IBIS Results and Recommendations

TWG Meeting

September 4, 2019

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Contents

Transient and Small Signal Stability

Section 1

Transient Stability Study Results

- TSAT response of the provided model is benchmarked against PSS/E results
  - Dominant 0.56Hz oscillatory mode with sufficient damping is observed in SPP footprint for both sets of results
- TSAT responses of 8 screened faults by the Fast Fault Screening (FFS) was simulated
  - Instability occurred for faults close to Wolf Creek U1 unit
  - Sensitivity studies points to its exciter model data issue
  - Prony analysis finds the dominant mode indicating sufficient damping in all cases except those close to Wolf Creek; the issue disappears once Wolf Creek exciter model is removed

WC Instability

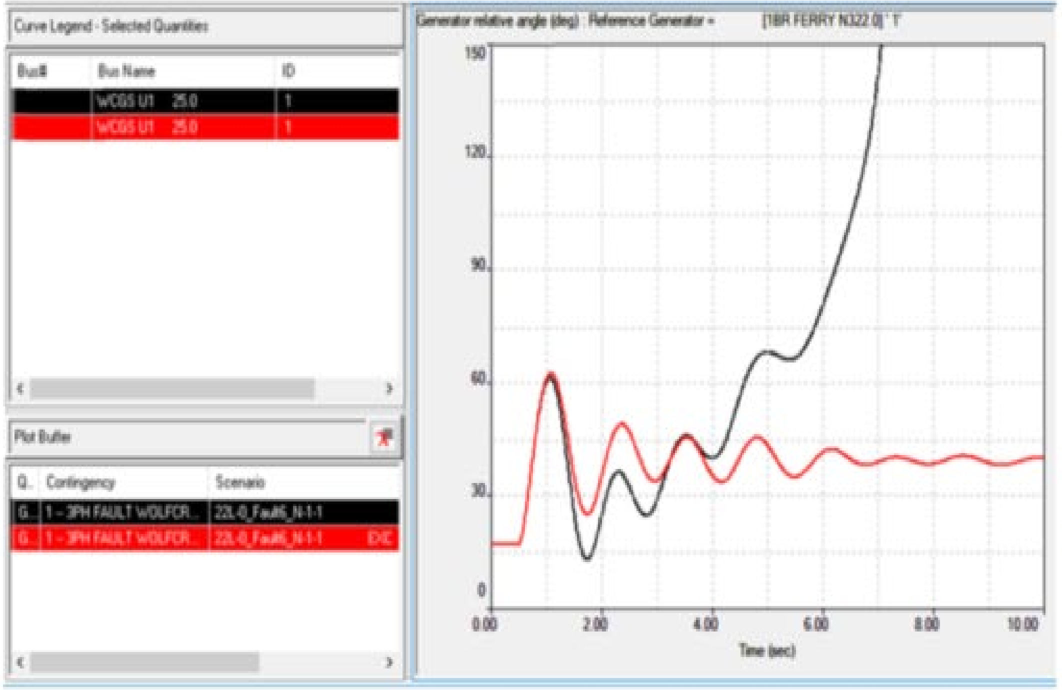

Figure 6.5.17: 22L-0 Fault 6 – Relative Rotor Angle with (Black) and without (Red) WCGS U1 Exciter

