ERCOT Voltage Ride-Through Study

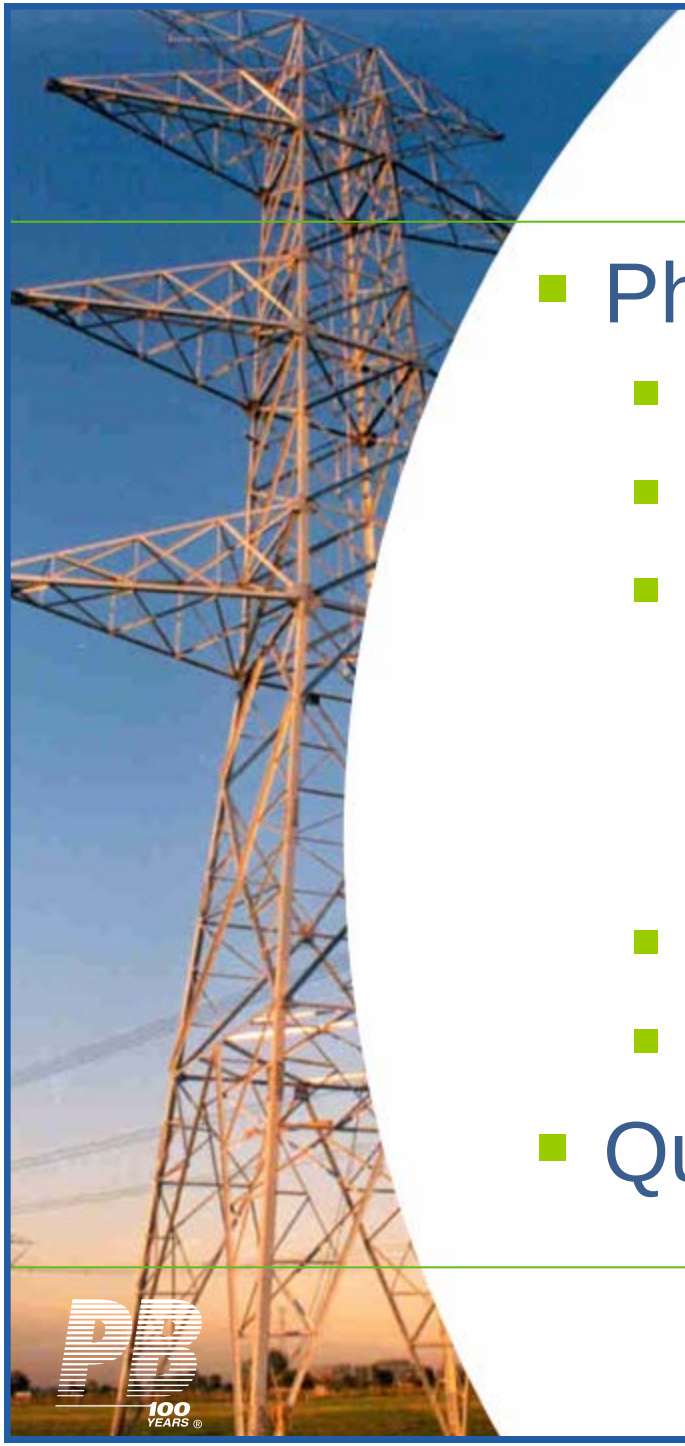
Phase III

June 25, 2010






Engineering a sustainable future



Agenda

- Phase II
  - Objectives
  - Data Collection & Modeling
  - Collection System Aggregation
    - Approach Overview
    - Implementation
    - Testing & Validation
  - Deliverables
  - PB Contribution
- Questions

Agenda

- Phase III
  - Objectives
  - Case Definitions
  - Event Definitions & Reliability Metrics
  - Results
  - Observations/Conclusions
  - Deliverables
  - PB Contribution
- Questions

Phase II

Engineering a sustainable future

Objectives

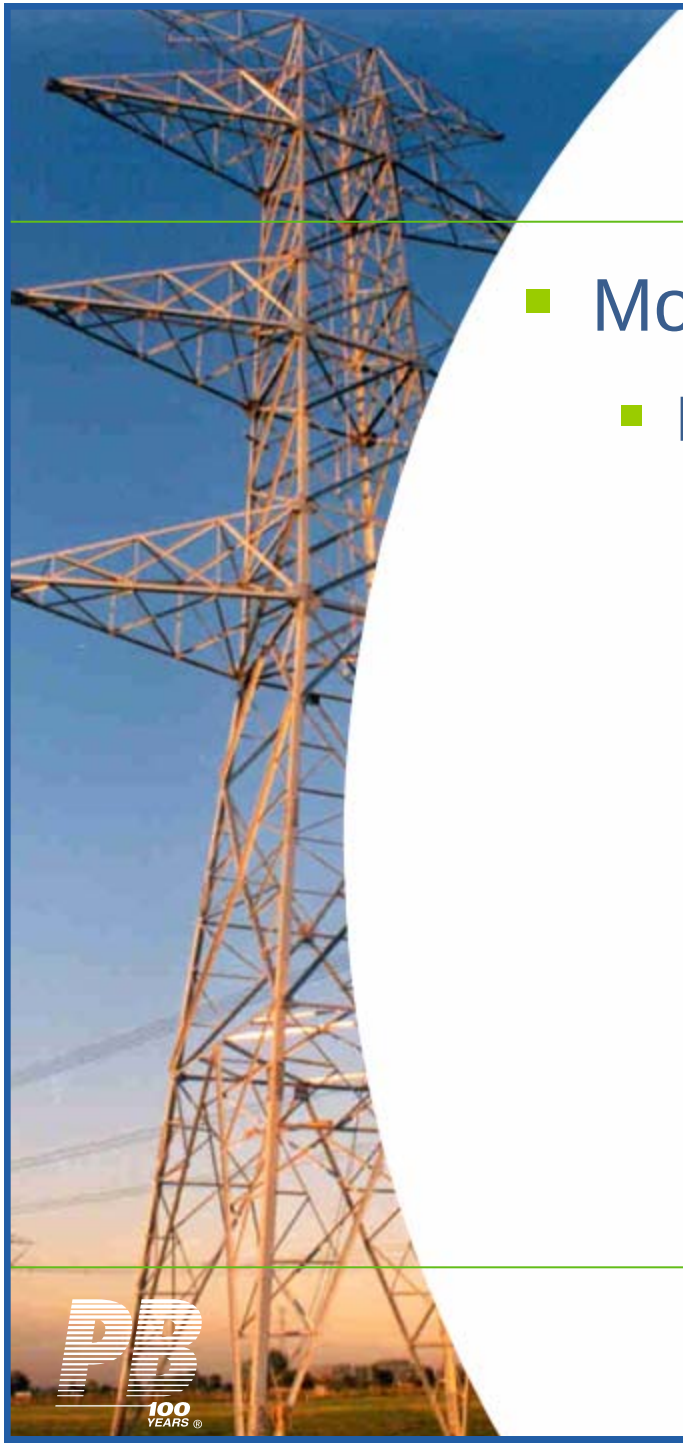
- WGR Data Collection & Validation
- WGR model development
  - Steady State Standpoint
  - Dynamic/VRT Standpoint
- Incorporation of updated WGR models
  - Dynamic Data Set
- WGR model testing & validation
  - PSS/E Version 31
- Acceptable Wind Flat Start

Data Collection & Modeling

- Data Collection
  - Data requirements organized as a VRT Data Request Form
    - Comments from ERCOT & WGRs incorporated
  - Data Request
    - Turbine & PM Transformer Data
    - Collection System Data
    - Turbine Reactive Capability Data
    - Sub-station transformer & capacitor/reactor bank data

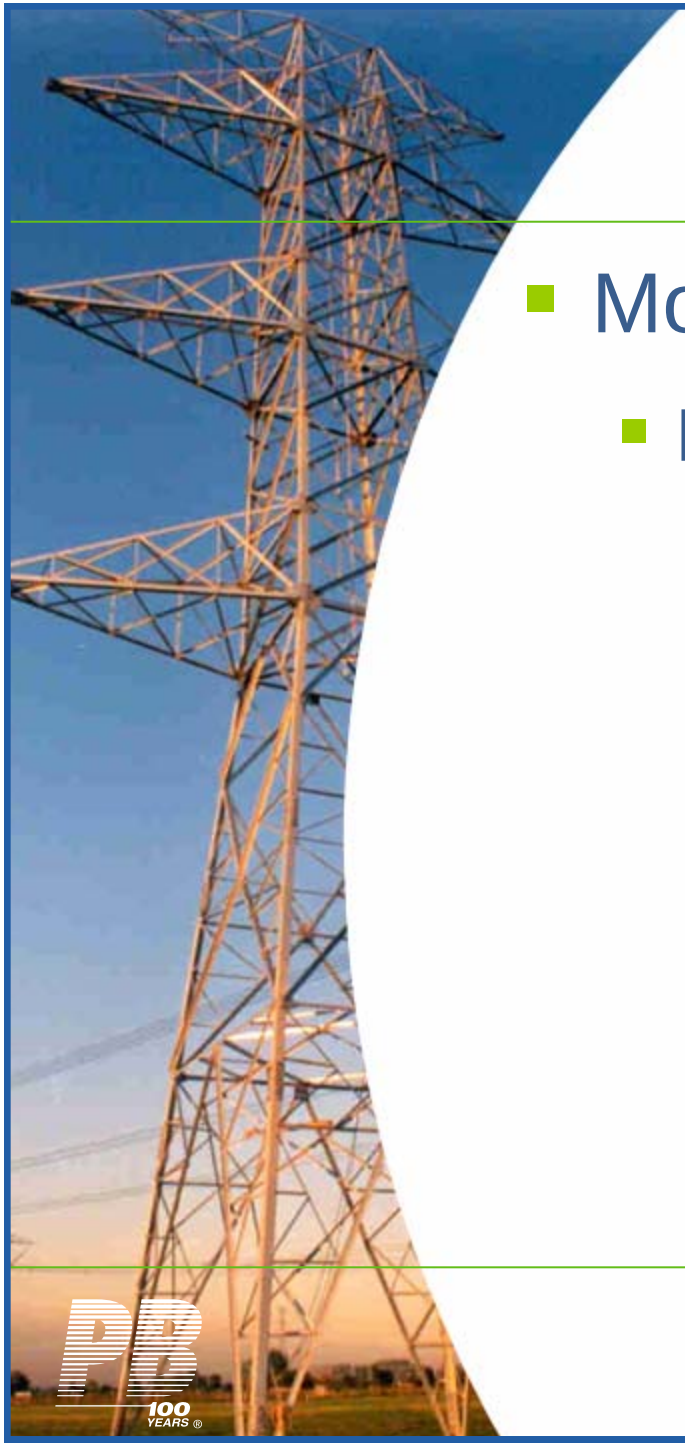
Data Collection & Modeling

- Data Collection
  - Data Request
    - Turbine VRT Capability Data
    - O/H line Data
    - Facility & Collection System SLD
  - Data collection & validation performed for 65 WGR campuses
    - VRT Data Request Forms
    - Detailed facility model in “raw” format



