to poor model quality.
- Presence of series capacitors present complicating technical challenges.

For the current time, it is not recommended to use WSCR in defining real-time operating limits for the South Texas System. These limits should be set using conventional transient stability and voltage stability analysis tools, and checked periodically using detailed EMT simulation tools.

1.3.4 Panhandle Voltage Regulation

Detailed wind plant controllers were available for 80 % of the Panhandle resources as a result of prior recommendations. The speed of 85 % of these controllers was fast enough to provide voltage support in the first few seconds following an event. As a result of this support, several critical contingencies were able to maintain adequate voltage profiles throughout the Panhandle and provide improved performance over earlier studies. It was noted that some wind plants provided significantly more voltage control support than others.

The planned VAR support devices in the Panhandle (Tesla, Tule Canyon, and Alibates) reach maximum limits for several contingencies, indicating low reactive power margin and potential reactive power deficiency in the system. This can be improved by ensuring the remaining wind plants implement fast dynamic voltage control.

Since the wind resources in the Panhandle are the primary source of dynamic reactive power, it is recommended that a significant amount of plant level voltage support be provided in less than 3 seconds where feasible in the Panhandle. Additional coordination is required for plants which are controlling voltage in regions electrically close to each other. The purpose of this coordination is to avoid negative interaction between controllers or instability which was observed in some cases in these studies. The precise coordination required may vary according to the specific connection topology, but may include droop (at a minimum), or centralized "multi-plant controllers" where a large number of devices in close proximity require too much droop to maintain effective voltage control.

1.3.5 South Texas Voltage Regulation

For more than half of the 22 wind plants in this study a plant level voltage controller model was not provided despite ERCOT's request for this information. These wind plants were simulated in constant Q control, with the Q setpoint taken from the powerflow models.

The region has 7 existing and planned dynamic reactive devices. These are fast devices which are required to support power transfers to load, and maintain a steady post-fault voltage profile so that the wind generation can ride-through events. Generic PSCAD models were used to represent these dynamic reactive devices at this time. It was found that the specific tuning of these dynamic reactive devices is important in determining:

a. Post fault voltage profile control, which in turn impacts wind plant ride-through.
b. Introduction of system wide undamped oscillations at sub-synchronous frequencies. The magnitude and frequency of these oscillations is dependent on tuning of the dynamic reactive devices in many cases.

Since the wind resources in South Texas are one of the primary sources of dynamic reactive power, it is recommended that plant level voltage support be fast (substantial response in less than 3 seconds if feasible) for all wind plants. As in the Panhandle, additional coordination is required for plants which are controlling voltage in regions electrically close to each other.

1.3.6 Simulation Tool Adequacy

As the WSCR drops below 1.5 in the Panhandle, the need for more detailed EMT models becomes more important. **It is recommended that periodic studies be done in the Panhandle region with detailed EMT models to validate PSS/E studies and further develop and test WSCR planning guidelines.**

In the South Texas system, it is recommended to continue using PSS/E for reliability analysis and setting of operating restrictions. However, it is recommended to perform regular PSCAD studies to confirm these results.

The reasons for this confirmation is:

a. Inability of PSS/E to represent SSCI and other transient phenomena relating to series capacitors (including instability and series capacitor related ride-through failures)
b. The possibility of insufficient detail in PSS/e to always predict ride-through failures or control interactions as the system is weakened and transfers increase.
c. Transient effects in the system can have a large influence on ride-through behaviour, and effects of surge arresters, series capacitor protection, transformer saturation, and frequency dependent transmission lines can bear on these transient effects. These effects are always important for ride-through, but can be exacerbated (ie. ride-through made more difficult) as the grid strength weakens.

In both the South Texas and the Panhandle systems, the PSCAD model was extremely extensive and used the best available models for generator and voltage support equipment. However, the complexity of observed issues in the South Texas System revealed inadequacies and approximations in the available data, and revealed that a higher level of accuracy may be required to correctly predict system behaviour. **Further PSCAD model improvement and PSCAD studies are recommended in the South Texas system.**

1.3.7 Sensitivity of System Strength to Load (Panhandle)

It is understood that conventional power transfer limitations and voltage stability constraints are often related to “weak grid” issues. It has been observed that the presence of load in the vicinity of generation can offset these conventional limitations, and can also relieve some of the difficulties associated with low system strength.

In the Panhandle, there is very little local load, so this relationship between local load and system strength is less important. However, it was found that connection into the Lubbock load area, adding additional circuits (and so increasing SCMVA), as well as reducing transfers out of the area improves performance of the Panhandle wind region. **Due to the effect of increased transfer capability, the damping effect of load, and the increased short circuit strength, an increase in wind dispatch under the “Lubbock Connected” scenario to 100% is likely possible, but care should be taken to evaluate VAR adequacy for this scenario.**

Increasing the level of detail in load models (adding a component of induction motor load) was found to have a small positive impact on stability in the Panhandle region. **It is recommended to use detailed load models, including a component of induction motor load if applicable, for any future PSCAD effort in the Panhandle region if the Lubbock system integrates into ERCOT.**

1.3.8 Sensitivity of System Strength to Load (South Texas System)

In the South Texas System, loads are integrated much more tightly than in the Panhandle, and variation in load can cause very different operating conditions for the region. This, combined with the complexity of the various issues observed in the South Texas System made determining the precise impact of load difficult. In general, it can be said that:

a. Addition of load offsets the flows in the HV lines during high wind, and has a positive impact on region stability.
b. Sensitivity analysis was performed to evaluate the impact of variation in load type on performance under stressed conditions. Replacing simple load models with complex models (including induction motor components) improves damping on subsynchronous oscillations, but makes fast voltage control

(and plant ride-through) more challenging, since induction motor load requires fast dynamic VARs to aid with voltage recovery when a fault is cleared.

Because of the influence of load type on simulation outcomes, it is recommended to use an appropriate component of induction load in models for any future PSCAD effort in the South Texas System region.

1.3.9 Additional Recommendations

The following are additional recommendations that stem from this work:

a. In the South Texas system particularly, but also in general, the presence of fast dynamic VAR controlling devices can be a very strong influence on stability. If properly tuned, they can provide strong damping for SSO modes and other modes of instability in the system. Conversely, if poorly tuned they can introduce new modes of instability or exacerbate existing issues. This was made clear by the presence of generic dynamic reactive device models in the South Texas model, which caused undamped oscillations to appear at sub-synchronous frequencies for many contingencies. **It is recommended to ensure all new dynamic reactive devices are specified such that they provide damping at sub-synchronous frequencies, and are studied to ensure no negative modes are excited when added to the system.**
b. In addition to the generic dynamic reactive devices, several inadequacies were identified with the wind plants in the South Texas system. **Due to the complexity of the issues in this region, it is recommended that these model adequacy concerns be resolved prior to new study being undertaken. Future interconnections should be required to submit PSCAD models that are able to demonstrate minimum adequacy requirements[2].**

1.4 Acknowledgements

Electranix gratefully acknowledges Shun Hsien (Fred) Huang, Yunzhi Cheng, and John Schmall from Transmission System Planning at ERCOT for their valuable assistance and participation in these studies.

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[2] "Recommended PSCAD model requirements" Rev. 5, Dated February 15, 2018 is available at: http://www.electranix.com/publication/technical-memo-pscad-model-requirements/

2.0 Assumptions and Methodology

2.1 PSCAD and E-Tran Software

The studies in this report were done using the PSCAD/EMTDC program (V4.6.2 and V4.5.3). The E-Tran program (V4.2.1) was used to translate PSS/E.raw loadflow cases into PSCAD. E-Tran V4.2.1 has parallel processing simulation features.

Detailed models such as transmission lines, fault logic, wind turbines, synchronous condensers and SVCs are maintained in PSCAD "substitution libraries" and are automatically imported into the PSCAD case (and initialized) by E-Tran - this process is automated and therefore can be quickly performed for different loadflow cases. Separate substitution libraries were created for each wind turbine manufacturer, Tesla SVCs and various network models to keep the libraries as simple as possible, as there are a large number of wind plants associated with this project. This eases case conversion and data handling.

2.2 PSCAD Parallel System Model

2.2.1 E-Tran Plus PSCAD Parallel Processing

2.2.1.1 Details of E-Tran Plus Parallel Processing capabilities

The use of multiple PSCAD detailed power electronic-based simulation models (such as wind plants) introduces numerous possible problems:

- *Slow simulations:* Power electronic models are inherently slow due to switching of IGBT/diode models. Source-based or interface based models can be used (which avoid the switching) however are less accurate and can be numerically unstable (particularly in weak systems). The simulation time step requirements of some models can also be very small (as low as 1-5 µs as compared to the normal 50 µs time step required for system modeling) which requires the entire simulation to be performed with the minimum required step size.
- *Compiling/linking issues:* Binary .obj/.lib code from many suppliers needs to be linked into one executable .exe – each vendor supplies models compiled with various Fortran or C compilers, and compatibility problems can occur (known affectionately as "Fortran Hell").
- *Confidentiality problems:* Models from the suppliers often are based on actual code from the real hardware (just compiled into PSCAD) – they are extremely sensitive to NDA (non-disclosure agreements) and do not want the code/models to become generally available (for fear of reverse-engineering or probing of the controls to determine capabilities).

To resolve these issues, the modeling approach used in these studies uses parallel processing using a commercially available PSCAD add-on program called "E-Tran Plus for PSCAD" as shown in Figure 1 (see reference paper entitled "Parallel Processing and Hybrid Simulation for HVDC/VSC PSCAD Studies", ACDC conference 2012).

The speed of simulation issues are solved by placing each wind plant onto its own CPU/CORE (either on one computer or on other computers connected to the LAN). Each wind plant is modeled on its own CPU/processor (through a Bergeron line model) – this allows each wind plant PSCAD model to:

- Use a different time step (so the entire simulation is not slowed down if one model needs a small time step)

- To be compiled with different Fortran/C compilers (solving compiling/linking/compatibility issues)
- To be generated with different versions of PSCAD (ie older PSCAD V4.2.1 models can be run with PSCAD V4.6.2/newer versions)
- Be completely black-boxed to solve confidentiality problems. The total linked executable .exe needs to be pre-generated by PSCAD, but once available, individual .f source code for each page/model, PSCAD models/components/data do not need to be distributed.
- The modeling approach used in these studies is based on a database approach – ie each detailed model is maintained in a PSCAD/E-Tran database, which allows a PSCAD case to be quickly generated for any existing or future loadflow conditions. The simulations are also more accurate, because the complete system and wind plant models are fully initialized by the standard PSS/E loadflow setup.