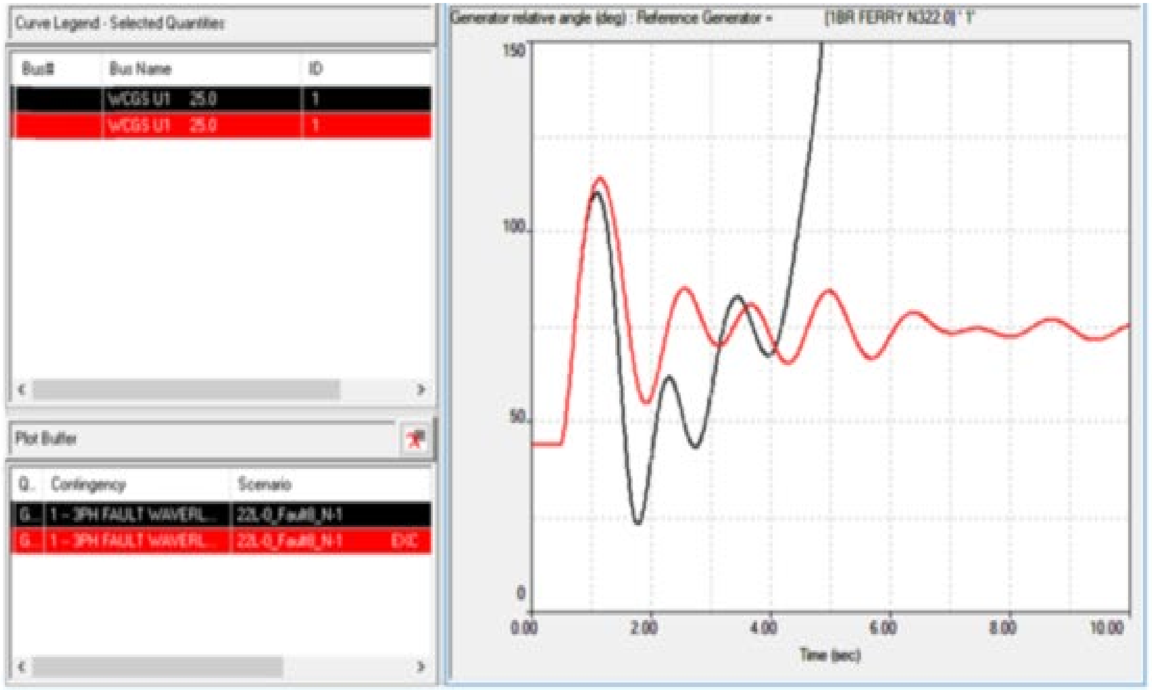

Figure 6.5.21: 22L-0 Fault 8 – Relative Rotor Angle with (Black) and without (Red) WCGS U1 Exciter

Small Signal Stability Study Results

- Eigenvalue scans of base cases and 8 FFS contingency cases
  - Two inter-area modes identified, ~ 0.5 – 0.6 Hz with different mode shapes, having significant participations of the generators in SPP footprint
  - Damping ratios ~ 6% or more in all cases except for cases with contingencies close to Wolf Creek
  - Damping issues resolve if WC exciter model is removed
- Outside of WC issue, no sign of real small signal stability in SPP
- Evergy notes future AVR replacement at WC

SCR Analysis

Section 2

Grid Strength

When grid disturbances occur:

Strong Grid

Bus voltages change little

Grid Strength

When grid disturbances occur:

Weak Grid

Bus voltages change a lot

Short Circuit Ratio

$$SCR = \frac{Ssc}{MWn}$$

Maximum Available Short Circuit Power (MVA) before connection of the resource

Power Rating (MW) of resource to be connected

- Measures the strength (voltage stiffness) at a point (bus) in the power system
- Measured at the point of interconnection (POI) of a resource to be connected
- Low SCR indicates weakness and additional analysis may be required

Short Circuit Ratio

$$CSCR = \frac{CSCMVA}{MW_n}$$

Composite Short Circuit Ratio

$$WSCR = \frac{\sum_i^N SCMVA * MW_i}{\sum_i^N MW_i}$$

Weighted Short Circuit Ratio

- A large concentration of wind plants connected in the vicinity of a transmission node can result in low grid strength
- Ratio calculation becomes more complicated
- Composite and Weighted SCR better measure of Ratio

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Inverter Oscillatory Instability

- High levels of Inverter-based generation will have a different impact on SCR than with conventional generation
- Inverter Oscillatory Instability – adverse control interactions between inverter controllers
  - Of two or more inverter-based plants
  - Of one inverter-based wind plant and a synchronous machine
  - Of one inverter-based wind plant and any other controller present in the system
- May lead to negative damping and system instability
- May lead to sustained inter-area oscillations

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See NERC Reliability Guideline: *Integrating Inverter-Based Resources into weak Power Systems* for details

Lowest Short Circuit Ratios

Gen Bus Name	MW	POI Bus Name	SCC MVA @ POI	SCR (POI)
OAKTREE WIND	20.4	CLARK JCT	79.5	3.897
GEN 37	288	DOVERSW4	1380.1	4.792
IRONWD WTG1	151.8	IRONWOOD 1	755.7	4.978
GEN 29	54	LG-DIXON 2	294.2	5.448
WTH WIND	147	WTH WF 4	802.9	5.462