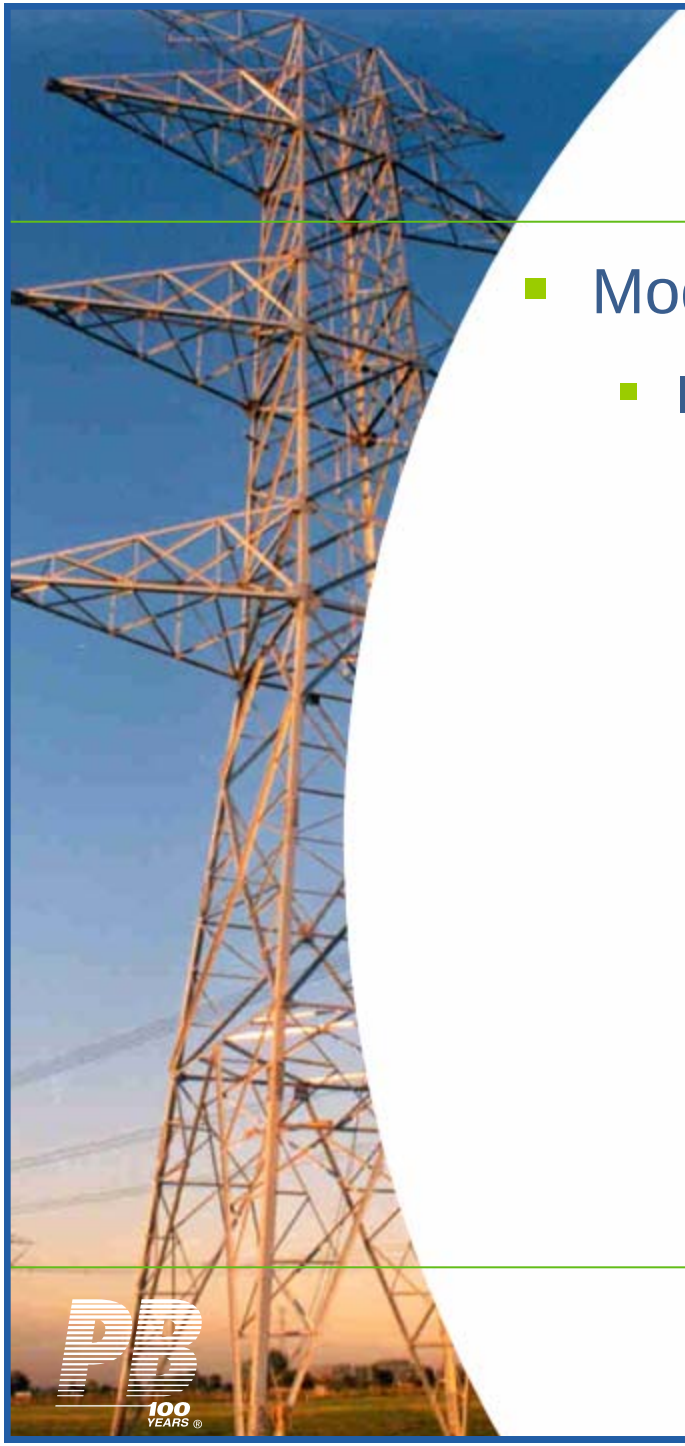
Data Collection & Modeling

- Model Development
  - Key Aspects
    - Accurate modeling of reactive capability of various wind turbines
    - “Three-point” distinction for turbine reactive capability
      - Type of Control
      - Range of Control
      - Point of Control
    - Accurate modeling of station transformer LTC, if any
      - LTC location – High/Medium Voltage side
      - LTC control – High/Medium Voltage side



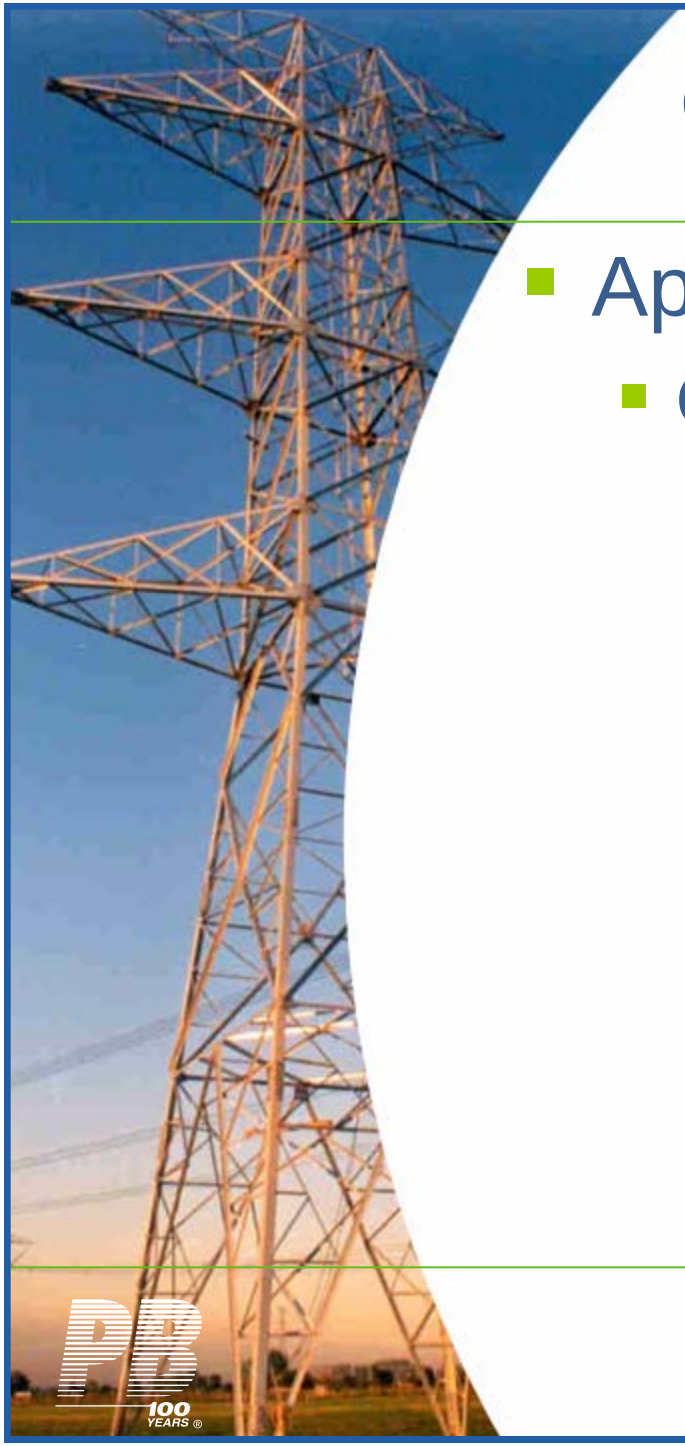
Data Collection & Modeling

- Model Development
  - Key Aspects
    - Medium Voltage Cap Banks
      - Size
      - Type – Fixed/Discrete/Continuous
      - Control Mechanism – Manual/Automated Switching
      - Control Point & Settings – Avoid conflicts with LTC and/or turbine control
    - Accurate X_{source} for various turbine types
    - **Accurate & Detailed Collection System**