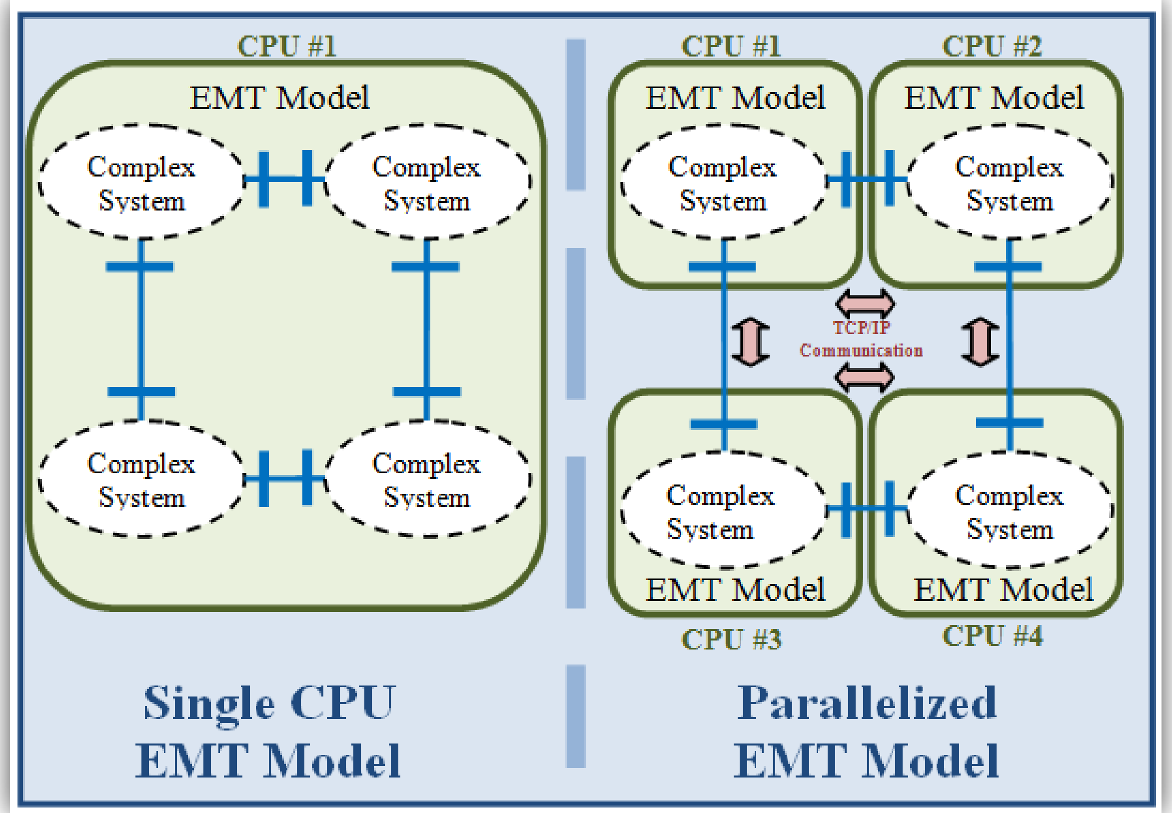

Figure 1 PSCAD single processing Vs. E-Tran Plus Parallel Processing in PSCAD

The "E-Tran Plus for PSCAD" parallel processing method also includes the following features:

- Auto-start component - a single "start" button on one PSCAD case will automatically launch all other cases, including duplication of settings (ie if the main PSCAD case is setup to write output files, then all cases will run output files – if the main case takes a snapshot at 1 second, they all take snapshots at 1 second etc.). This includes starting the PSCAD processes on remote computers, killing processes (which during initial debugging may not have exited cleanly), starting with the process priority and locked to a given cpu core (although the "auto" assignment of processes to cores is recommended) etc.).

- Communication/plotting between PSCAD cases (an array of any size can be assigned to transfer variables from one case to another – this is useful if real/physical communication is required (say a line relay at one side communicates with the other via fiber) or simply for plotting (so the main simulation can plot quantities from the entire set of simulations).
- Compatibility with the multiple run features of PSCAD.

The communication method used between processes is based on standard TCP/IP networking protocols, using custom code (included in E-Tran Plus products) written with low-level (ie no overhead) interfaces and absolute minimum latency requirements (ie a standard LAN gigabit switch is sufficient).

2.2.1.2 Application of E-Tran Plus Parallel Processing to the Panhandle System

The Panhandle system has a wind capacity of 5,536 MW, consisting of 30 wind plants, as well as two SVCs at Tesla 345 kV substation and two synchronous condensers at Alibates and Tule Canyon 345 kV substations. A total of 7 wind plants adjacent to the Panhandle system consisting of 1,355 MW of wind capacity were modeled in PSCAD with and without the Lubbock load (total 37 wind plants inside and outside the Panhandle). In addition, Lubbock network and load are included to explore the impact of load distribution on low system strength grid issues. Simulation of the Panhandle system in a single PSCAD case is not possible due to computational restrictions. Instead, E-Tran Plus for PSCAD was used to create 28 parallel PSCAD cases with acceptable simulation speeds[3]. The 28 PSCAD cases are created as shown in Table 1 by carefully analyzing the location and complexity of the wind plants and the system.

2.2.1.3 Application of E-Tran Plus Parallel Processing to the South Texas System

The South Texas system has a wind capacity of 4,339 MW, consisting of 22 wind plants, as well as 7 dynamic reactive devices. Simulation of the entire South Texas system in a single PSCAD case is not possible due to computational restrictions. Instead, E-Tran Plus for PSCAD was used to create 16 parallel PSCAD cases with acceptable simulation speeds[3]. The 16 PSCAD cases are created as shown in Table 2 by carefully analyzing the location and complexity of the wind plants and the system.

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[3] Simulation computers were based on a AMD Ryzen Threadripper platform, with 16 physical cores overclocked to 4.0 GHz (simultaneously), and 64 MB RAM. Each simulation required approximately 1-2 hours to run.

Table 1 E-Tran Plus Computer Processor allocation (Panhandle). Lubbock network is encompassed in the “System” processer.

System/Wind Plant/DVAR/Load		
Code	Project Name	Processor
System	Panhandle Network	0
	Tesla SVC	
	Alibate SYNC	
	Tule Canyon SYNC	
SS	Spinning Spur Wind Two	1
	Spinning Spur Wind Three	
PH1	Panhandle Wind 1	2
PH23	Panhandle Wind 2	3
	Panhandle Wind 3	
MM	Miami Wind 1 Project	4
GV	Grandview Phase I (Conway Windfarm)	5
	Colbeck's Corner W (Grandview Phase II)	
	Grandview W 3	
HF	Hereford Wind (GE)	6
	Hereford Wind (VESTAS)	
	Jumbo Road Wind	
R6	Route66 Wind (AMSC)	7
SP1	South Plains I (AMSC)	8
SP2	South Plains Iia	9
	South Plains Iib	
BR	Briscoe Wind Farm	10
LH	Longhorn Energy Center North (AMSC)	11
	Longhorn Energy Center South	
WK	Wake Wind	12
CP	Cotton Plains Wind	13/13B
	Old Settler Wind	
	Pumpkin Farm Wind	
SF	Salt Fork Wind (AMSC)	14/14B
SW	Swisher	15
	Swisher	
HW	Happy Whiteface Wind (Falvez Astra W)	16
ME	Mariah Del Este	17
MN	Mariah Del Norte	18
MD	Mariah Del Sur	
BS	Blue Summit Windfarm	19
ET	Electra Wind	20
LK	Lockett Wind Farm	24
HC	HORSECRE_43	21
MQ	Mesquite Creek	22
SR	Stephens Ranch Wind	23
	Stephens Ranch Wind B	
LPL	Lubbock Load	25

Table 2 E-Tran Plus Computer Processor allocation (South Texas)

System/Wind Plants/DVAR/Load		
Code	Project Name	Processor
MainSys1	Part 1 of South Texas Network	0
LV1A	Los Vientos 1A	1
LV1B	Los Vientos 1B	2
LV3	Los Vientos III	3
LV4	Los Vientos IV	4
CW	Cameron County Wind	
SW	Sendero Wind	
LV5	Los Vientos V	5
SR	San Roman Wind	
WW	Whitetail Wind Energy Project	
HS	Hidalgo & Starr Wind	6
CR	Chapman Ranch Wind I	7
TWA	Torrecillas Wind A	
TWB	Torrecillas Wind B	
AW	Albercas Wind (Javelina 2)	
JW	Javelina Wind	8
PaW	Patriot Wind	
RW	Redfish Wind (Magic Valley)	9
CH	Cedro Hill Wind	10
BB	Redfish2 (Bruennings Breeze)	
MainSys2	Part 2 of South Texas Network	11
GW	Gulf Wind	12
BW	Baffin Wind	13
PW	Penascal Wind Farm	14
MainSys3	Part 3 of South Texas Network	15

The Physical arrangement of the E-Tran plus parallel PSCAD cases are shown in Figure 2 and Figure 3. There are two types of PSCAD cases:

1. System PSCAD case (Master Case)

In the Panhandle, the system PSCAD case consists of all the line models, Tesla SVCs, Synchronous condensers, Lubbock load (Lubbock load was modeled as a separate processor in some cases) and equivalent boundary buses in the Panhandle system. This is the Master PSCAD case and it is electrically connected to the other Slave PSCAD cases (primarily wind plants). Data from the Slave PSCAD cases such as active power (P), reactive power (Q), voltage (V) and trip/status signals are transferred to the Master PSCAD case. All the controls (such as contingency settings) can be carried out at the Master PSCAD case level. In the South Texas system, a similar setup was performed, but to improve simulation time the system model was split into 3 separate subsystems.

2. Wind plant PSCAD cases (Slave Cases)

All the wind plants were modeled as slave PSCAD cases and electrically connected thorough E-Tran plus components to the Master PSCAD case. Wind plants were modeled using custom wind turbines provided by their respective resource entities and/or manufacturers. Dispatch and voltage levels were set according to the PSS/E dispatch levels.

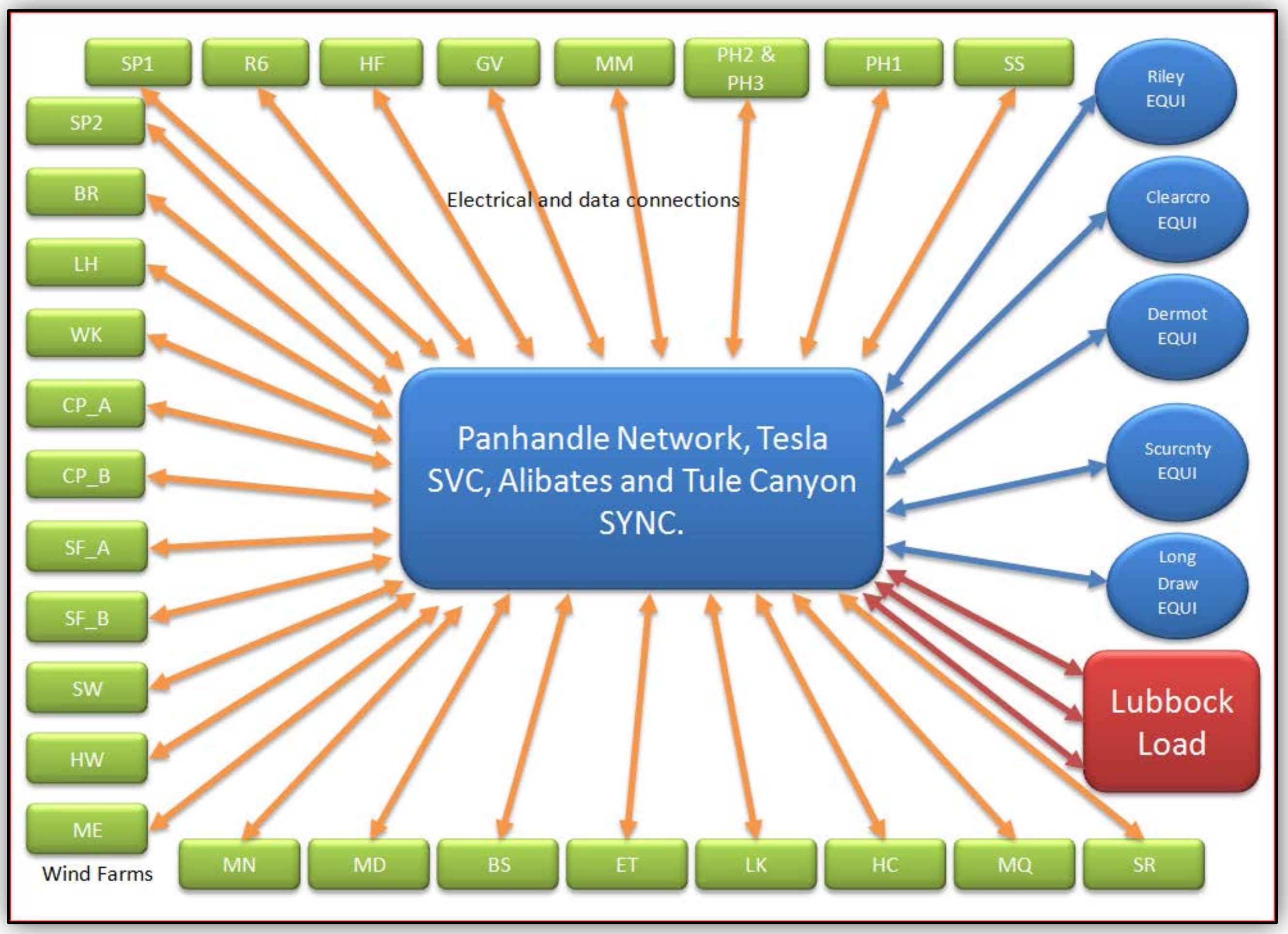


Figure 2 Representation of Panhandle Parallel PSCAD system (Lubbock load only included in cases studying Lubbock interties to the Panhandle.)