SCR Below 6.0 Threshold

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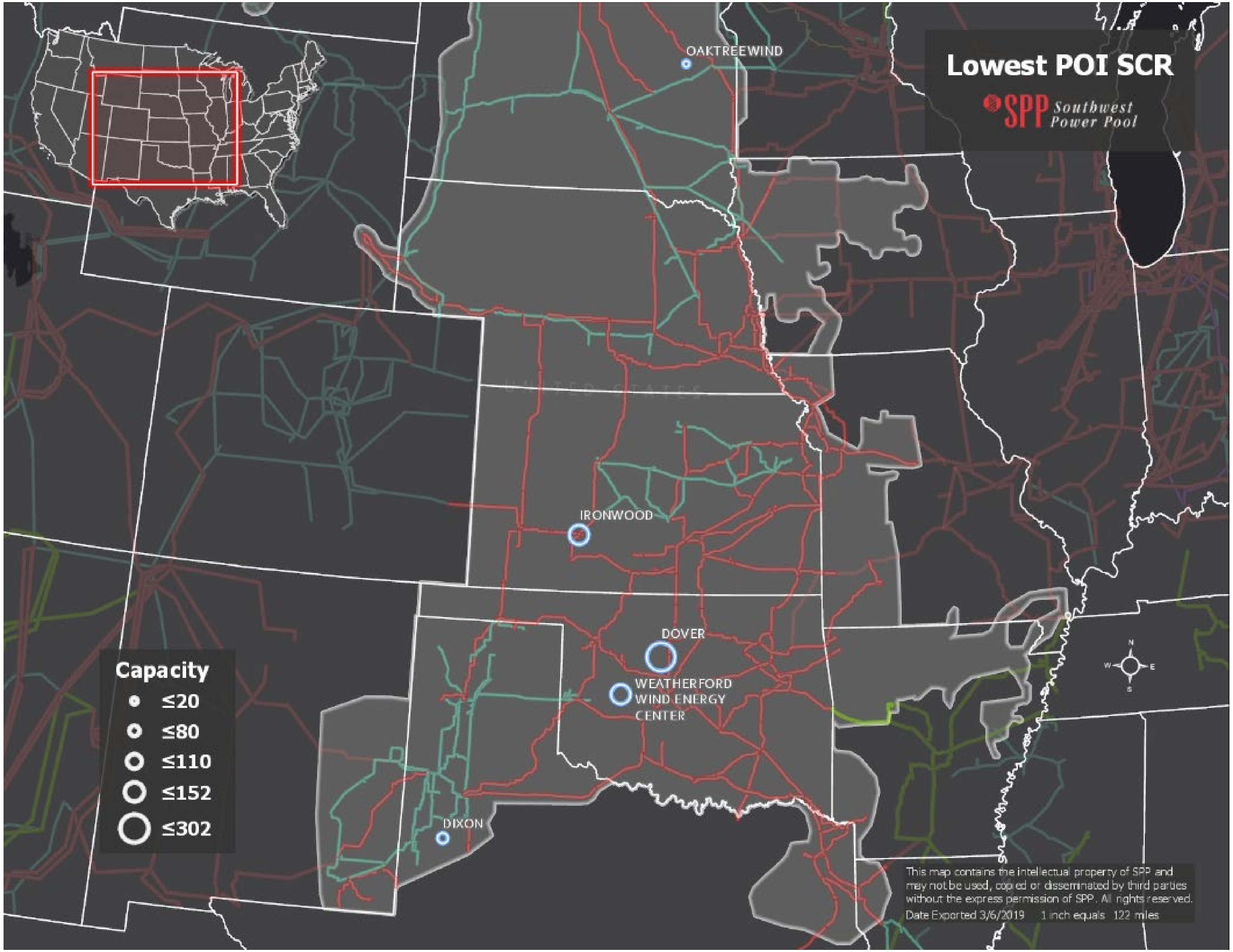
Lowest POI SCR
SPP Southwest Power Pool
OAKTREEWIND
IRONWOOD
DOVER
WEATHERFORD WIND ENERGY CENTER
DIXON
Capacity
≤20
≤80
≤110
≤152
≤302
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Lowest Weighted Short Circuit Ratios

Buses	WSCR
CRKCK 3, CENT 4	3.477
GOODWELLWND3, CRKCK 3, WILDOR2_JUS6	4.484
CRKCK 3, AINSWND.PLTD	4.25
CRKCK 3, PETERSBRG.N7	5.385
CRKCK 3, CAMPBELL 4	5.461
CRKCK 3, LINDAHLS-MW7	3.574
CRKCK 3, CLARK JCT	5.372
GOODWELLWND3, EXCELN4-HV23, CRKCK 3, MUSTANG 3	3.752
GOODWELLWND3, EXCELN4-HV23, CRKCK 3, MADDOX 3	4.418
CRCK 3, BAILEYCO 3	4.228
GOODWELLWND3, CRKCK 3, RDRUNNER 3	3.375

WSCR Below 6.0 Threshold

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SCR does not provide the entire picture…

- For an inverter plant, a low or high value of SCR may not provide the entire picture.
- The possibility of instability is governed by,
  - The short circuit capacity at the converter plant's terminals and the POI
  - The values of the controller gains
  - The MW power output level of the converter plant
  - The fault clearance time of transmission protection
- For this purpose, a new metric termed as **critical clearing time (CCT)** has been developed.
- CCT in this context is the maximum time a fault near the POI of the inverter plant is allowed to remain on the system to eliminate the possibility of instability of the inverter plant