Data Collection & Modeling

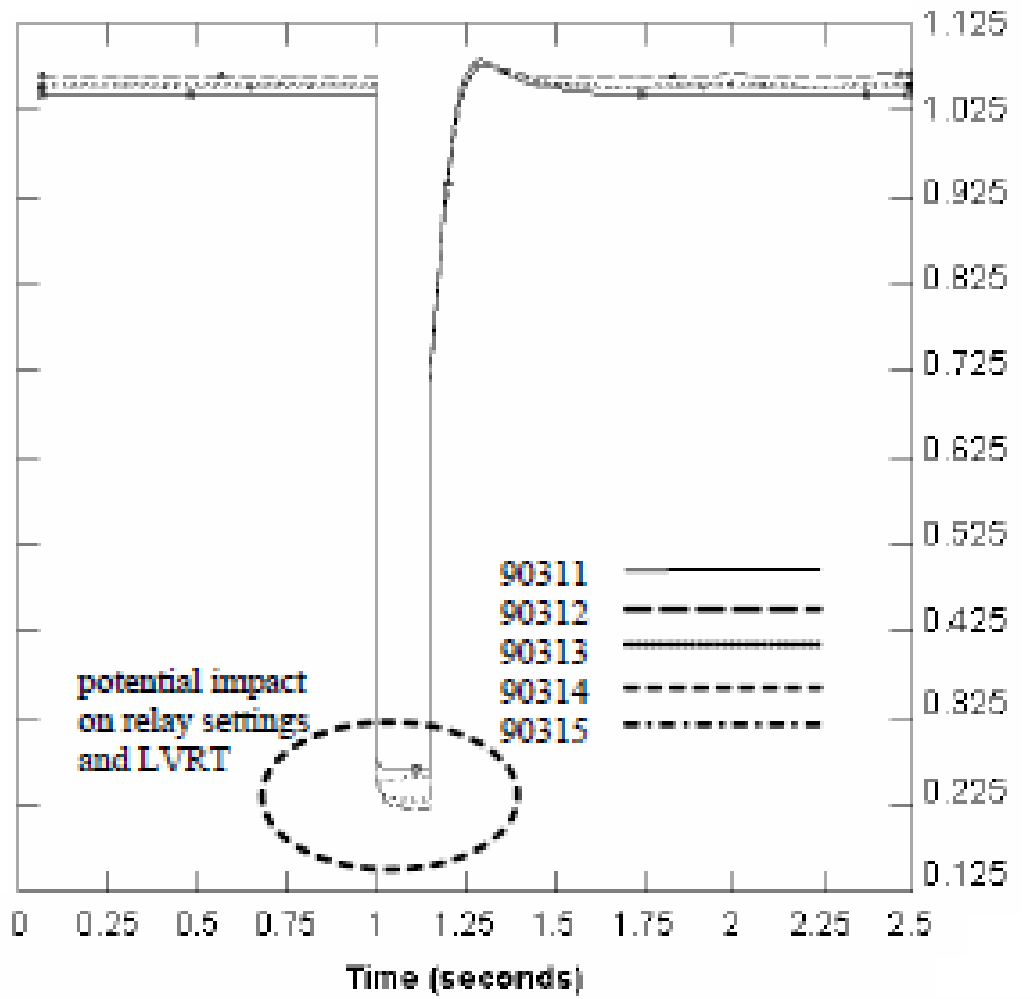
- Model Development
  - Issues Addressed
    - Detailed “individual turbine level” models developed for all WGRs modeled in study
    - Consistency in reactive capability modeling
      - Steady State & Dynamic Database
    - Accurate representation of detailed WGR facility from steady state standpoint
    - Accurate & updated impedances for WGR SC contributions
    - Detailed WGR models developed in “raw” format
      - Compatible with PowerWorld, PSS/E & ASPEN



Collection System Aggregation

- Approach Overview
  - Critical Aspects
    - Adequate & Accurate reflection of detailed facility
      - Steady State Standpoint
      - Dynamic Response Standpoint
    - Account for voltage profile diversity across facility
    - Ease of implementation
    - Practically Feasible

Collection System Aggregation



Issues arising from Voltage Profile diversity at turbines in wind farm under Steady State and/or dynamic event conditions

(Source: "Comparing Single & Multiple Turbine Representations in a Wind Farm Simulation", E. Muljadi & B. Parsons, U.S DOE-NREL)

Collection System Aggregation

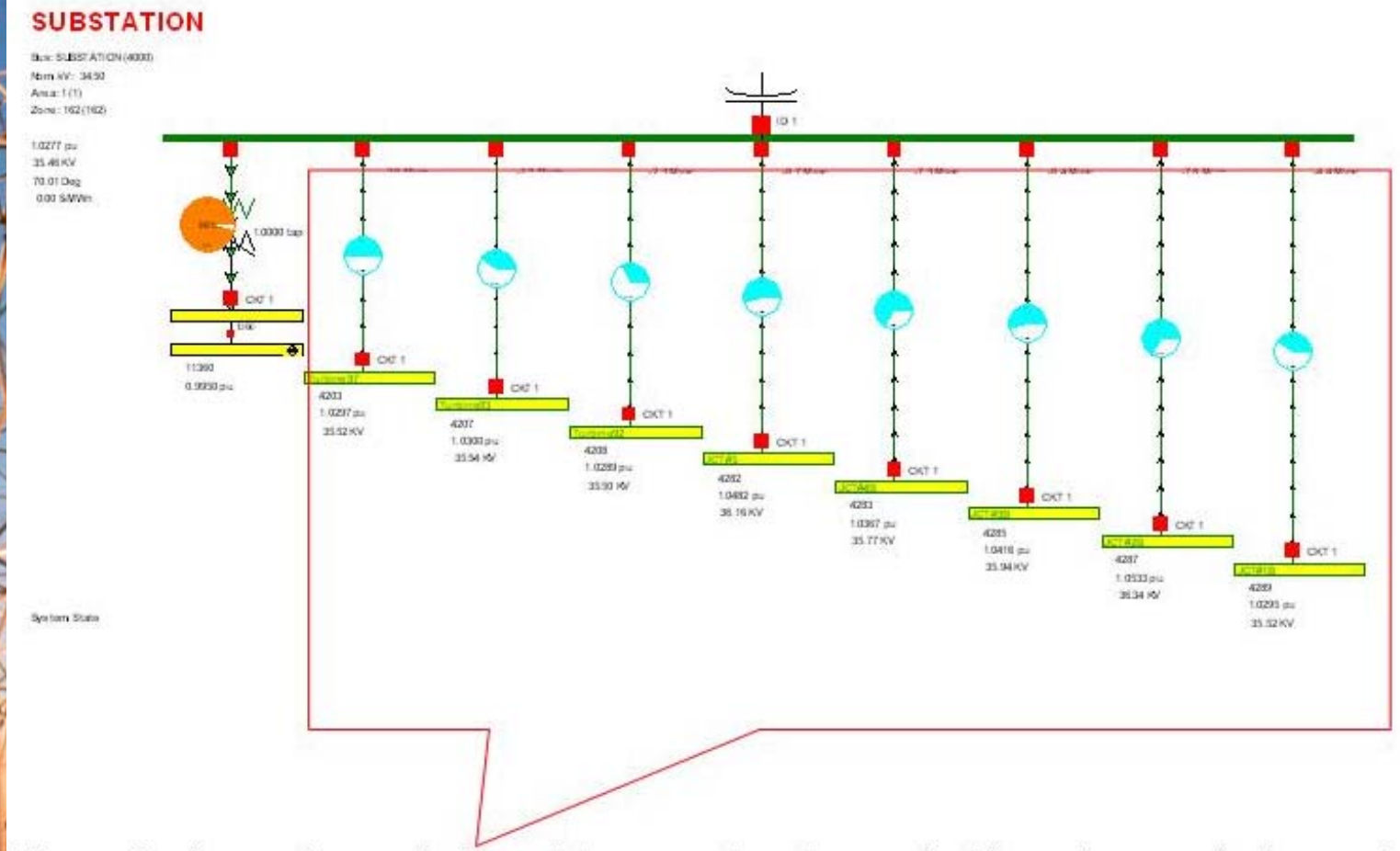
- Approach Overview
  - Key factors governing WGR trips from VRT standpoint
    - Voltage experienced at turbine terminals
    - Under-voltage relay settings
  - Utilize combination of both factors to develop aggregated model
    - Automatically account for voltage diversity across WGR facility

Collection System Aggregation

- Approach Overview
  - Steady State Validation
    - Comparison of P & Q loss at POI b/w detailed & aggregated models
  - Short Circuit Validation
    - Comparison of 3-Ph SCC levels at POI
  - Dynamic Response Validation
    - Turbine Terminal Voltage Response
    - Turbine Active & Reactive Power Response
    - POI Voltage & Frequency Response

Collection System Aggregation

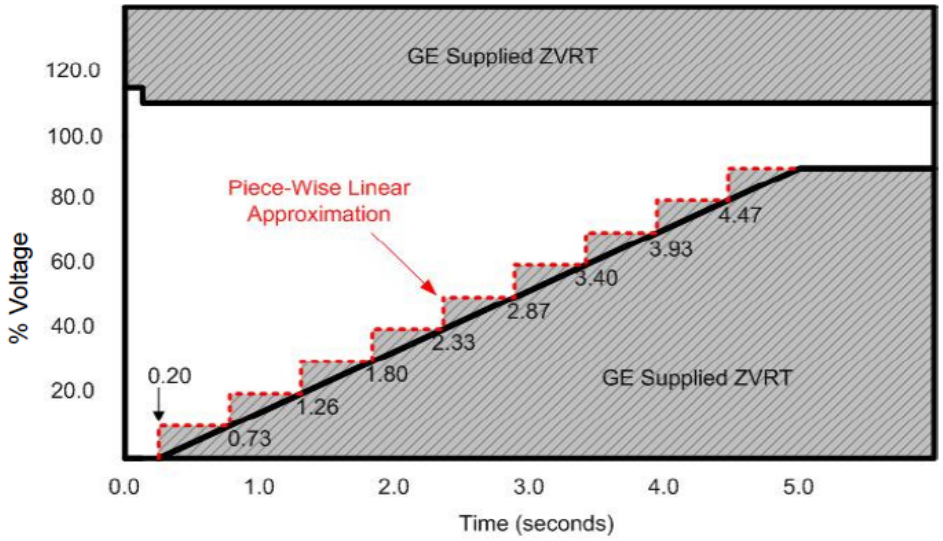
Detailed Collector System Representation – Obtained via PB custom module to develop collector system one-lines from VRT DRF forms – Sample WGR Campus GE 1.5 MW Machines



The collector system, wind machines, and pad-mounted transformers to be equivalent