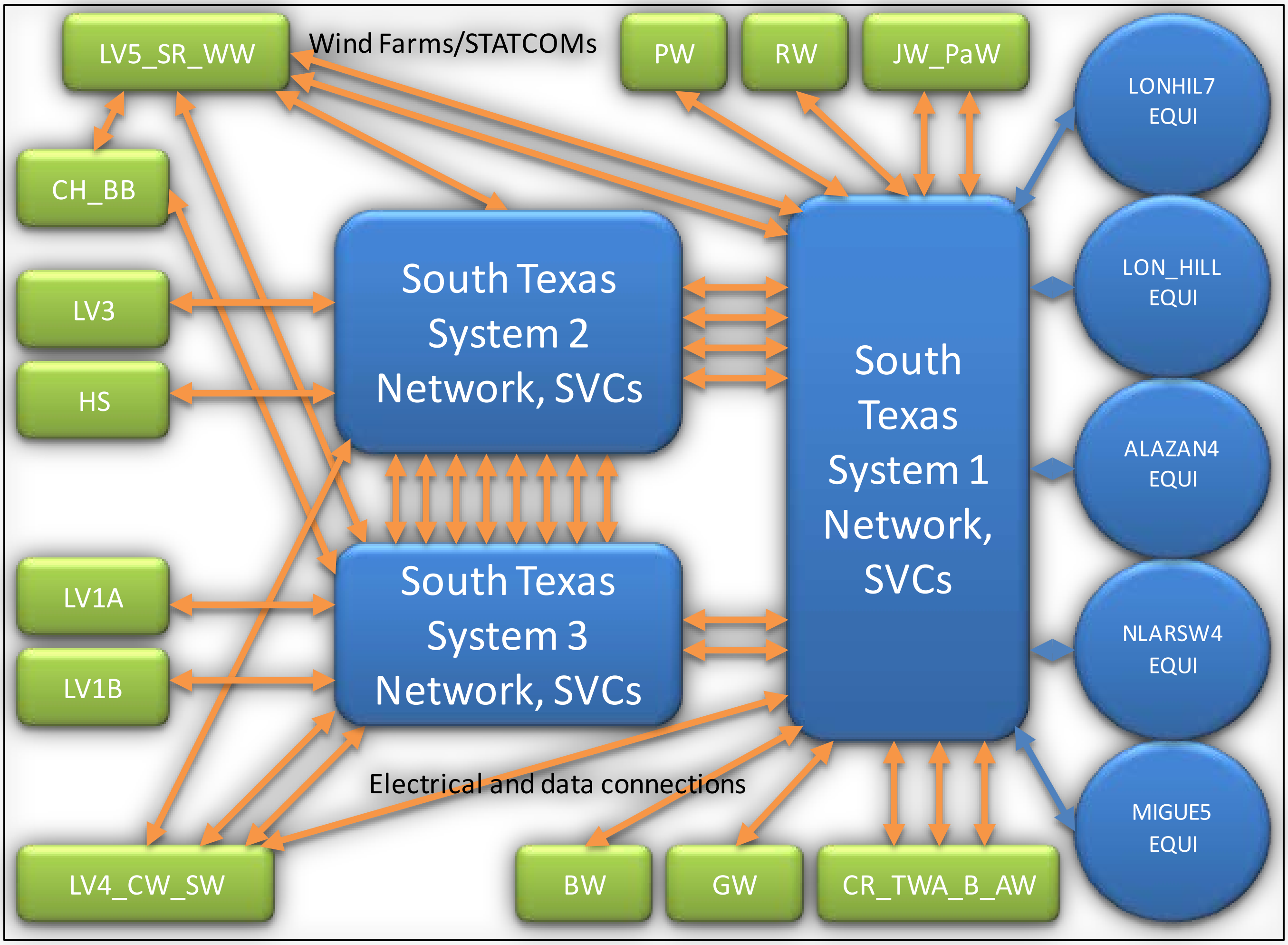


Figure 3 Representation of South Texas System in the PSCAD parallel processing cases. Loads are included in the three main system cases.

2.3 Wind plants (Panhandle)

There were 25 detailed PSCAD wind plant models provided from respective manufacturers/project developers, and separate substitution libraries were created for each wind plant for the large Panhandle case creation. Detailed PSCAD models were not available for 9 wind plants at the time of study commencement, so similar wind plant models were used for the simulations as an approximation. Although all possible efforts were made to match the type and the capacity of the wind plants for substitution, it is noted that further refinement of controls and turbine types may cause the behavior in the Panhandle to differ slightly.

Some wind plants are equipped with DVAR STATCOM devices, and these were modeled in detail in the PSCAD cases. The details of each wind plant within Panhandle boundary were dispatched at 70% (equivalent to WSCR of approximately 1.5 when not including Lubbock network). Seven other wind plants adjacent to the Panhandle system (outside the Panhandle boundary) dispatched at 82% were also modeled in the PSCAD case because it is within the defined boundary in the PSCAD case and is electrically close to the Panhandle system.

Detailed PSCAD models of the wind plant were inserted into each PSCAD case. Detailed DVAR PSCAD models were substituted and switching capacitors and inductors were modeled inside the detailed DVAR models as applicable. The DVARs were set to operate with a droop and dead bands, and include 300% overload capability for a 2 second period. The DVAR devices switch shunt capacitors or inductors according to VAR requirements, with 3 to 5 second time delays, as provided in the models. The DVARs were set to keep their dynamic reactive power output at minimum level during normal operation by switching shunt devices to maintain maximum dynamic range during contingency conditions.

The 345 kV transmission line from wind plants to the Panhandle system was replaced by the E-Tran Plus parallel communication component to enable parallel processing in PSCAD. This component consists of a Bergeron line model with parallel communication capability to other PSCAD cases.

With respect to optional controllers such as SSCI damping controllers, plants were modeled as provided by the manufacturer, except for certain wind turbines, which failed to ride through faults when the optional SSCI protection was turned on. This SSCI protection was turned off to allow the study to proceed.

Detailed plant controllers were available for 80% of the Panhandle resources as a result of prior recommendations. The speed of 85% of these controllers was fast enough to provide voltage support in the first few seconds following an event (Most of the wind plants with fast PPCs reach 90% of reactive power order within approximately 2 seconds).

2.4 Wind plants (South Texas)

There were 20 detailed PSCAD wind plant models provided from respective manufacturers/project developers, and separate substitution libraries were created for each wind plant for the South Texas system. Detailed PSCAD models were not available for two wind plants at the time of study commencement, so similar wind plant models were used for the simulations as an approximation. Although all possible efforts were made to match the type and the capacity of the wind plants for substitution, it is noted that further refinement of controls and turbine types may cause the behavior in the South Texas System to differ slightly.

Some wind plants are equipped with DVAR STATCOM/DSTATCOM devices, and these were modeled in detail in the PSCAD cases as in the Panhandle.

A substitution library was built for each wind plant separately and the detailed PSCAD models of the wind plant was later substituted into separate PSCAD cases. All the wind plants and including the South Texas system were split up on 16 different PSCAD cases. Since the step up transformers are usually modeled inside the manufacturer's wind turbine models, all the components towards the low voltage side from the step up transformer are typically substituted from the detailed model.

SSCI damping controllers features if explicitly included were mostly enabled as provided with the PSCAD models.

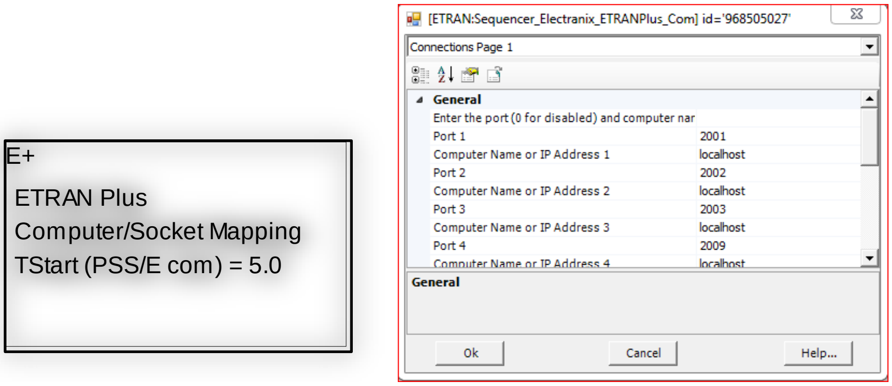
For more than half of the 22 wind plants in this study a PPC/voltage controller was not provided. Due to model issues and simulation efficiency, additional assumptions and adjustments were made during the model development of the South Texas system.

2.5 PSCAD System Model

The PSCAD system model includes fault automation and case parallelization,

2.5.1 E-Tran Plus components

Two E-Tran Plus components are modeled inside the Global Initialization page to communicate between parallel PSCAD cases as shown in Figure 4 and Figure 5.