Lowest Critical Clearing Times

Gen Bus Name	MW	POI Bus Name	CCT (s)
RUSHSPRW1-1	249.9	RUSHSPRW1-1	7.97
SPNSPUR_WND1	160	SPNSPUR_WND1	8.73
HALE_WND1 1	239	HALE_WND1 1	8.76
SPRVILL-WTG1	154.5	SPRVILL-WTG1	8.76

CCT Below 9.0 Threshold

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Comparisons of SCRs and CCTs

Gen Bus Name	MW	POI Bus Name	SCR (POI)	CCT
OAKTREE WIND	20.4	CLARK JCT	3.897	15.23
GEN 37	288	DOVERSW4	4.792	-
IRONWD WTG1	151.8	IRONWOOD 1	4.978	45.6
GEN 29	54	LG-DIXON 2	5.448	-
WTH WIND	147	WTH WF 4	5.462	10.88

Target POI →

SCR Below 6.0

Gen Bus Name	MW	POI Bus Name	SCR (POI)	CCT
RUSHSPRW1-1	249.9	RUSHSPRW1-1	17.5	7.97
SPNSPUR_WND1	160	SPNSPUR_WND1	23.19	8.73
HALE_WND1 1	239	HALE_WND1 1	20.58	8.76
SPRVILL-WTG1	154.5	SPRVILL-WTG1	26.32	8.76

CCT Below 9.0

EMT Analysis

Section 3

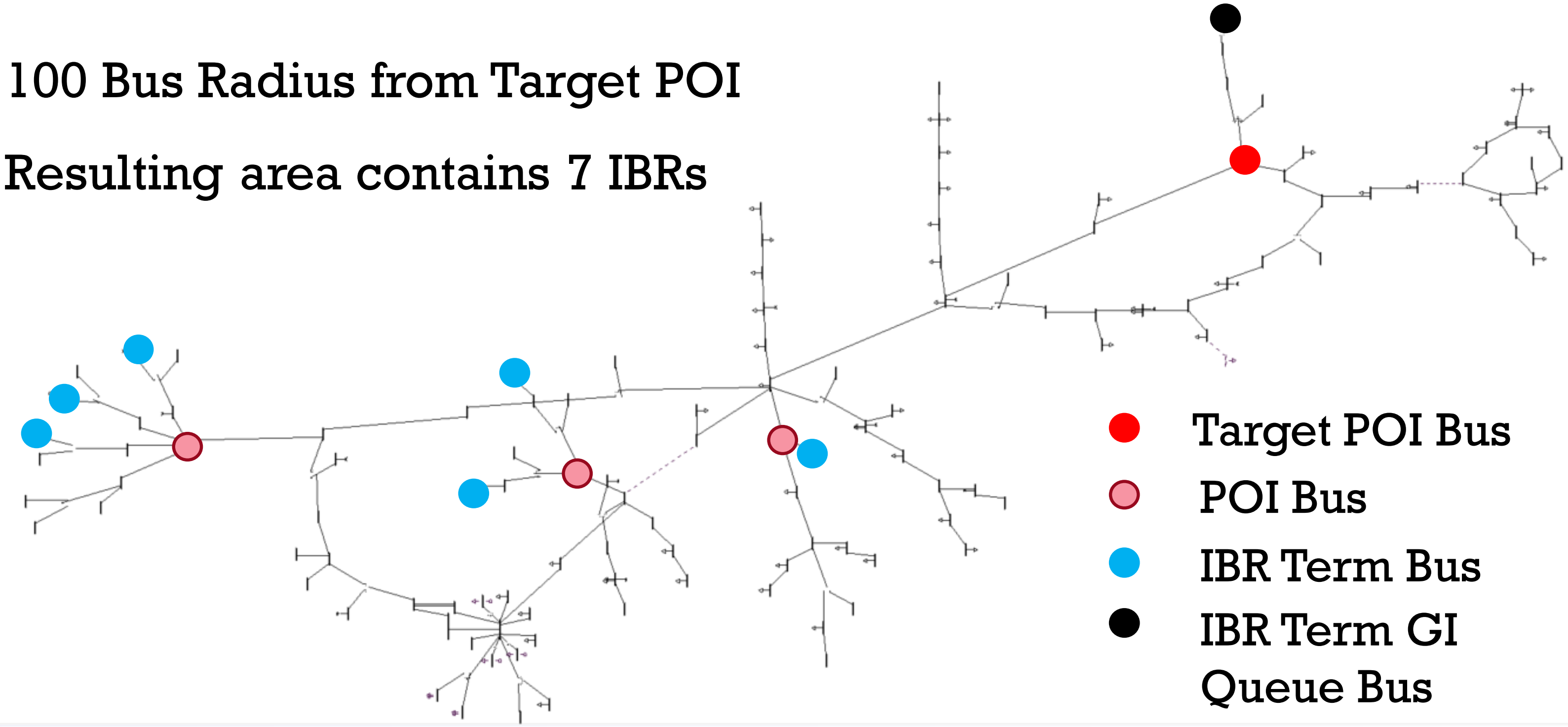
Wind Plants and Low SCR

- Full 3-phase Electromagnetic Transient Analysis traditionally required when low SCRs are found in connection with wind plants
- Requires detailed models to represent control characteristics not seen in normal dynamics models
- PSCAD is an EMTP Software tool
- Used to validate CCT calculations