Collection System Aggregation

- Sample WGR dispatched at full capacity
  - P_{loss} = 2.1 MW
  - Q_{loss} = 12.3 MVAR
  - I_{sc3P} for 3-Phase fault at POI = 2.331 p.u.
  - Average voltage of each machine in detailed collector system during 3-Phase fault @ POI: 0.204 pu
    - Maximum Voltage: 0.237 pu
    - Minimum Voltage: 0.177 pu




```
0 'USRMDL' 0 'VTGTPA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.1 5.0 0.200 0.08 /
0 'USRMDL' 0 'VTGTPA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.2 5.0 0.733 0.08 /
0 'USRMDL' 0 'VTGTPA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.3 5.0 1.267 0.08 /
0 'USRMDL' 0 'VTGTPA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.4 5.0 1.800 0.08 /
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0 'USRMDL' 0 'VTGTPA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.9 5.0 4.467 0.08 /
0 'USRMDL' 0 'VTGTPA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.0 1.1 0.100 0.08 /
0 'USRMDL' 0 'VTGTPA' 0 2 6 4 0 1 7002 7005 '1' 0 0 0 0.0 1.15 0.0  0.08 /
```
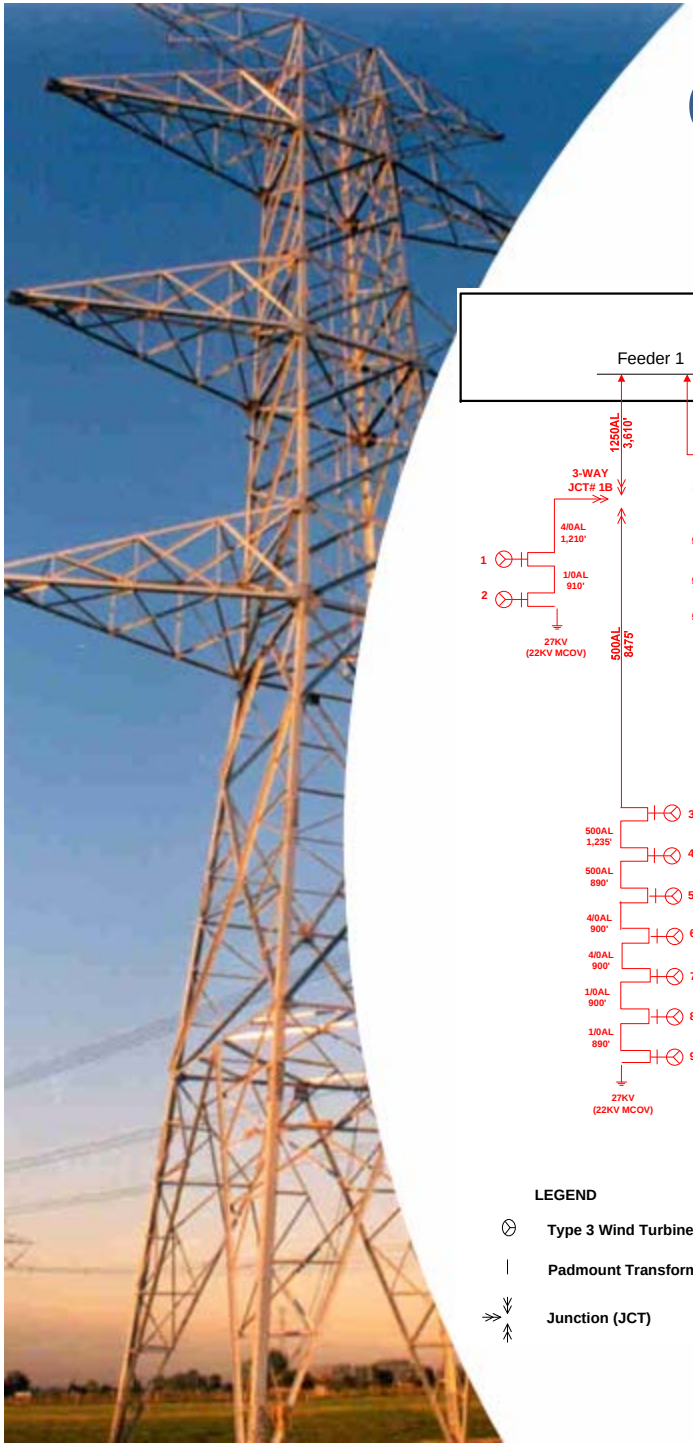
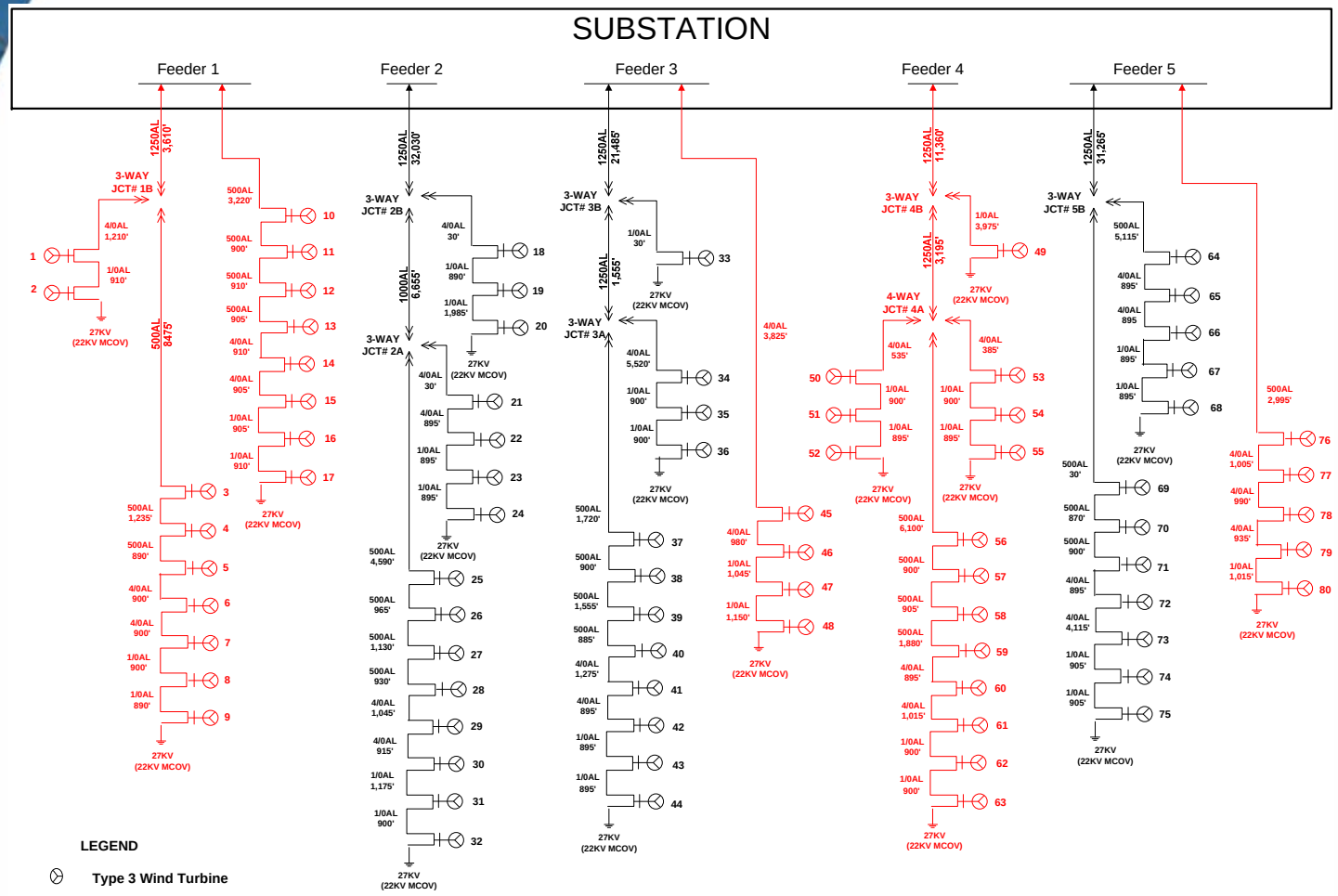

Voltage Profile vis-à-vis Voltage Relay Settings



Collection System Aggregation



Turbines Highlighted in Red – Group A (41 Turbines)

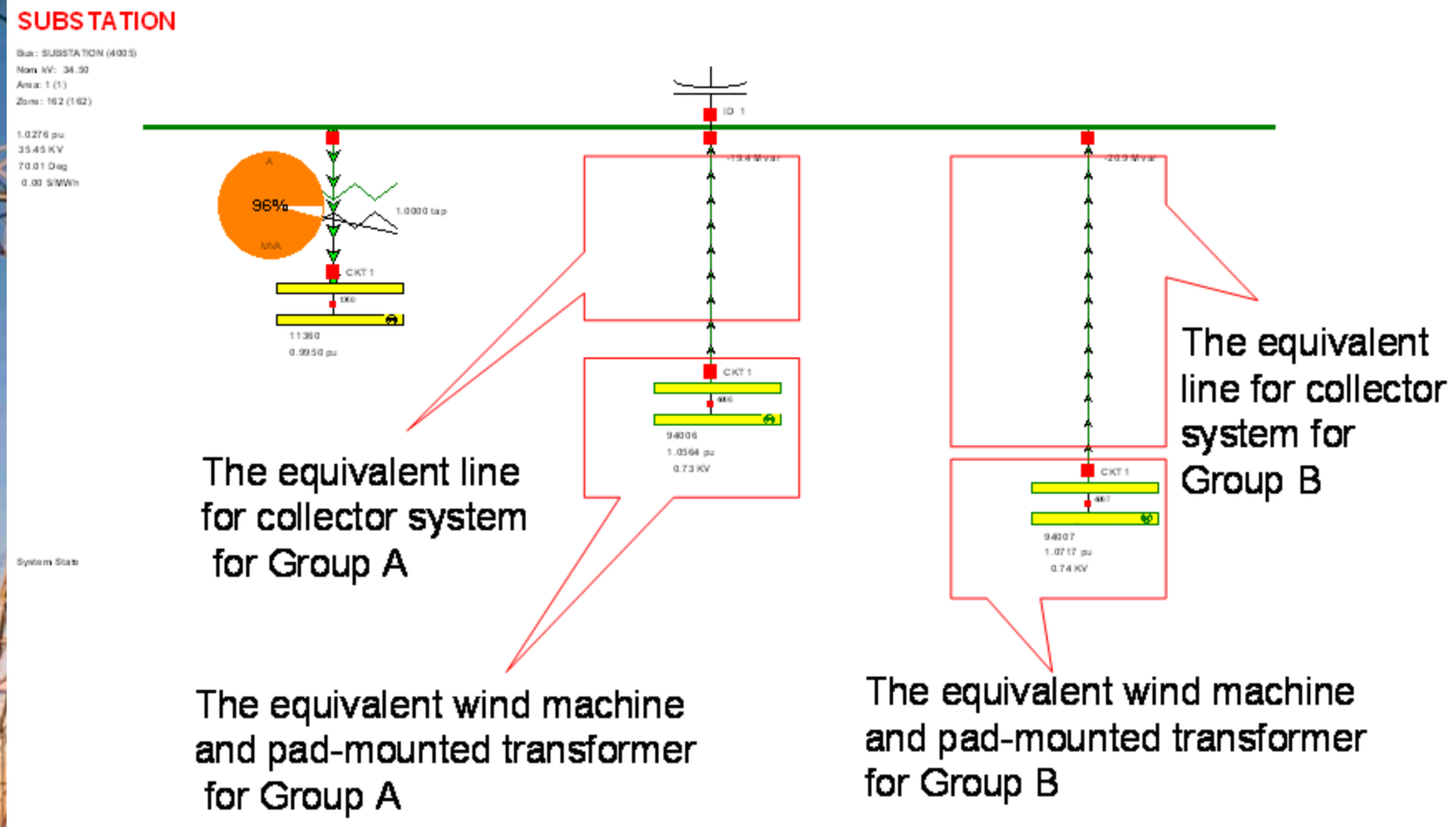
Turbines highlighted in Black – Group B (39 Turbines)