[ETRAN:Sequencer_Electranix_ETRANPlus_Com] id='968505027'

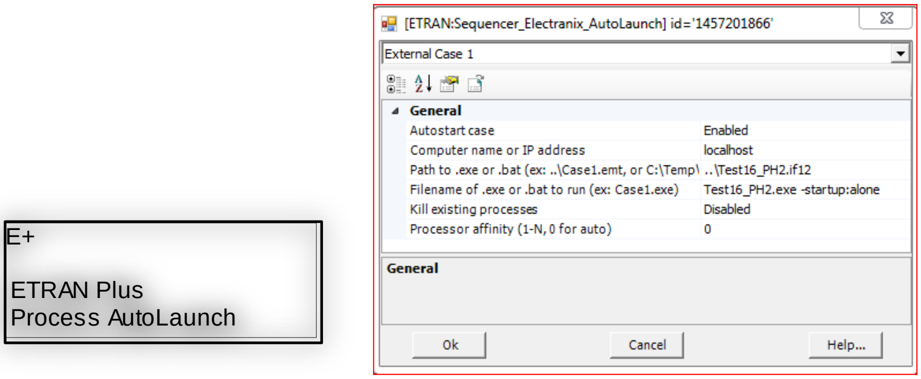
Connections Page 1

General

Enter the port (0 for disabled) and computer nar	
Port 1	2001
Computer Name or IP Address 1	localhost
Port 2	2002
Computer Name or IP Address 2	localhost
Port 3	2003
Computer Name or IP Address 3	localhost
Port 4	2009
Computer Name or IP Address 4	localhost

General

Figure 4 E-Tran Plus Socket Mapping Component



[ETRAN:Sequencer_Electranix_AutoLaunch] id='1457201866'

External Case 1

General

Autostart case	Enabled
Computer name or IP address	localhost
Path to .exe or .bat (ex: ..\Case1.emt, or C:\Temp\	..\Test16_PH2.if12
Filename of .exe or .bat to run (ex: Case1.exe)	Test16_PH2.exe -startup:alone
Kill existing processes	Disabled
Processor affinity (1-N, 0 for auto)	0

General

Figure 5 E-Tran Plus AutoLaunch Component

The E-Tran Plus Computer/Socket Mapping component has TCP/IP numbers to communicate with parallel PSCAD cases during the simulation. Elecrical signals and data singanls are transferred between parallel PSCAD cases through TCP/IP sockets.

The E-Tran Plus Autolaunch component launches parallel PSCAD cases from the main PSCAD case.

2.5.2 Transmission Line modeling

All the transmission lines in the Panhandle system were modeled using Bergeron line models as shown in Figure 6. Fault logic, measuring and signal transferring were modeled inside the transmission line model to connect to the outside controller pages.

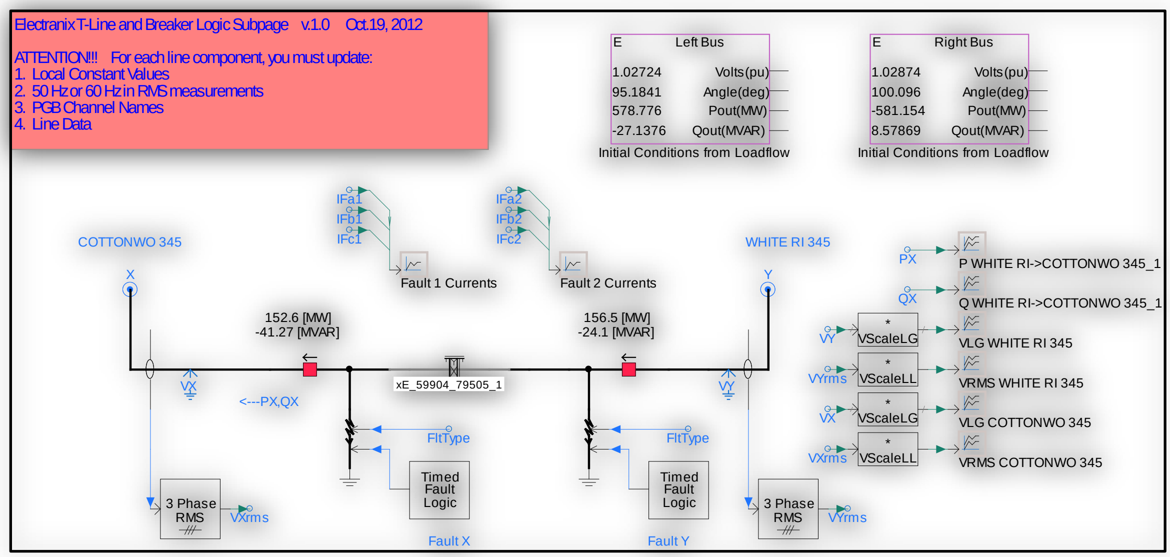


Figure 6   345 kV Transmission Line Model with faults

2.5.3 South Texas dynamic reactive device models

The actual models of the seven dynamic reactive devices were not available at the time of this study. Instead, the ones used were Electranix generic SVC models, which consist of a TCR with some filter and a simple PI-type voltage controller. The locations of these devices are listed below and the sizes are specified at the high voltage side of the transformer.

- MILITARY0A (bus# 80003) +130/-180 MVAR
- LAREDO0C (bus# 80012) +130/-180 MVAR
- FALFUR0A (bus# 88508) +50/-40 MVAR
- LAPALMA0C (bus# 80319) +130/-80 MVAR
- LAPALMA0E (bus# 80321) +130/-80 MVAR
- PHARR0A (bus# 80372) +130/-80 MVAR
- PHARR0C (bus# 80374) +130/-80 MVAR

2.5.4 Series Capacitor Models

Detailed series capacitor models used in the South Texas system were obtained from AEP and used in the study with permission.

2.5.5 Tesla SVC model

A detailed SVC model was provided by the Transmission Service Provider (TSP) for the Tesla SVC.

2.5.6 Alibates and Tule Canyon Synchronous Condenser Models

Alibates and Tule Canyon Synchronous Condensers were represented with custom PSCAD models provided by Sharyland TSP and the manufacturer with 175 MVAR nominal capacities with overloading capability.

2.6 Study Cases and Contingencies (Panhandle)

ERCOT provided six study cases with 5,536 MW Panhandle wind capacity dispatched as follows:

1. PH70 Case : Panhandle wind plants dispatched at 70%
2. PH100 Case : Panhandle wind plants dispatched at 100%
3. PH100LPL Case : Panhandle wind plants dispatched at 100% with Lubbock network and load connection
4. PH70ALSW Case : Panhandle wind plants dispatched at 70% with a prior outage of the ALIBATES to AJ SWOPE line (N-1-1 prior outage)
5. PH70ALGR Case : Panhandle wind plants dispatched at 70% with a prior outage of the ALIBATES to RAILHEAD/GRAY line (N-1-1 prior outage)
6. PH61TC Case : Panhandle wind plants dispatched at 61% with a prior outage of the TULE CANYON Substation

A total of eighteen contingencies, including double circuits three phase fault and single line to ground fault with breaker failure, were provided by ERCOT for the Panhandle study.

2.7 Study Cases and Contingencies (South Texas)

ERCOT provided one study case with 4,339 MW wind capacity with all the wind plants dispatched at 100% in the South Texas system. A total of twelve contingencies, including single circuit and double circuit three phase faults, were provided by ERCOT for the South Texas case. Conventional synchronous machines in the South Texas system were all turned off in all cases.

2.8 AC System Representation (Panhandle)

All the buses inside the Panhandle system were modeled in PSCAD. Riley, Clear Crossing, Dermot, Long Draw and Scurry County 345 kV buses were selected as boundary buses and were modeled with passive network equivalents in the PSCAD model. A total of 435 buses were kept in the PSCAD network.

2.9 AC System Representation (South Texas)

All of the buses in the South Texas system up to and including buses MIGUEL5, LONHILL7A, NLARSW4A, LON_HILL4A, and ALAZAN4A were modeled in PSCAD. These five buses were selected as boundary buses and were modeled as a passive NxN network equivalent in the PSCAD model. In addition, several sub-transmission 69 kV lines with very little powerflow were disconnected to allow a simpler interface to the passive boundary system. A total of 469 buses were kept in the PSCAD network.

To split up the South Texas system on multiple processors, the electrical length of the line from ALBERTARDSB8 to DOEDYNSUB8 was increased slightly so that it was long enough to be a Bergeron line model.

2.10 Performance Criteria

The following general wind plant performance requirements were applied in these studies to evaluate whether performance was acceptable[4].

2.10.1 Capability to ride through disturbances

Capability to ride through disturbances, or fault ride-through requirements as commonly referred in the grid codes, normally state in some fashion that:

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[4] For a more detailed discussion of weak system performance requirements, see Technical Brochure – Cigre B4.62 Chapter 3

1. The Wind Power Plant (WPP) should not be tripped in the event of normally cleared system faults. Fault ride through is a requirement where wind generators are required to stay connected to the grid during and after the clearance of a system fault. Following the clearance of the fault, the WPP should be able to provide real and reactive power to the grid. This will assist to maintain angle and voltage stability of the system.

   This requirement may be more critical in weak systems because of the following reasons:
   - Local reactive power support to maintain system voltages is more critical in weak systems.
   - Active power deficiencies as a result of WPP tripping can be easily compensated by other generators in strong interconnections. Thus, fault ride through can be more critical in weak systems (In case of generation tripping, power electronics based generation such as nearby wind plants can ramp up power faster to compensate in strong systems compared to weak systems, since reactive power is more difficult to control in weak systems, and changes in active power cause more severe voltage fluctuations)
   - Tripping of a significant generator is more likely to result in undesirable poorly damped power oscillations in weak system compared to a strong system.

2. The wind plant should be able to control active and reactive power injection during the fault recovery. A typical requirement of a weak grid during fault recovery is curtailment of power and boosting of reactive power injection to support voltage. Power electronics based wind generation has this inherent capability. This is achieved through fast control of active and reactive currents.

2.10.2 Post-fault steady state voltages

If the system is too weak and has insufficient voltage support, the system may experience post fault steady state voltage violations before the power plant voltage controller is able come into action (which may take 20 to 30 seconds depending on the time constants of these plant level controllers). This may lead to low post fault voltage values, and some wind plants may enter fault ride through modes multiple times before the plant controller can respond.

2.10.3 Stable coordination of dynamic controllers

Generators are expected to operate in a stable fashion, and to avoid interfering with the controls of neighboring equipment. Modern power electronics based wind generators are equipped with numerous control systems performing numerous control functions. These control functions can interact with nearby power electronic based dynamic devices with comparable control system time constants. This can lead to detrimental dynamic oscillations. The potential of such oscillations is greater when the devices are connected to a weak grid.

Generators are also expected to operate in a stable fashion during varying system conditions, including following outages which may significantly weaken the connection strength.

2.10.4 Sufficient contribution to network voltage support

Generators are expected to contribute to the support of the bulk electric system. This includes reactive power available to regulate voltage (fast and slow support), as well as frequency control in some cases. ERCOT requires all Generation Resources to provide reactive support per ERCOT Protocol 3.15. The reactive support from wind plants in this analysis is based on the provided model and data from Resource Entities, and it is clear from this analysis that the extent to which the generators contribute to this support is critical in overall performance.

2.10.5 Frequency and Power ramp rate

There is currently no specific requirement for active power ramp rates in the ERCOT system. The active power ramp rates of the wind plants are very important for weak system performance. If the ramp rates are too low, the system may experience frequency violations as energy is not supplied during the post fault period. If the ramp rates are too high, the system may experience voltage violations in weak system conditions, and the ability of the plant controllers to remain stable is reduced as the system is weakened.

The wind plants in the Panhandle system have different active power ramp rates, ranging from as low as 0.2 sec to others as high as 2.0 sec. Drastically varying the mix of ramp rates in the Panhandle system may impact the results of this study.

2.11 Additional Assumptions

Additional assumptions were made for parallel simulation.