Subsystem for PSCAD Study

100 Bus Radius from Target POI

Resulting area contains 7 IBRs

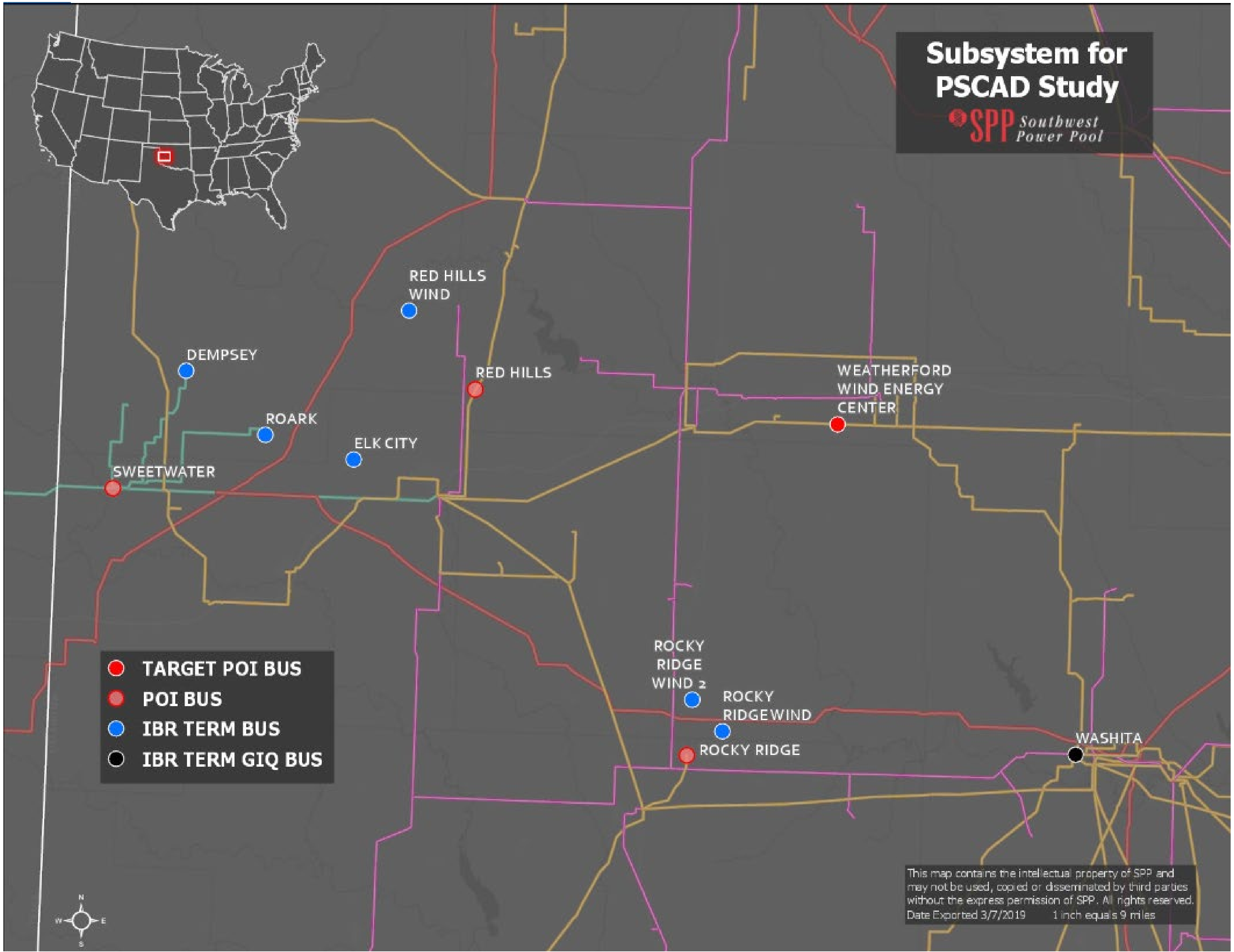


Target POI Bus

POI Bus

IBR Term Bus

IBR Term GI Queue Bus


Subsystem for PSCAD Study
SPP Southwest Power Pool
RED HILLS WIND
DEMPSEY