Collection System Aggregation

- Wind Farm Collector system equivalent
  - Group A
    - R_{EQ} = 0.008 p.u.
    - X_{EQ} = 0.02 p.u.
    - B_{EQ} = 0.02796 p.u.
  - Group B
    - R_{EQ} = 0.02 p.u.
    - X_{EQ} = 0.071 p.u.
    - B_{EQ} = 0.06363 p.u.

Collection System Aggregation

Collector System Equivalent – Sample WGR Campus

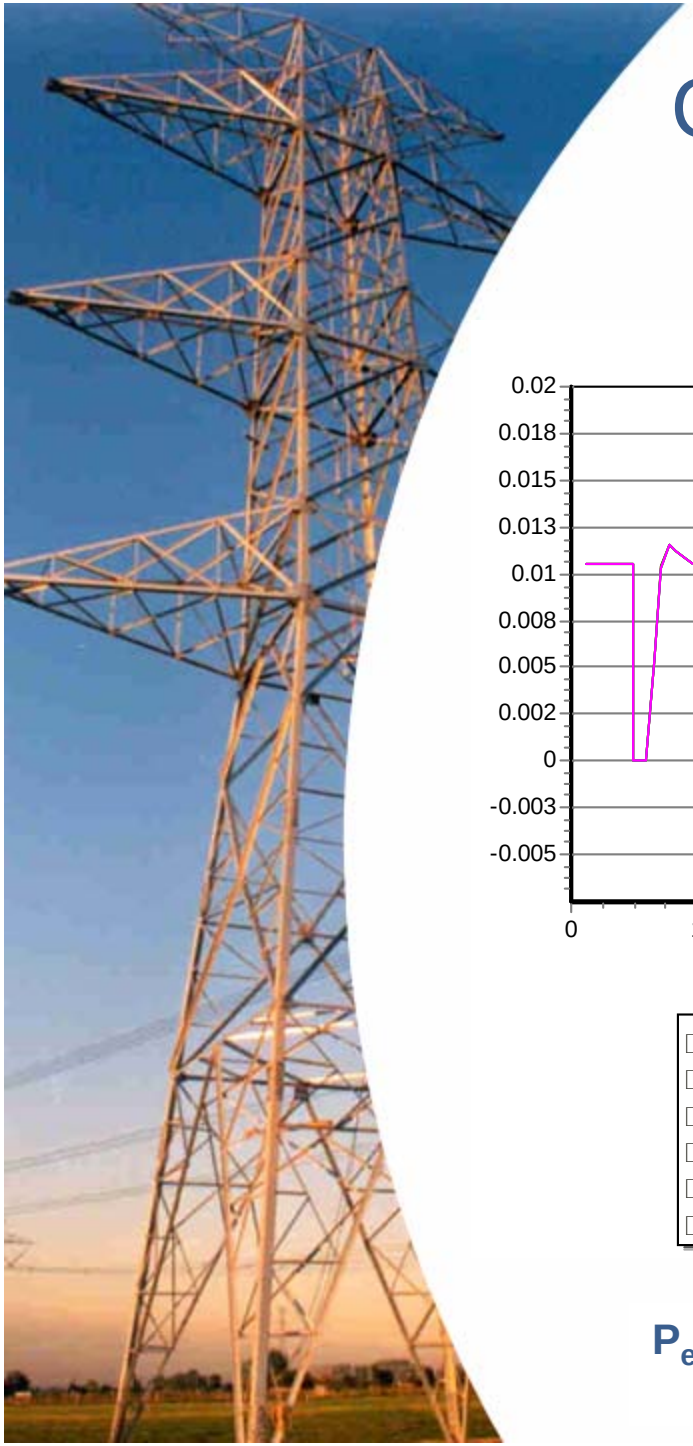


Collection System Aggregation

- Collector System Equivalent Validation
  - Steady State Standpoint
    - P_{loss} = 2.1 MW
    - Q_{loss} = 12.3 MVAR
    - Active & Reactive power losses match with detailed model
  - Short Circuit Standpoint
    - I_{sc3P} = 2.33 p.u. utilizing collector system equivalent
    - SC contribution from detailed collector and aggregated models match
  - Voltage of the equivalent machine in collector system equivalent during 3-Phase fault @ POI
    - Group A: 0.189 pu
    - Group B: 0.219 pu

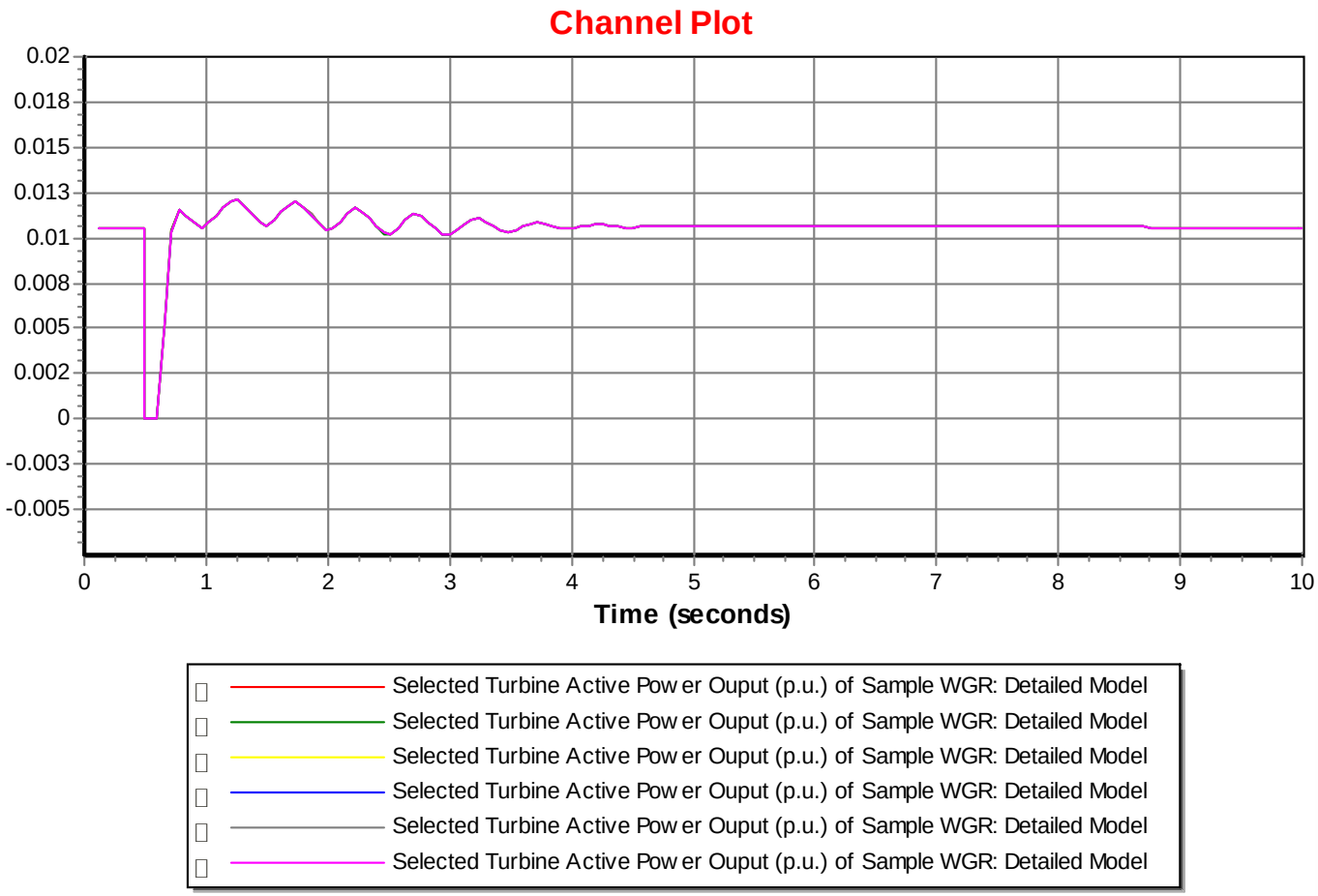
Collection System Aggregation

- Dynamic simulation with detailed collector system representation for Sample WGR included in ERCOT HWHL case
  - Contingency at POI
  - 3P fault @ POI, cleared after 6 cycles, no line trips
- P_{elec}, Q_{elec} & E_{term} monitored for
  - Turbines near POI: #104 & #152
  - Turbines in the middle: #111 & #137
  - Turbines far away from POI: #104 & #152