1. The PSCAD simulation was run for up to 18 seconds of simulation time in order to get a steady state flat run. This is due to the presence of many dynamic devices (wind plants, DVARs and SVCs) which ramp up during the first few seconds. Infinite source models were connected during the first five seconds of the simulation to support ramp up of all the wind turbines at the same time.
2. This study was carried out in order to gain an understanding of the weak system issues. No Sub-synchronous oscillation issues were specifically studied. The selection of boundary buses excludes some series compensated lines (outside the Panhandle system) from the main PSCAD system case.
3. Line arresters and MOVs of the series capacitors were not modeled in this simulation.
4. Transmission lines were modeled as Bergeron line models.
5. The performance of the system may differ if the wind capacity is increased with same dispatch levels due to reactive power performance of the additional wind turbines added to the system.
6. Approximately 80% of the wind plant models in the Panhandle system reflect a Wind Power Plant Controller (WPPC). The remainder of the wind plants were simulated in constant Q control.
7. Less than 50% of the wind plant models in the South Texas system reflect a WPPC. The remainder of the wind plants were simulated in constant Q control, except one plant which was in constant power factor control.
8. Most the PSCAD simulations were run with a 20 μs simulation time step and several of the wind turbine models were run with a 10 μs simulation time step. The PSCAD multiple run and snapshot features were not used in the simulations as some models do not support these features.
9. Transformer saturation was enabled using typical saturation characteristics in the Panhandle and the South Texas system.

3.0 Dynamic Performance Studies (Panhandle)

3.1 Summary of Dynamic Performance Study Results

Several system scenarios were studied in the Panhandle area with different dispatch levels with 5,536 MW wind capacity. These cases include system intact cases and prior line and substation outage cases and Lubbock load connection cases. A summary of key results for the Panhandle weak system study is shown in Table 3.

Table 3 Summary of Panhandle Results by Case

Case	Study Case	Panhandle Wind Capacity (MW)	Panhandle Wind Dispatch (MW)	Results	Maximum wind tripped for any contingency (MW)
1	PH70	5,536	3,780	Wind Trips*	≈ 256
2	PH100	5,536	5,536	Fail **	≈ 1,165
3	PH100LPL	5,536	5,536	Wind Trips*	≈ 248
4	PH70ALSW	5,536	3,780	Wind Trips*	≈ 94
5	PH70RLGR	5,536	3,780	Wind Trips*	≈ 192
6	PH61TC	5,536	3,385	Fail **	≈ 714

(*) Localized tripping not resulting in wide area system impact.
(**) System collapse or widespread instability.

The high level summary of the study case results can further be described as follows:

3.1.1 Panhandle 70% generation case (PH70)

- Tesla SVC, Tule Canyon and Alibates synchronous condenser reach maximum limits for several contingencies during voltage sags, indicating a lack of reactive power margin in the system. Any reactive power deficiency can be alleviated using following steps:
    1. Improve PSCAD models to include PPC modeling for wind plants that didn't provide such function in the submitted models.
    2. Coordinate and improve the response times of wind plants to help any reactive power deficiency just after the fault by easing pressure on SVC and SYNCs.
    3. Optimize reactive power contribution from each wind plant at common POI.
- Protection of the Tule Canyon and Alibates SYNCs are not modeled. Active power swings as much as -150 MW were observed and capability of actual equipment should be verified.
- The Panhandle system has the capability to handle 70% wind generation with modeled operating conditions. The generation level may be increased if voltage support is improved, but this should be verified by a detailed study.

3.1.2 Panhandle 100% generation case (PH100)

- Tesla SVC, Tule Canyon and Alibates synchronous condenser reach maximum reactive output for most of the contingencies indicating a lack of reactive power margin in the system. Same measures as indicated for 70% case can be implemented to overcome these issues.

- For critical contingencies, oscillations in system quantities coupled with voltage collapse was observed with up to 1,165 MW of wind tripping.
- Most of the wind plant tripping, voltage collapse and poor ride through behaviour are due to the low system strength as well as not enough voltage support in the system. It is not recommended to operate with 100% generation without additional system improvements.

3.1.3 Panhandle 100% generation case with Peak Lubbock Load (PH100LPL)

- The Lubbock load (594 MW + 83 MVAr) is connected to the Panhandle system by three transmission lines. The Lubbock load connection helps to improve the performance of the system following ways:
    1. The new lines add an extra transmission path to flow power through and out of the Panhandle during contingency conditions while providing additional short circuit capacity in the Panhandle.
    2. The Lubbock load absorbs 594 MW of Panhandle generation while easing transfer flows through and out of the Panhandle.
    3. System load adds more damping to the system and helps to damp out transients from power electronic devices.
- Improved system performance in both system strength and voltage was observed due to connection of the Lubbock load while continuing to show minimal reactive power capacity margin in the system. No voltage collapse or wind plant mode cycling was observed.
- The Tesla SVC, Tule Canyon and Alibates synchronous condensers hit maximum limits for several contingencies during voltage sags indicating potential reactive power deficiency (or lack of margin) in the system.
- The sensitivity of the Lubbock loads were checked with both ZIP and CLOD models. The CLOD model marginally improves the transient response of the system due to the increased inertia and damping provided by induction motor loads.
- The Panhandle system is capable to handle 100% wind generation with the Lubbock load connection with modeled operating conditions. Note: Since Lubbock load was high in this case, further analysis may be needed to evaluate performance under light load conditions.

3.1.4 Panhandle 70% generation with prior outage case (PH70ALSW)

- The Tesla SVC, Tule Canyon synchronous condenser hit maximum limits for several contingencies indicating low reactive power margin in the system.

3.1.5 Panhandle 70% generation with prior outage case (PH70RLGR)

- The Tesla SVC, Tule Canyon and Alibates synchronous condensers hit maximum limits for several contingencies indicating low reactive power margin in the system. Steady state post fault voltages as low as 0.94 pu were observed for several contingencies.

3.1.6 Panhandle 61% generation with prior outage case (PH61TC)

- The Tesla SVC hits maximum inductive limits for several contingencies indicating low inductive reactive power margin in the system.

- Oscillatory behaviour coupled with voltage collapse was observed with up to 714 MW wind tripping. Mode cycling was observed for most of the wind plants for certain contingencies. The system does not have enough strength or voltage support to handle all contingencies for this study scenario.

3.2 Discussion of Dynamic Issues

3.2.1 Planning Margins for WSCR

The 3,780 MW generation cases (corresponding with 70% capacity, and a WSCR of 1.5) do not show critical low system strength signs or voltage violations issues, other than isolated wind plant tripping and reaching reactive power limits of SVCs and synchronous condensers. Adding PPC capability to all the wind plants, decreasing response time, proper coordination of PPCs and adding additional reactive power capability if required will improve the post fault voltage profile of the system. This will potentially allow an increase in the dispatch level and should be supported by a detailed study.

The improved performance observed with fast PPCs is an important result compared to the last round of studies, as it demonstrates the unique characteristics of wind and the importance of dynamic voltage control planning. It is possible for wind plants to support the voltage across a system, but these controllers may not be configured to operate in the fast timeframes required to prevent voltage collapse in the few seconds following a fault, and the controllers may not be available if the wind plants are out of service, or the wind is not blowing. A mix of network based voltage support and wind power plant voltage support is desirable, and special care is required in conventional planning to ensure sufficient VARs are available in the immediate post-fault timeframes as well as the extended simulation timeframes typically examined in powerflow studies.

3.2.2 Low system strength issues and voltage collapse

Voltage collapse coupled with system wide oscillations were identified for the PH100 case as shown in Figure 7. These same issues were identified in the PH61TC case (Tule Canyon substation outage case). The system does not have enough voltage support or system strength under the studied outage condition or for the 100% generation case.

3.2.3 Instantaneous trip just after the fault

Wind plant tripping was observed for several faults in the PH70 case. These tripping events are mainly due to Temporary Over Voltage (TOV) conditions just after the fault clears and subsequent internal DC overvoltage and over current issues. This tripping does not have system wide impact. Careful tuning of control parameters on a plant-by-plant basis could be effective in improving voltage controller response and avoiding plant tripping.

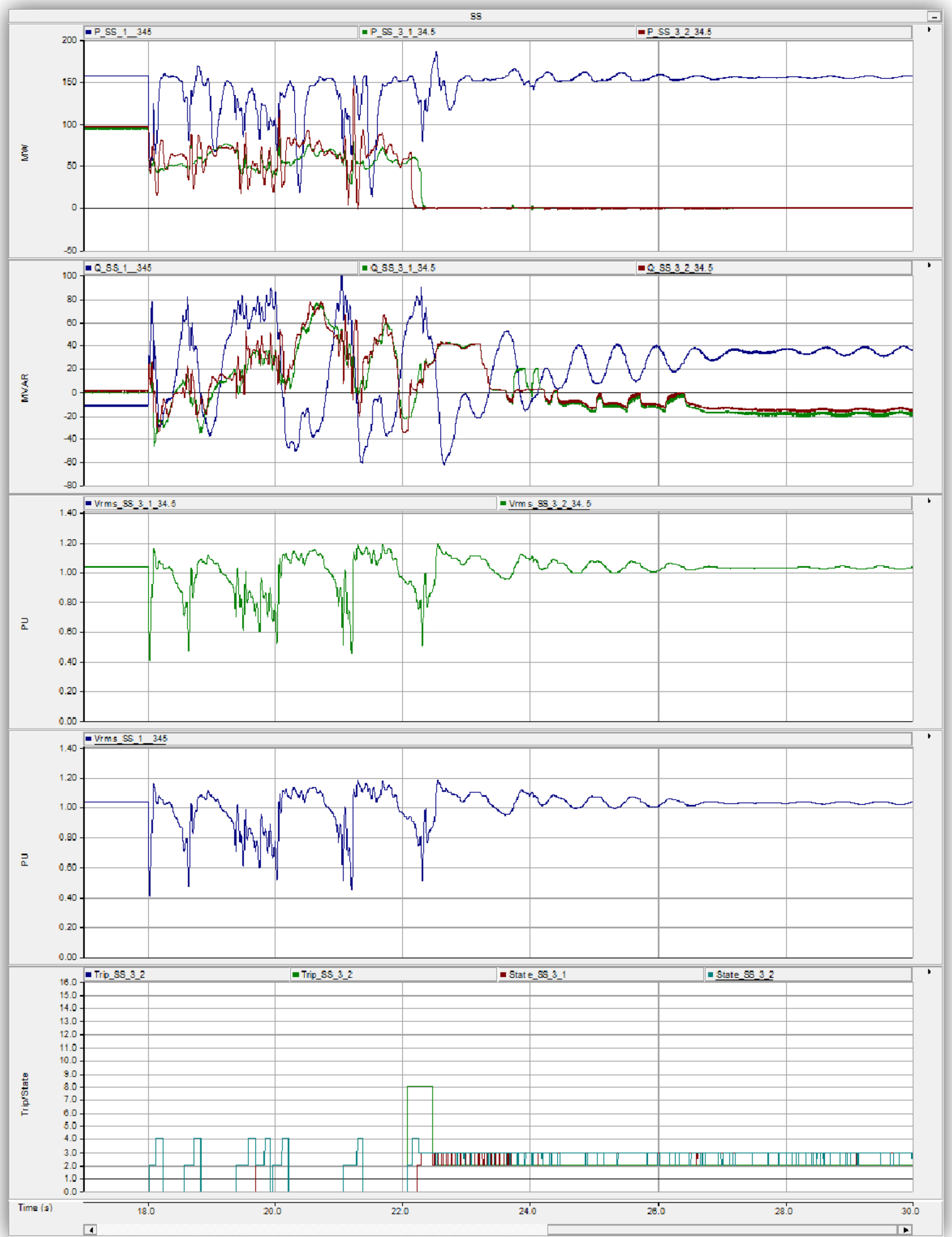


Figure 7 Voltage collapse and oscillation issues for PH100 case

4.0 Dynamic Performance Studies (South Texas)

4.1 Summary of Dynamic Performance Study Results

The results from the South Texas System study are summarized in Table 4 below, showing the overall performance associated with the two dynamic reactive power device assumptions that were tested. All of the contingencies were run with a 3LG and SLG to ground fault. The table compares the behaviour of the system when the dynamic VAR devices (SVCs or STATCOMs) are tuned to respond quickly (0.005 second control time constant) or slowly (0.1 second control time constant). Sensitivity runs were performed for three contingencies with the dynamic load “CLOD” models.