RED HILLS
WEATHERFORD WIND ENERGY CENTER
ROARK
ELK CITY
SWEETWATER
ROCKY RIDGE WIND 2
ROCKY RIDGEWIND
ROCKY RIDGE
WASHITA
TARGET POI BUS
POI BUS
IBR TERM BUS
IBR TERM GIQ BUS
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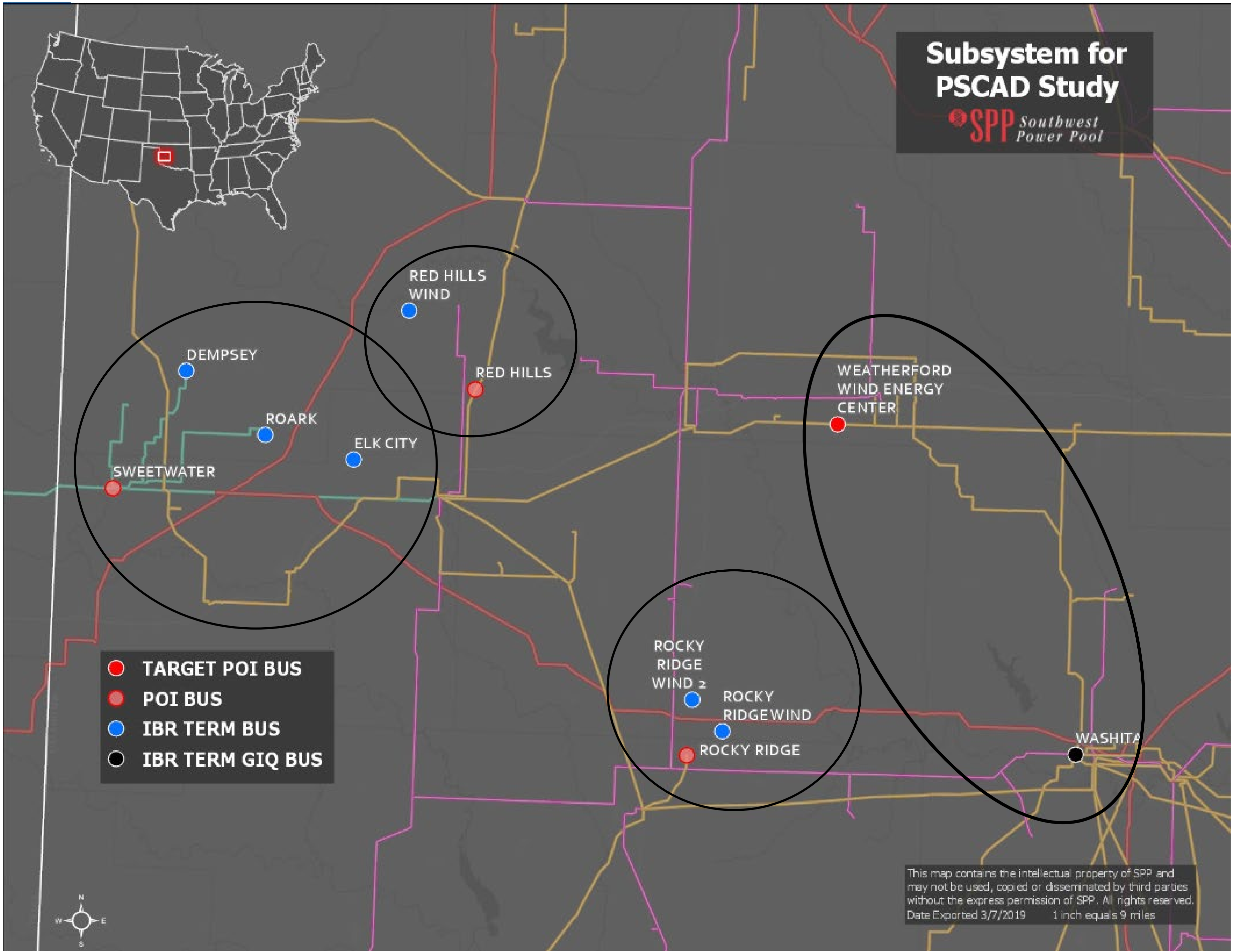