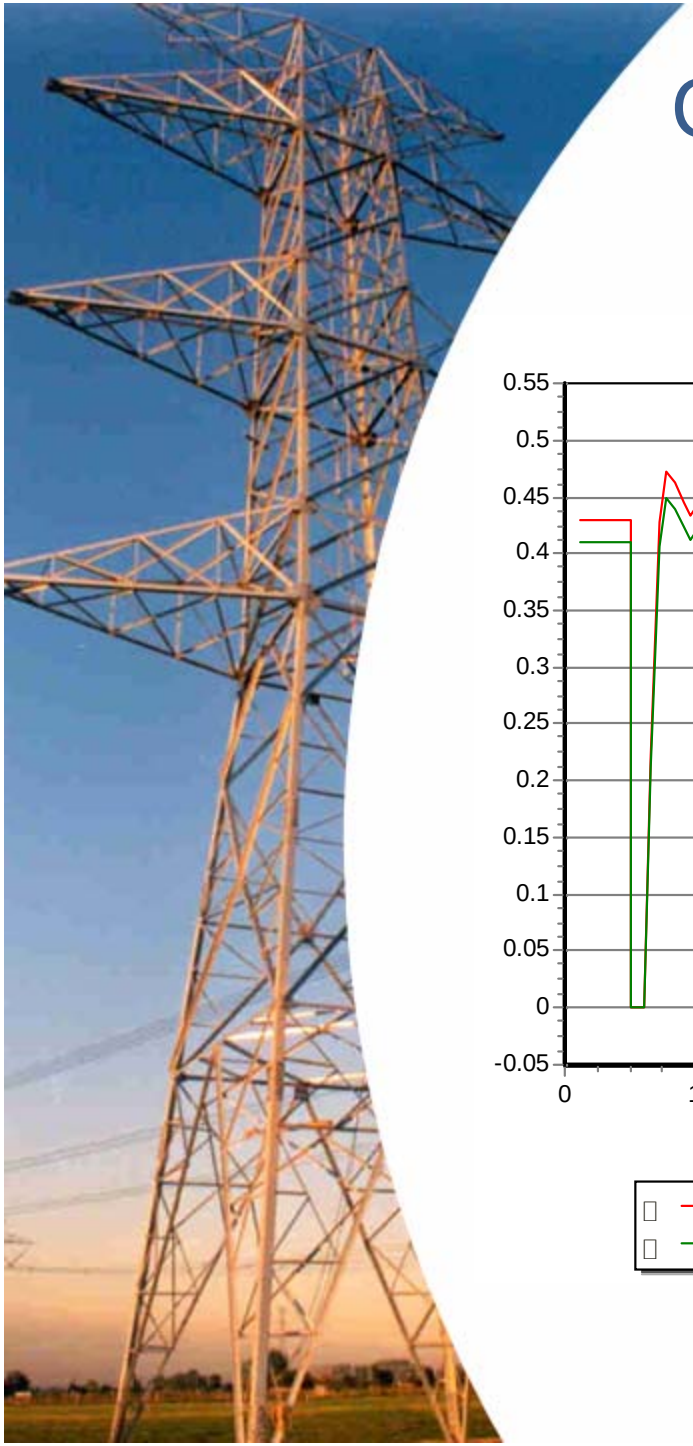


Collection System Aggregation

Active Power Response – Comparative Analysis



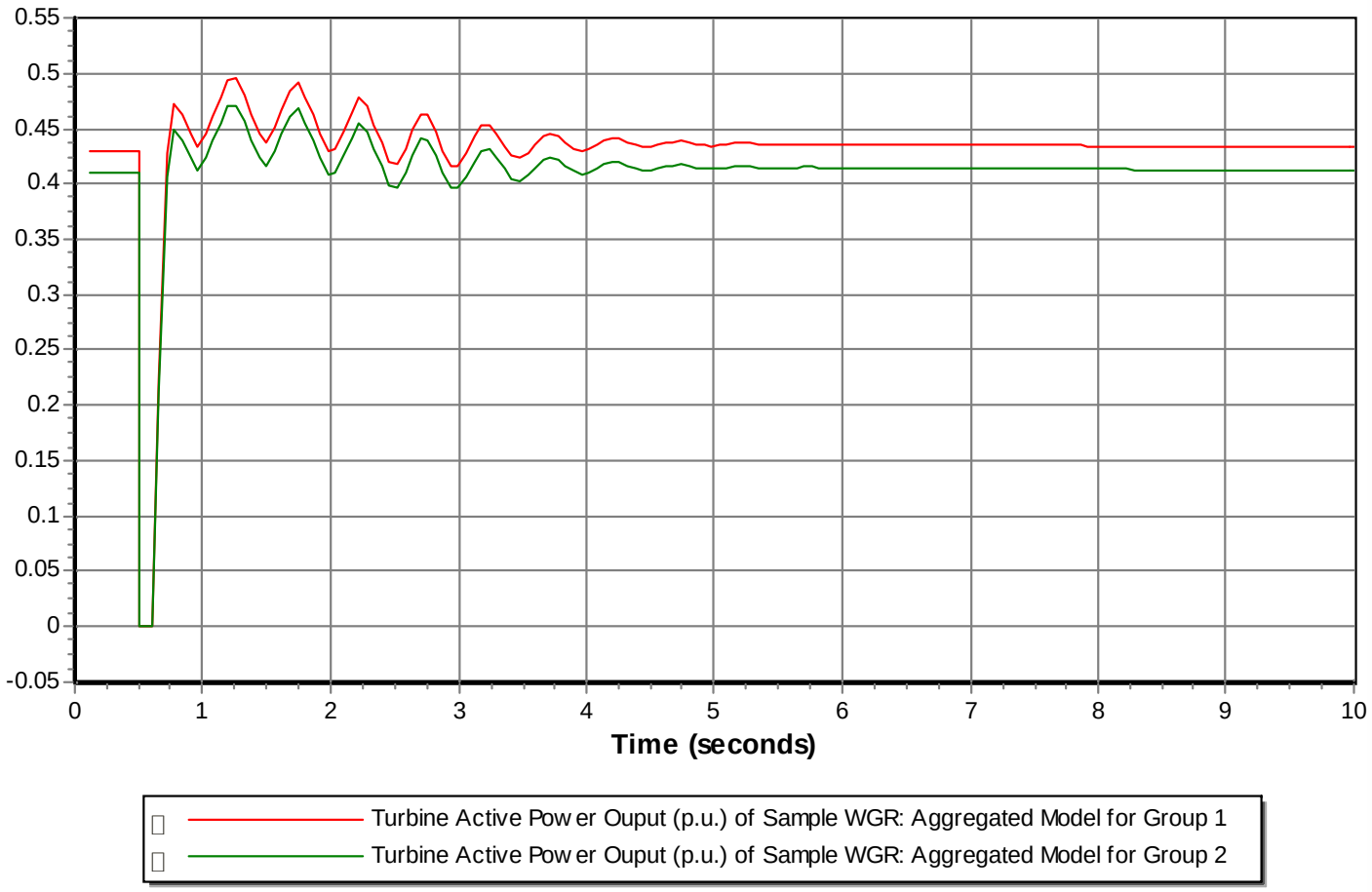
P_{elec} for Turbines chosen across Sample WGR Campus – Detailed Model