The cases chosen for detailed study in the South Texas network represented transmission faults and outages occurring while the network was stressed by full output of wind plants in South Texas and no thermal generation committed in the South Texas system. These cases demonstrated numerous dynamic performance issues, including the following:

- Certain wind plants failed to recover and tripped following most contingencies. The cause of tripping varies between event transients (insufficient Fault Ride Through capability), control oscillations, and insufficient voltage support. In some cases, loss of wind generation was spread across a wide region and amounted to significant portions of the total amount of South Texas generation.
- Voltage control following contingencies was poor in the region. This is the result of slow or absent wind plant voltage controllers in many of the PSCAD models. Additionally, dynamic reactive device models in the region were approximated and used generic control parameters and topologies (except for distribution STATCOMs that were integrated into wind projects).
- The presence of series capacitors can introduce numerous modes of instability. This is being addressed in other study efforts.
- Many of the issues observed were highly dependent on model assumptions or depended on old or poor quality vendor models.

Based on this analysis the future scenarios as studied are currently prone to risk of uncontrolled tripping and unstable oscillations. Anticipating more renewable generation will be added in the South region, model quality improvement are highly recommended and a follow up study should be conducted soon to verify and mitigate the issues identified in this study.

Observe from Table 4 that for most contingencies at least some of the wind plants tripped. For the contingencies where no wind trips there are other minor issues. In general, more wind tripped when dynamic reactive control devices were tuned to be relatively slow (time constant of 0.1 seconds) than when they are tuned to be very fast (0.005 s time constants). Inclusion of dynamic load models requires the dynamic reactive control devices to be relatively fast to support voltage recovery, and inclusion of these more detailed load models therefore often caused additional ride-through failure.

Note that all frequencies in this section are measured from RMS quantities.

Table 4 A summary from the analysis of the PSCAD traces.

Contingency #	Fault Type	Dynamic Loads	Quantity of Wind Tripped (MW)		Severe Undamped Oscillations	
			With Fast Dynamic Reactive Device	With Slow Dynamic Reactive Device	With Fast Dynamic Reactive Device	With Slow Dynamic Reactive Device
1	3LG	Without	403.2	708.26	poor	no
	SLG	Without	201.6	604.8	poor	no
2	3LG	Without	403.2	708.26	poor	no
	SLG	Without	201.6	604.8	poor	no
3	3LG	Without	403.2	914.9	poor	poor
	SLG	Without	806.8	604.8	yes	no
4	3LG	Without	250	1,054.49	yes	no
	SLG	Without	201.6	604.8	poor	poor
5	3LG	Without	853.2	1164.8	yes	no
	SLG	Without	0	403.2	poor	no
6	3LG	Without	805.2	604.8	yes	poor
	SLG	Without	0	403.2	poor	poor
7	3LG	Without	403.2	506.66	yes	no
	SLG	Without	201.6	403.2	no	poor
8	3LG	Without	600	1204.8	poor	no
	SLG	Without	0	0	poor	yes
9	3LG	Without	650	1358.26	yes	yes
		With	N/A	1668.05	N/A	yes
	SLG	Without	851.6	604.8	yes	yes
10	3LG	Without	450	1358.26	poor	yes
	SLG	Without	100	1154.8	yes	yes
11	3LG	Without	603.2	403.2	poor	poor
		With	N/A	1196.26	N/A	no
	SLG	Without	403.2	403.2	poor	poor
		With	N/A	604.8	N/A	no
12	3LG	Without	403.2	804.9	poor	poor
	SLG	Without	403.2	604.8	poor	poor

4.2 Discussion of Dynamic Issues

4.2.1 Ride-Through Performance

For disturbances in which the wind plants do not become isolated from the system, they are required to ride-through. Not all wind plants were able to ride-through for all cases. A summary of wind plant ride-through observations is shown in Table 5.

Table 5 Summary of wind plant ride-through observations with the fast dynamic reactive devices.

Contingency #	Fault Type	Wind Plant																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
3	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
	SLG	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
4	3LG	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
5	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
6	3LG	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟥
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
7	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
10	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟨	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟨	🟨	🟩	🟩	🟩	🟩	🟥	🟨	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
11	3LG	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
12	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩
🟩 Wind Plant Rides Through																									
🟨 Undamped Oscillations																									
🟥 Wind Plant Trips																									

4.2.2 Oscillations due to tuning of generic dynamic reactive device models

Detailed PSCAD models were not provided for the dynamic reactive devices in the South Texas system. Therefore, generic PSCAD models of these dynamic reactive devices including simple PI controllers were used. Initially, the full set of runs was simulated with an integral time constant of 0.005s for the PI controller. In some cases sustained oscillations were observed throughout the system as shown in Figure 8, in other cases the oscillations were damped. The frequencies of these oscillations were in the range of 23 to 27 Hz.

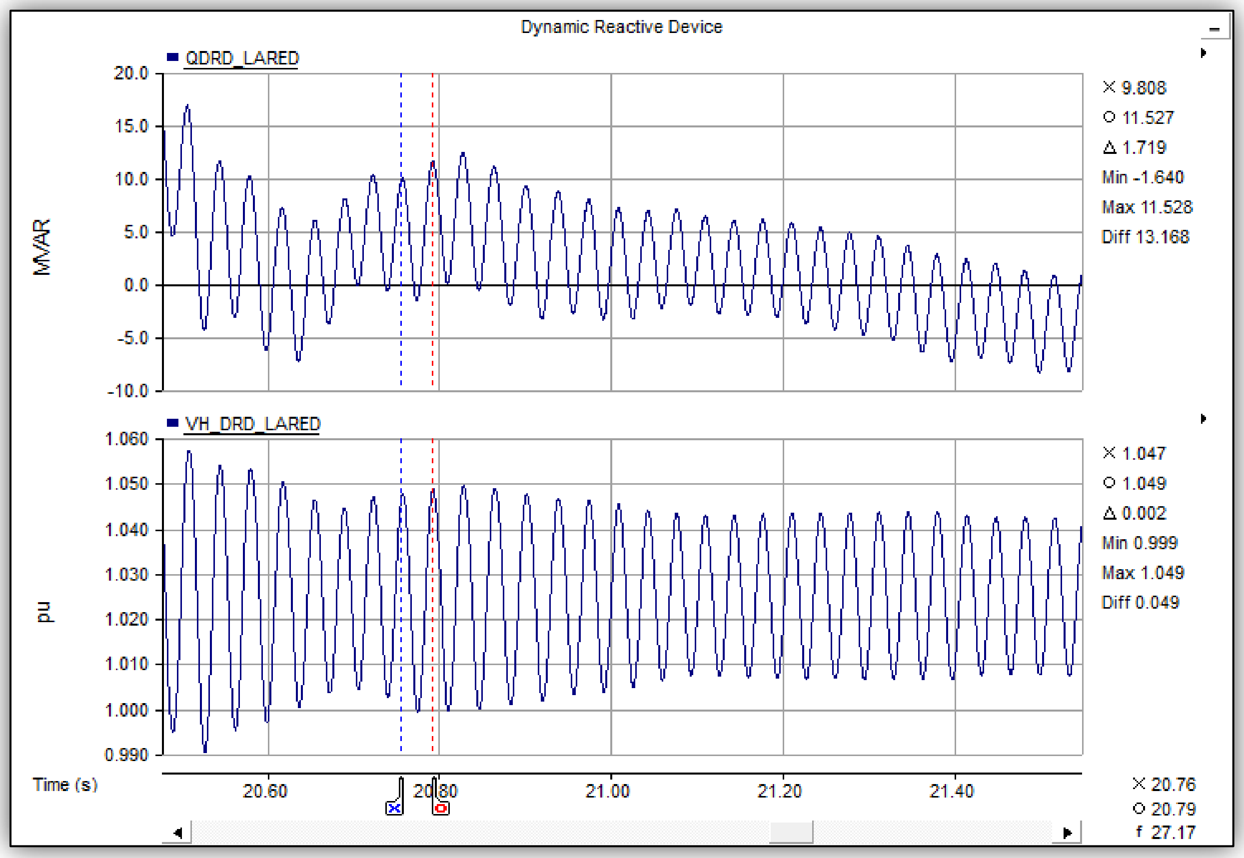
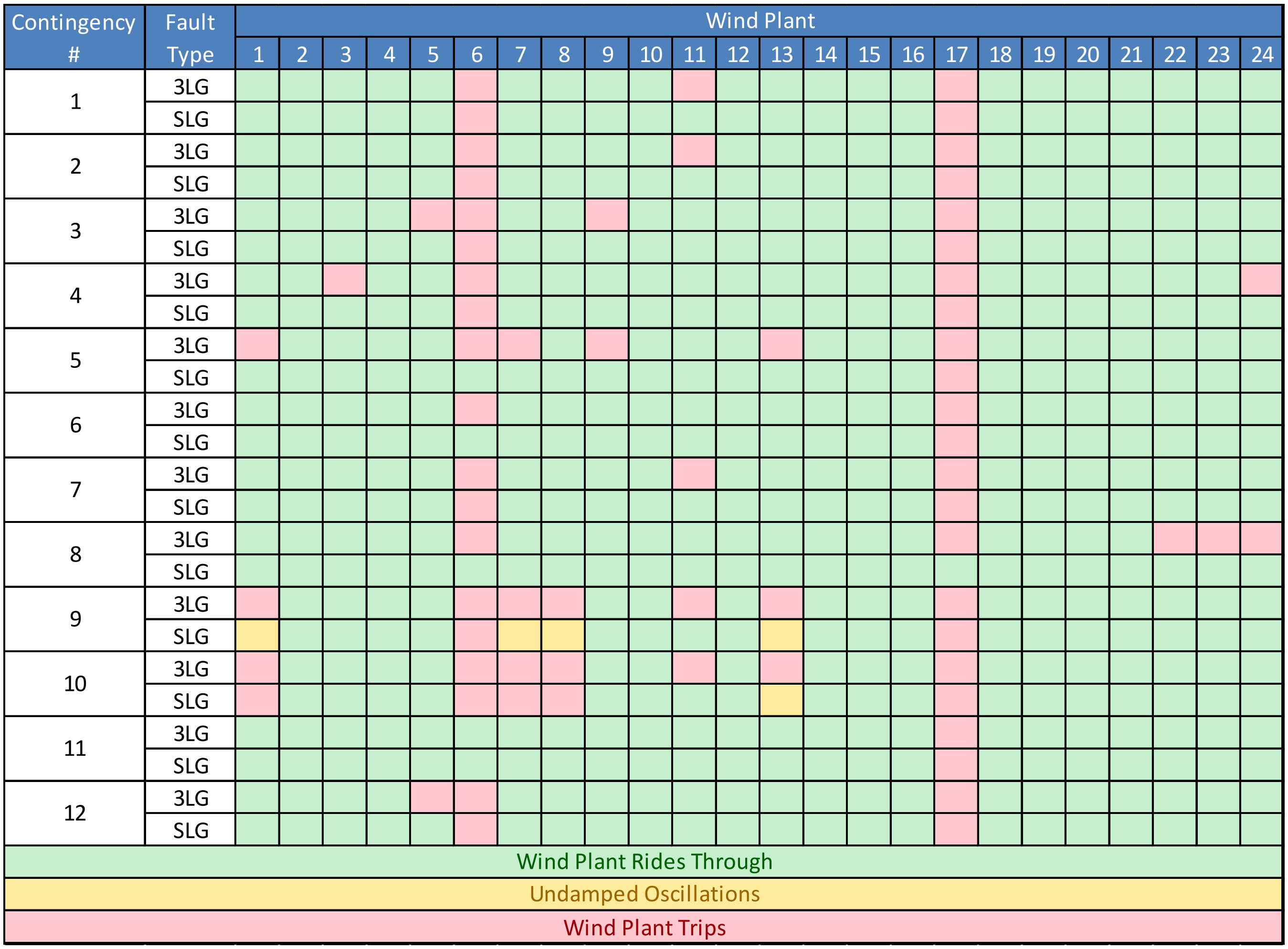


Figure 8 PSCAD traces showing the sustained oscillations at 27 Hz, with the fast generic dynamic reactive device.