Subsystem for PSCAD Study
SPP Southwest Power Pool
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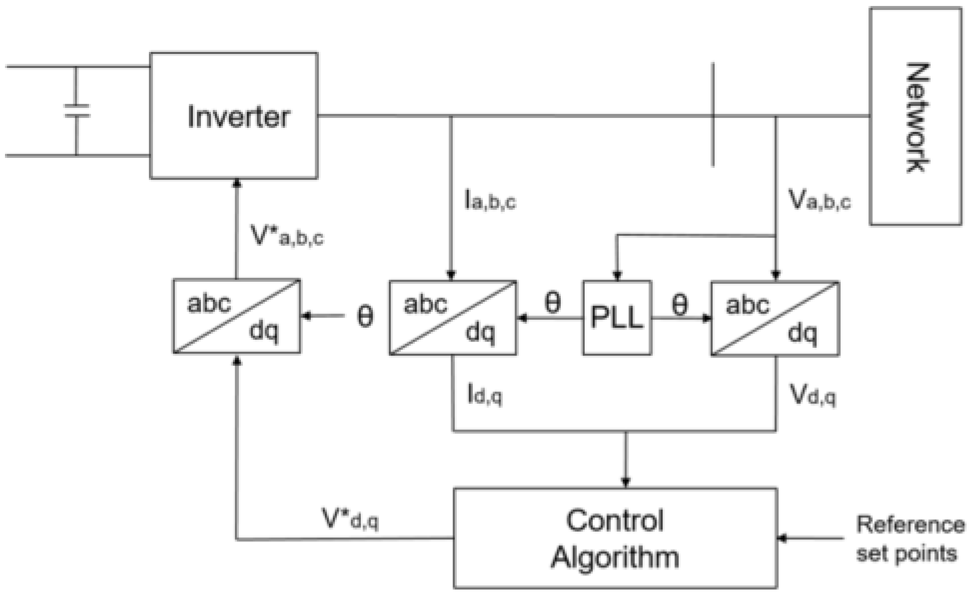
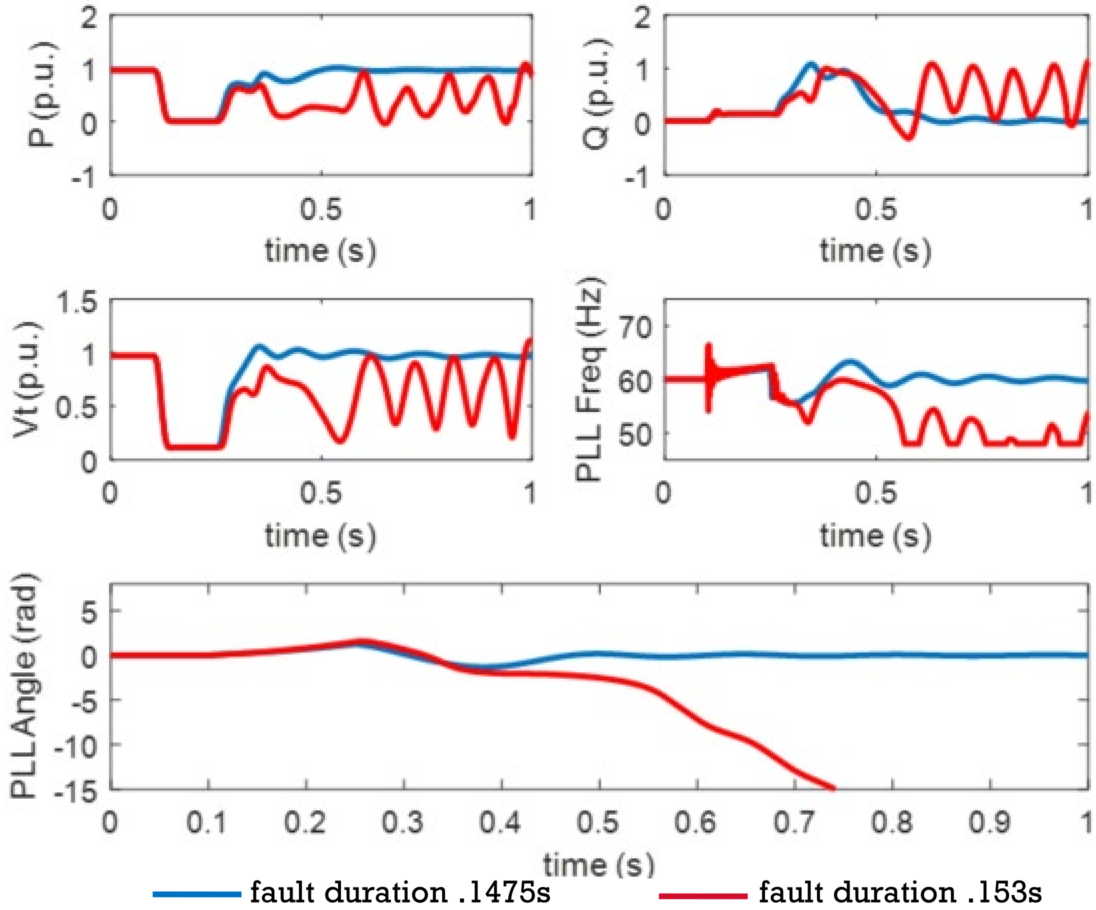
PSCAD Results