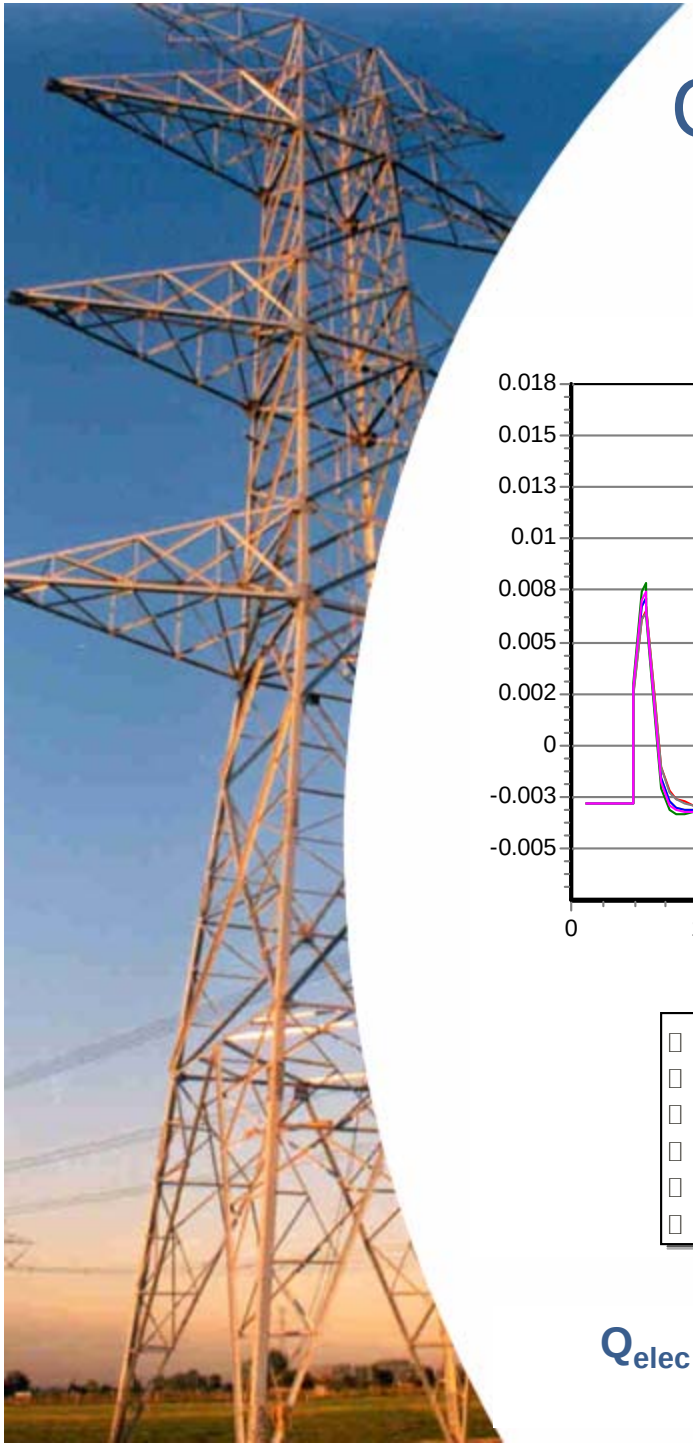
Collection System Aggregation

Active Power Response – Comparative Analysis

Channel Plot

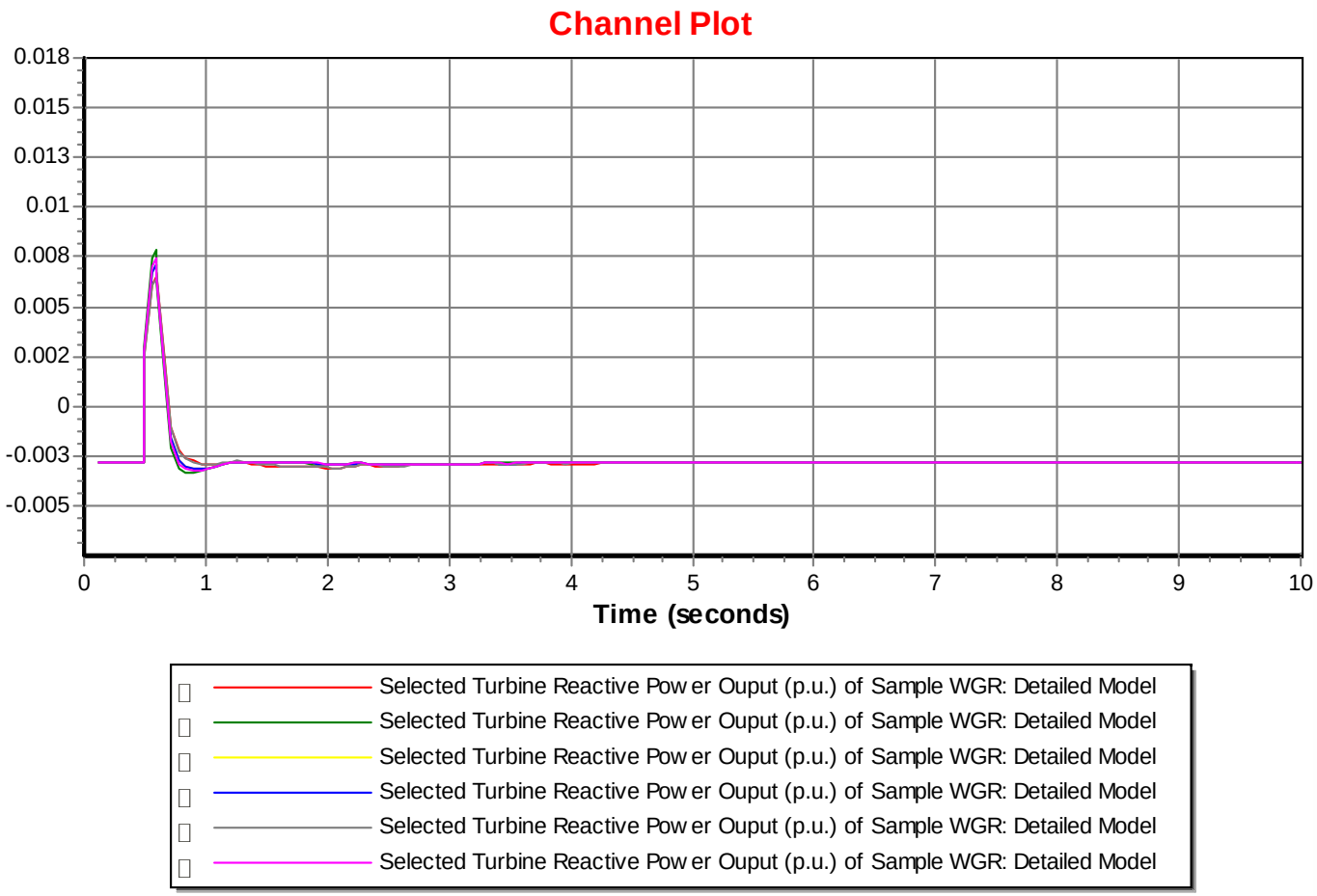


P_{elec} for Two Collector Equivalent Model

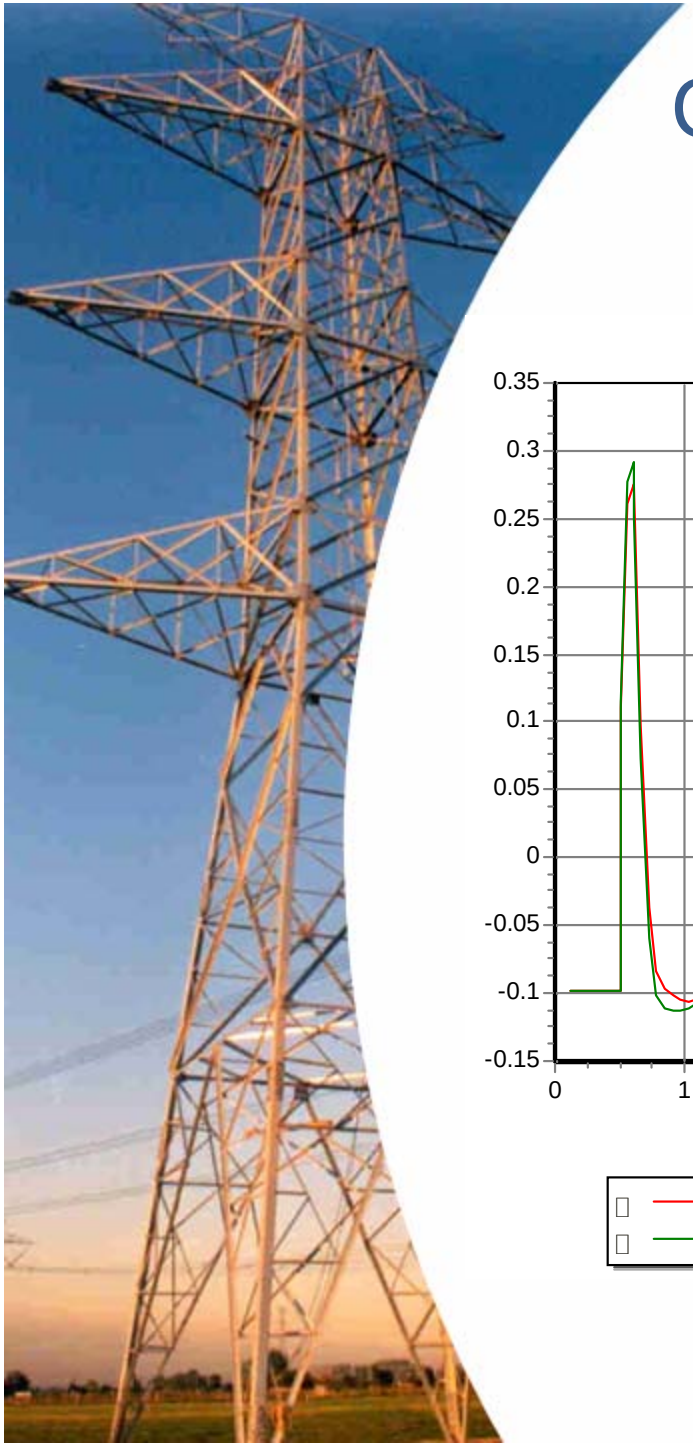


Collection System Aggregation

Reactive Power Response – Comparative Analysis