To show that the oscillations were influenced by dynamic reactive device tuning, these devices were slowed down. To do this the integral time constant was reduced for the next set of runs to 0.1s for the PI controller. In addition, a real pole was added to the measurement with a time constant of 0.1 seconds. For this set of runs, there were fewer cases with oscillations. Where observed, the oscillations were measured at 4 Hz as shown in Figure 9. However, since the voltage control with slow dynamic devices is less responsive, more wind plants trip in this set of runs than with the fast dynamic reactive devices (these wind plants trip due to poorly controlled voltage near their terminals). This is evident when comparing Table 5 with Table 6.

Table 6 Summary of wind plant ride-through observations with the slow dynamic reactive devices.



Contingency #	Fault Type	Wind Plant																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	3LG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2	3LG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
3	3LG	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
4	3LG	🟩	🟩	🟥	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
5	3LG	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
6	3LG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
7	3LG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
8	3LG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
9	3LG	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟨	🟩	🟩	🟩	🟩	🟥	🟨	🟨	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
10	3LG	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟩	🟩	🟨	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
11	3LG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
12	3LG	🟩	🟩	🟩	🟩	🟥	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
	SLG	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩

🟩 Wind Plant Rides Through

🟨 Undamped Oscillations

🟥 Wind Plant Trips

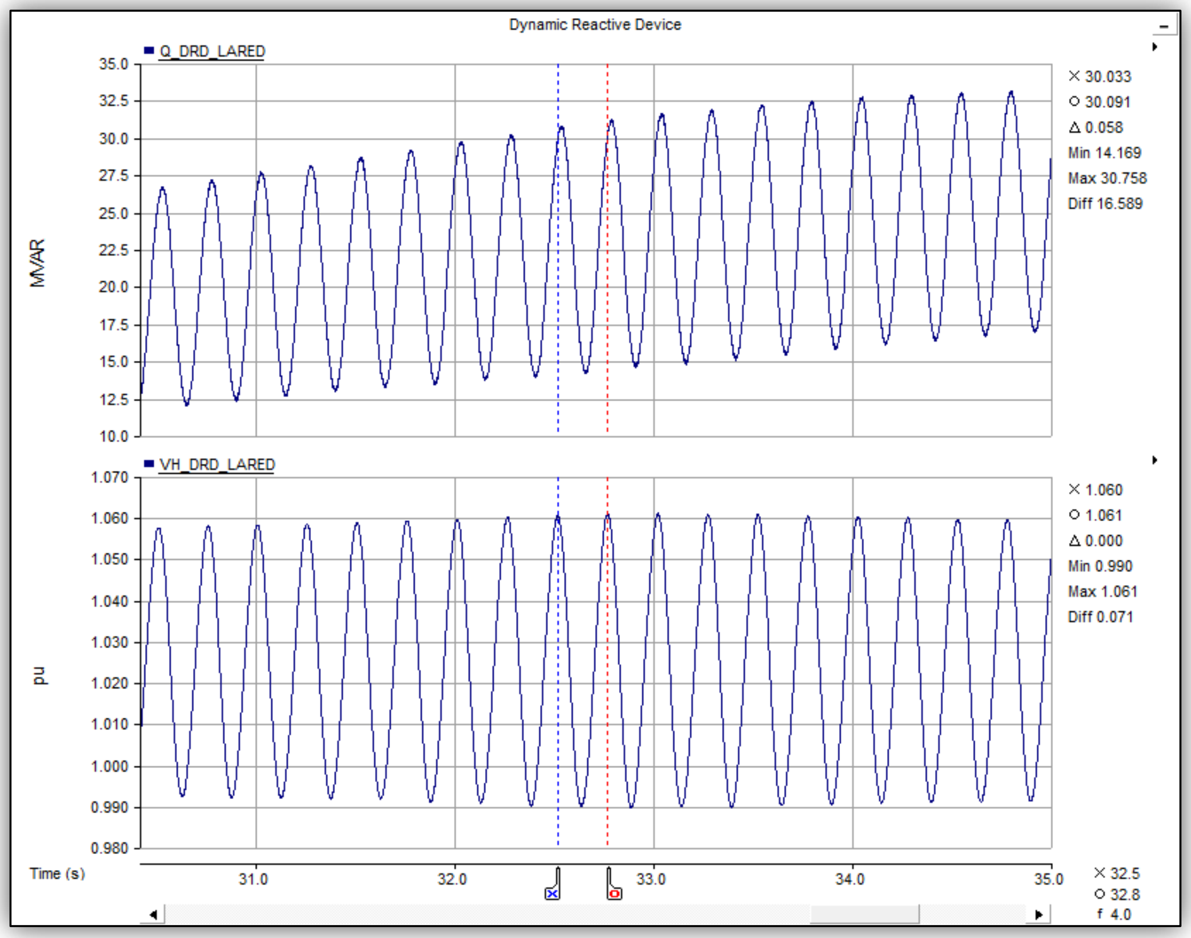


Figure 9 PSCAD traces showing the sustained oscillations at 4 Hz, with the slow dynamic reactive device.

4.2.3 Loads modeled as dynamic loads impact on the results

Sensitivities with the dynamic loads modeled were run for three contingencies. The results of these three sensitivities are tabulated in Table 7 to compare with the results where the loads are modeled without the dynamic loads. In general, modeling the loads with dynamic load models resulted in more wind plants tripping.

Table 7 Comparison of wind plant ride-through with and without dynamic load models.

Contingency #	Fault Type	Dynamic Loads	Wind Plant																							
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
9	3LG	Without	🟥	🟩	🟩	🟩	🟩	🟥	🟥	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
		With	🟨	🟩	🟩	🟥	🟥	🟥	🟥	🟨	🟥	🟩	🟥	🟩	🟨	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟥
11	3LG	Without	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
		With	🟥	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟥	🟩	🟥	🟩	🟩	🟥	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
11	SLG	Without	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
		With	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟥	🟩	🟩	🟩	🟩	🟩	🟩	🟩
🟩 Wind Plant Rides Through																										
🟨 Undamped Oscillations																										
🟥 Wind Plant Trips																										

4.2.4 PSCAD wind turbine model inadequacies

A list of inadequacies in PSCAD models has been provided to ERCOT.

4.2.5 Instabilities relating to Series Capacitors

Unstable behaviour is possible when wind plants are operated radially through series capacitors. This phenomena was observed in some cases.

4.2.6 Oscillations

For many faults and events, oscillatory modes were identified associated with specific wind plants, or combinations of wind plants. These were identified in detail in a separate report to ERCOT.

5.0 Parametric SCR Reduction Analysis (Panhandle)

5.1 Summary of SCR Reduction Analysis

A test system was developed to examine the behavior of the Panhandle system (with no Lubbock connection) by parametrically reducing the short circuit strength (increasing impedance) of the passive network equivalents at the boundary buses (Riley, Clear Crossing, Dermot, Long Draw and Scurry County 345 kV) for the case with no Lubbock connection. The PSCAD model of the Panhandle system (including detailed wind plants) was used for these tests. This analysis was designed to provide a basic screening-level understanding of the stability limits of the Panhandle as the relative strength of the supporting ERCOT network was reduced.

5.2 SCR Test System Development

The passive network equivalents of the boundary buses were replaced by the custom generators as shown in Figure 10. A resistor and an inductor were connected in series to the passive network equivalent generators as shown in Figure 11. A custom PSCAD component was developed which increase the series connected R and L reducing the effective short circuit strength of the boundary buses. This component was also used to maintain the voltage and relative angles at the boundary buses constant by adjusting the source terminal voltages of the equivalent generators.

The short circuit strength of the boundary buses was decreased linearly, and the corresponding WSCR values were calculated using PSS/E. The relationship between the SCR index at the boundary buses and the overall WSCR of the Panhandle system is shown in Table 8.