PLL Controller gains				Terminal Voltage Controller gains	
K_i	K_p	f_{max}	f_{min}	K_{vi}	K_{vp}
1400	60	72 Hz	48 Hz	120	0

Values used in study

Impact of Phase-Locked Loop Dynamics

PSCAD Results

Gen Bus Name	POI Bus Name	FAULTED BUS	GSAT CCT (CY)	PSCAD CCT (CY)	Field Settings CCT (CY)
REDHILLS WF	RHWIND4	RHWIND4	15.64	13.9	5.0
G0322….	WTH WF 4	WTH WF 4	7.72	6.09	N/A
RKYRDGW1-2WG RKYRDGW1-2WG	RKY_RDG4	RKY_RDG4	7.956	7.86	5.5
ROARK1 DEMPSEY1 ELK_CITY_WG1	SWEETWT6	SWEETWT6	10.266	8.85	5.5

Critical Clearing Time Comparisons

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PSCAD Results

PLL				Voltage Controller	
K_i	K_p	f_{max}	f_{min}	K_{vi}	K_{vp}
1400	60	72	48	120	0
700	30	72	48	120	0
2800	120	72	48	120	0
1400	60	72	48	60	0
1400	60	72	48	240	0

CCT Sensitivity to PLL Gains

PSCAD Results

Observations on Sensitivity to PLL Gains

- CCTs decrease as PLL gains increase
- CCTs decrease as voltage control gains decrease
- PLL gain settings can have a dramatic impact on stability

The problem we have is we don't know what these gain values are!

PLL				Voltage Controller	
K_i	K_p	f_{max}	f_{min}	K_{vi}	K_{vp}
1400	60	72	48	120	0
700	30	72	48	120	0
2800	120	72	48	120	0
1400	60	72	48	60	0
1400	60	72	48	240	0

What About Impact of Line Outage Contingencies?

Contingency ID	From Bus	To Bus	Stable?	Most Impacted WTG Bus
1	WTH WF4	CL-NGTP4	No	G0322G0420G1
2	CLINTJC4	CL-NGTP4	No	G0322G0420G1
3	ELKCTY-4	CLINTJC4	Yes	G0322G0420G1
4	CLINTJC4	CLINTON4	Yes	G0322G0420G1
5	S.W.S.-4	WASHITA4	Yes	Group 1
6	ELKCTY-4	CHISHOLM6	Yes	Group 1

No-Fault N-1 Impacts

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What About Impact of Line Outage Contingencies?

Contingency ID	From Bus	To Bus	Stable?	Most Impacted WTG Bus
1	WTH WF4	CL-NGTP4	No	G0322G0420G1
2	CLINTJC4	CL-NGTP4	No	G0322G0420G1
3	ELKCTY-4	CLINTJC4	Yes	G0322G0420G1
4	CLINTJC4	CLINTON4	Yes	G0322G0420G1
5	S.W.S.-4	WASHITA4	Yes	Group 1
6	ELKCTY-4	CHISHOLM6	Yes	Group 1

Original PLL parameters

PLL			
K_i	K_p	f_{max}	f_{min}
1400	60	72 Hz	48 Hz

Tuned PLL parameters

PLL			
K_i	K_p	f_{max}	f_{min}
140	12	72 Hz	48 Hz

Reducing PLL gains K_i and K_p stabilizes the system for Contingencies 1 and 2

Some Observations

- CCT index can indicate suspect IBRs
- IBRs with smaller CCTs more likely to become unstable due to nearby line outage
- PLL and Voltage controller gains can be tuned to improve transient stability of IBRs
- PLL gains unknown

Recommendations

Section 4

Recommendations

1. SPP recommends that TWG reviews and resolve exciter data issues found in the study.
2. Transient and small signal stability scenarios should be included in SPP's planning process.
3. SPP Operations to install a transient stability screening tool to identify the most severe fault locations that need to potentially be monitored.
4. SPP GI will incorporate a grid strength assessment tool into the GI process to identify vulnerable areas or buses in the SPP footprint requiring EMT analysis.
5. SPP to develop a criteria metric that includes SCR and CCT and defines possible inverter instability.
6. MDWG to require Proportional & Integral (PI) gains and frequency limits for phase lock loop (PLL) inverter-based resource controllers in the annual data request and for new generator interconnection requests.
7. SPP Operations to work with EPRI to consider incorporating the grid strength assessment tool into the Operations processes when appropriate.
8. SPP Engineering to acquire and install an Electromagnetic Transient Program (EMTP) study tool to investigate potential issues identified from a grid strength assessment tool so that appropriate requirements can be included in relevant GIAs.
9. SPP staff to work with the affected TOs and wind farm manufacturers to resolve the possible inverter oscillatory instability found in the SCR and EMTP analysis.

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Questions and Discussion