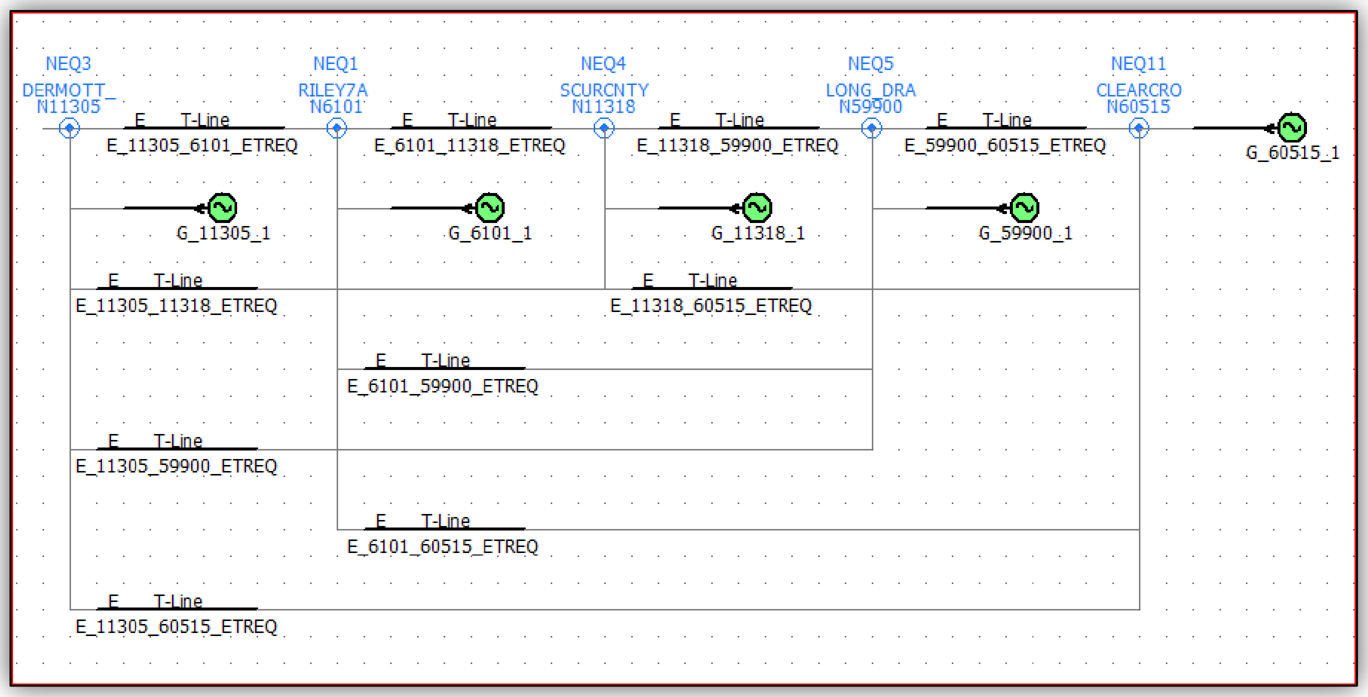
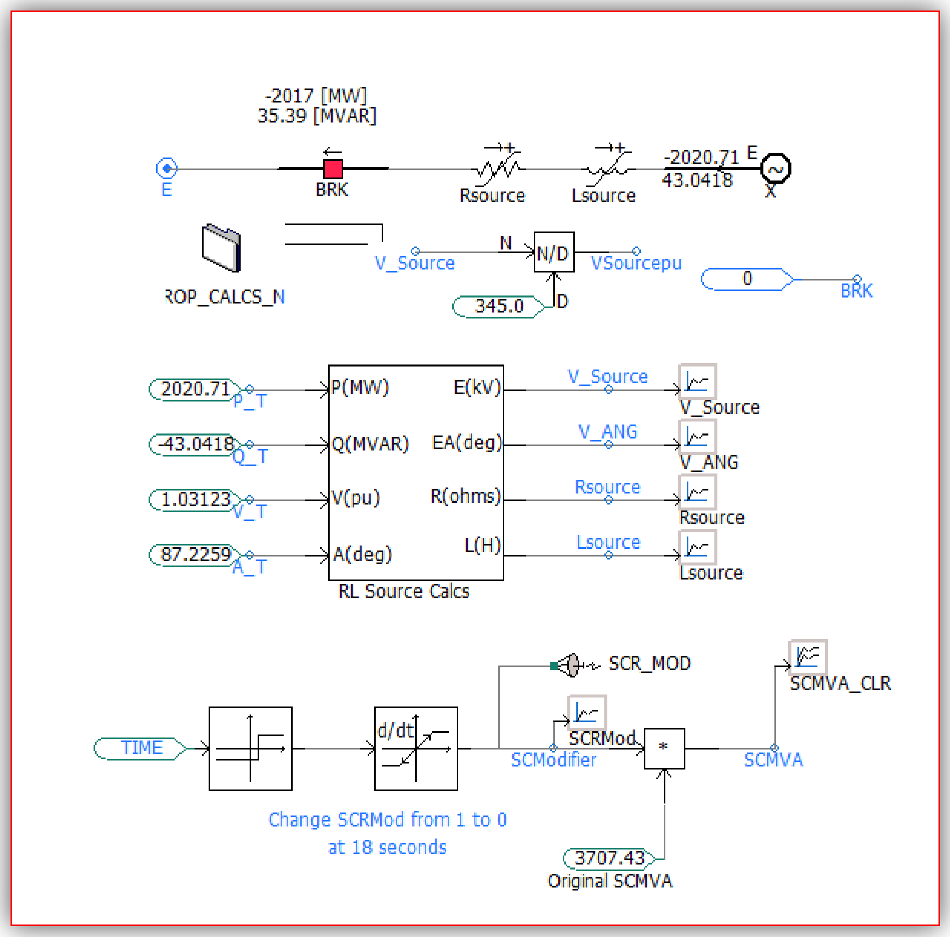


Figure 10 Modified passive network equivalents at the boundary buses



Change SCRMod from 1 to 0 at 18 seconds

Figure 11 Inside the modified passive network equivalent

Table 8 SCR index mapped to ERCOT WSCR metric

SCR index at boundary buses (pu)	WSCR
1	1.51
0.9	1.48
0.8	1.44
0.7	1.40
0.6	1.35
0.5	1.31
0.4	1.27
0.3	1.18
0.2	1.09

5.2.1 Large signal stability of the Panhandle system with reducing SCR

Three phase to ground faults were applied at the Tule Canyon 345 kV bus over four cycles and cleared, without any line outage, every 4 seconds as the SCR was linearly ramped down. The four second duration was chosen to provide enough time for wind plants to recover following the disturbance. The behavior of all wind plants and reactive power controlling devices was monitored for any abnormal behavior or tripping. Some wind plant trips were observed at the start of the WSCR reduction (approximately 130 MW total). These trips were mainly due to the local issues, and although they have a small impact on WSCR, do cause the remaining system WSCR to effectively rise (meaning that resulting WSCR numbers are slightly optimistic.) The test was continued until widespread wind tripping was observed.

5.3 Results of Parametric SCR Reduction Analysis

The results of the SCR test are shown in Table 9. Note that these results represent different thresholds than those used in dynamic performance testing – ie. pre-fault vs. post-fault. A 1.5 pre-fault WSCR in the detailed study is different from a 1.5 post fault WSCR in this test.

Table 9 SCR Test Results

SCR index at boundary buses (pu)	WSCR	Large Signal Stable
Simple Source Reduction (Applies to 70%)		
1	1.51	Yes
0.9	1.48	Yes
0.8	1.44	Yes
0.7	1.40	Yes
0.6	1.35	Yes
0.5	1.31	Yes
0.4	**1.27**	Yes
0.3	1.18	No
0.2	1.09	No

5.3.1 Large signal stability

The application of a three phase fault for four cycles makes all the wind plants go to fault ride through mode as shown in Figure 12. When the fault was applied at an SCR index of 0.3 (WSCR = 1.18), wind plants failed to ride through, and this level was considered to be “Large Signal Unstable”. The 0.4 pu SCR index is equivalent to WSCR of 1.27. It should be noted that this level is still “system intact” in the Panhandle, so this corresponds well with the post-fault levels studied in the dynamic performance analysis. (i.e. WSCR = 1.5 prior to the fault corresponds to a reduced (but stable) WSCR after the fault).

5.3.2 Conclusions of SCR Ramp Tests

The results of these SCR tests are in good alignment (except few early wind plants tripping) with the detailed time domain simulations described above. The SCR ramp test indicates that the system is stable with a WSCR of approximately 1.3 for N-0 conditions. The detailed contingency tests indicated that the system is stable with

WSCR of 1.5 prior to sixteen selected contingencies. The application of these contingencies lower the WSCR level approximately to 1.4 in the detailed simulations.

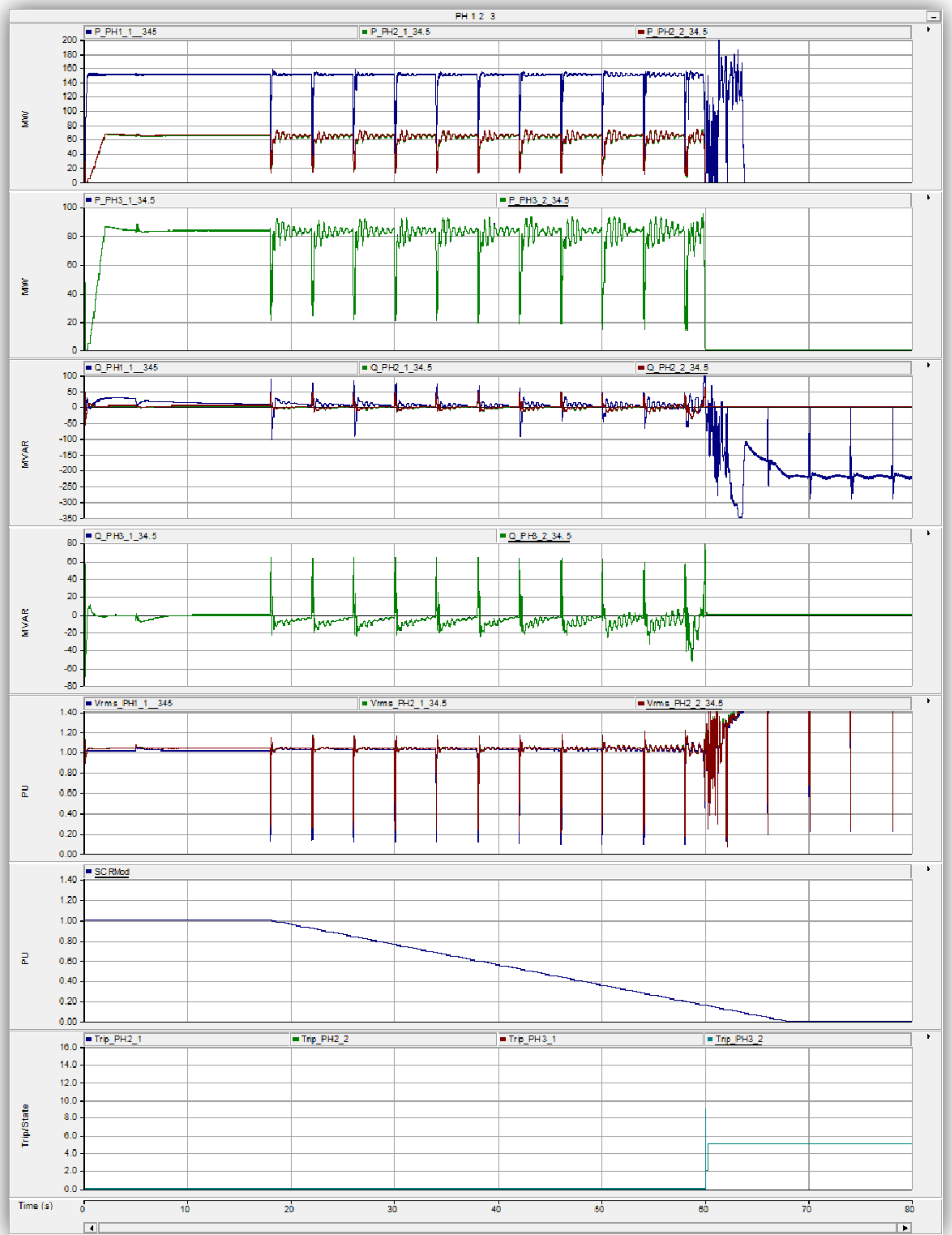


Figure 12 Large signal stability behavior of a Panhandle wind plant as SCR is linearly reduced

6.0 Parametric SCR Reduction Analysis (South Texas)

A detailed WSCR parametric ramp test was also performed in the South System, similar to that in the Panhandle, but is not reported here in detail. This system examined the behavior of the South Texas System by parametrically reducing the short circuit strength (increasing impedance) of the passive network equivalents at the boundary buses (MIGUEL5, LONHILL7A, NLARSW4A, LON_HILL4A, and ALAZAN4A 345/138 kV). The PSCAD model of the South Texas System (including detailed wind plants) was used for these tests. This analysis was designed to provide a basic screening-level understanding of the stability limits of the South Texas system as the relative strength of the supporting ERCOT network was reduced.

6.1 Summary of WSCR Reductions Analysis

It was determined that the WSCR metric has several limitations when applied in a region such as the South System, including:

- Susceptibility to variations in load
- Difficulty in defining boundaries for WSCR calculations as the wind generation disperses over a large area.
- Uncertainty in simulation due to poor model quality
- Presence of series capacitors present complicating technical challenges

These limitations were evident in both the detailed study and in the parametric ramp tests. For the current time, it is not recommended to use WSCR in defining real-time operating limits for the South Texas System. These limits should be set using conventional transient stability and voltage stability analysis tools, and checked periodically using detailed EMT simulation tools.