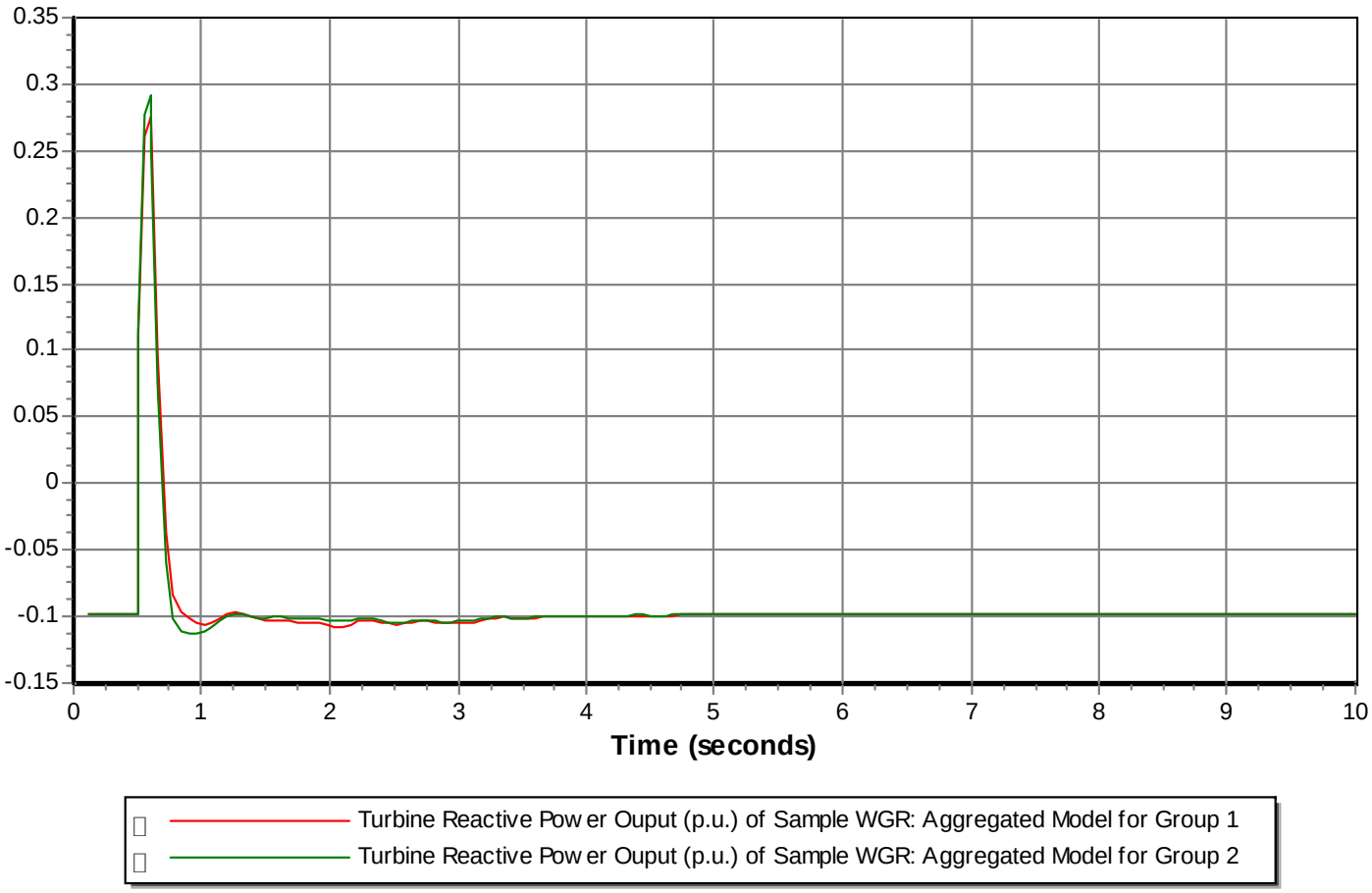
Q_{elec} for Turbines chosen across Sample WGR Campus – Detailed Model



Collection System Aggregation

Reactive Power Response – Comparative Analysis

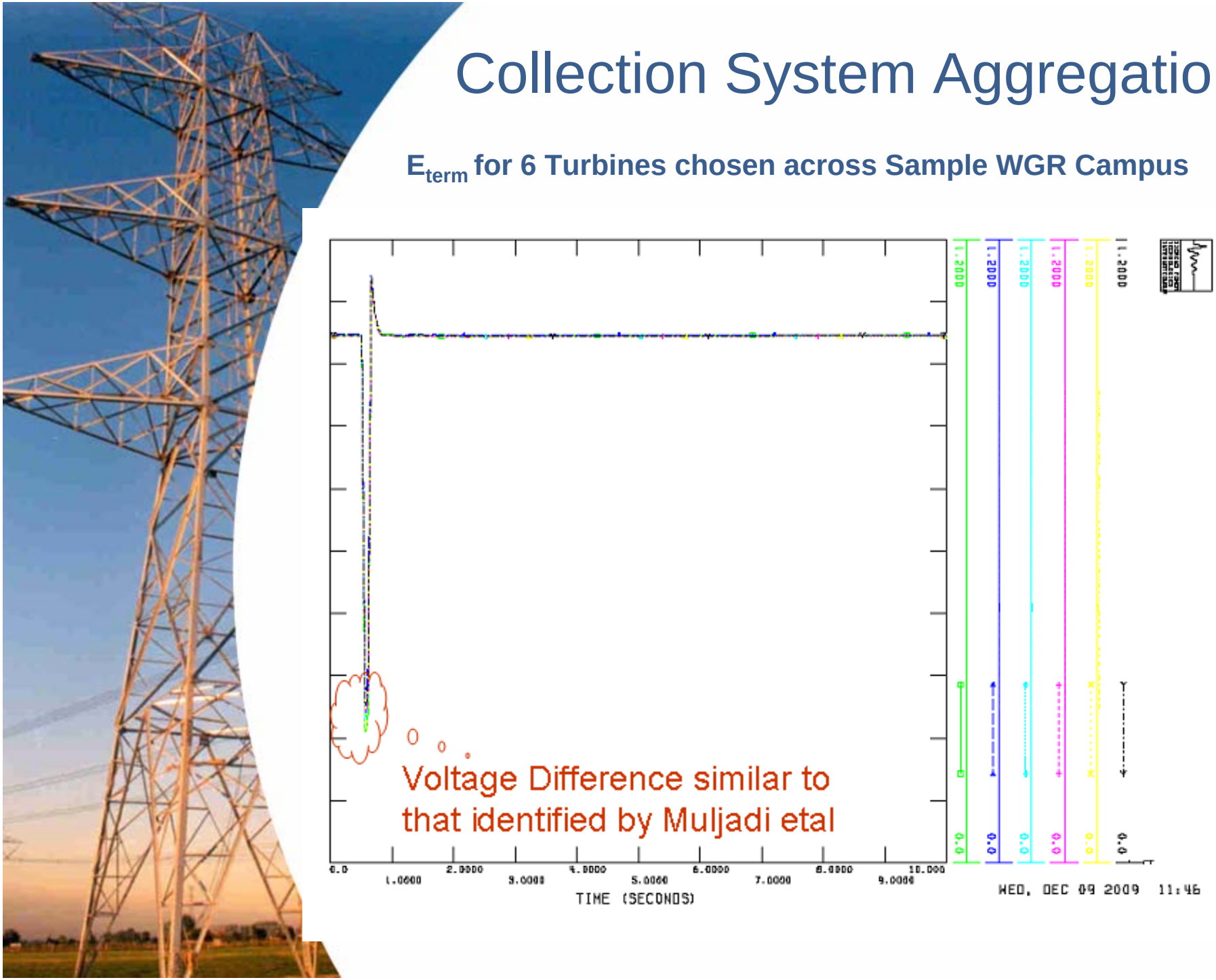
Channel Plot



Q_{elec} for Two Collector Equivalent Model

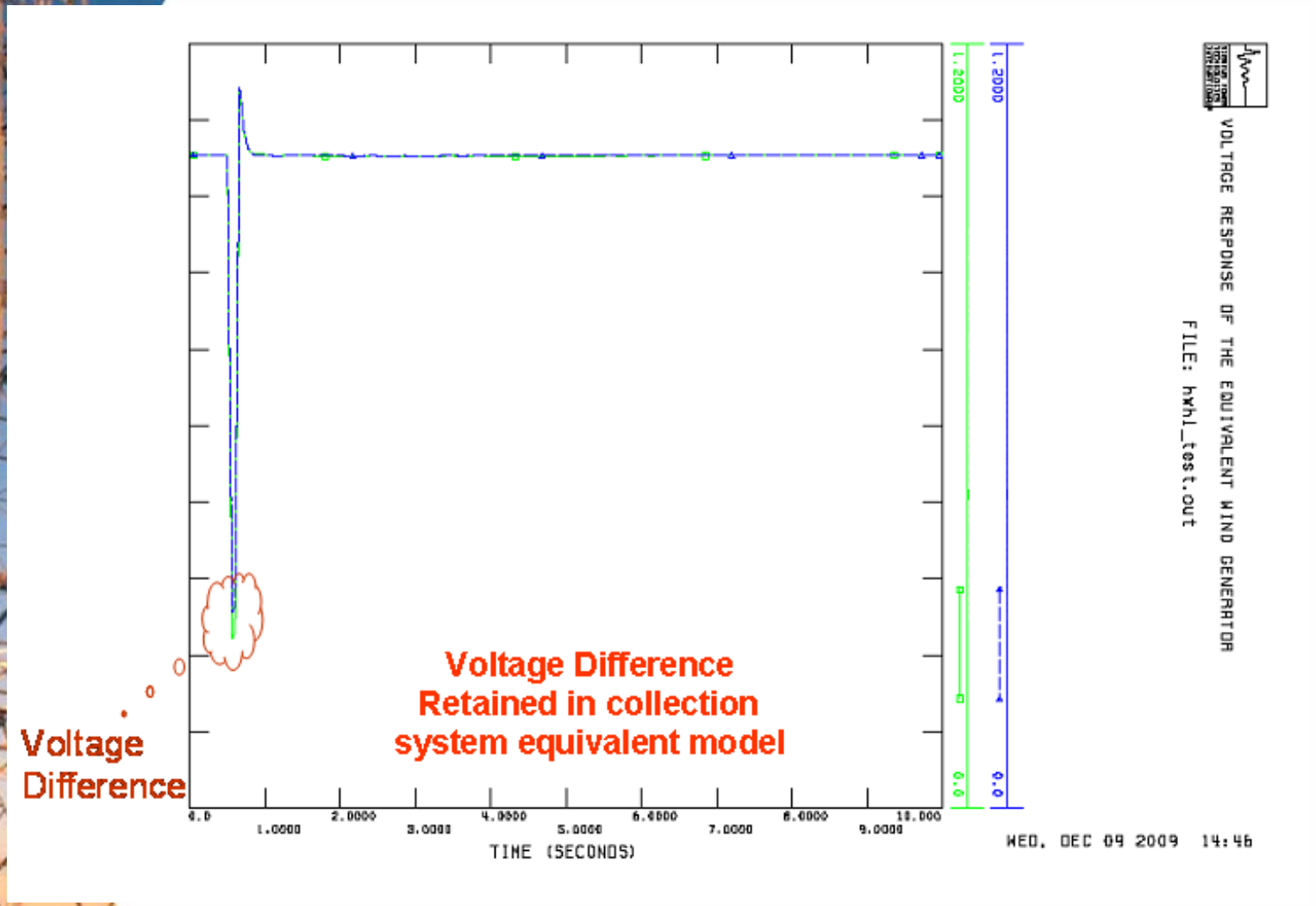
Collection System Aggregation

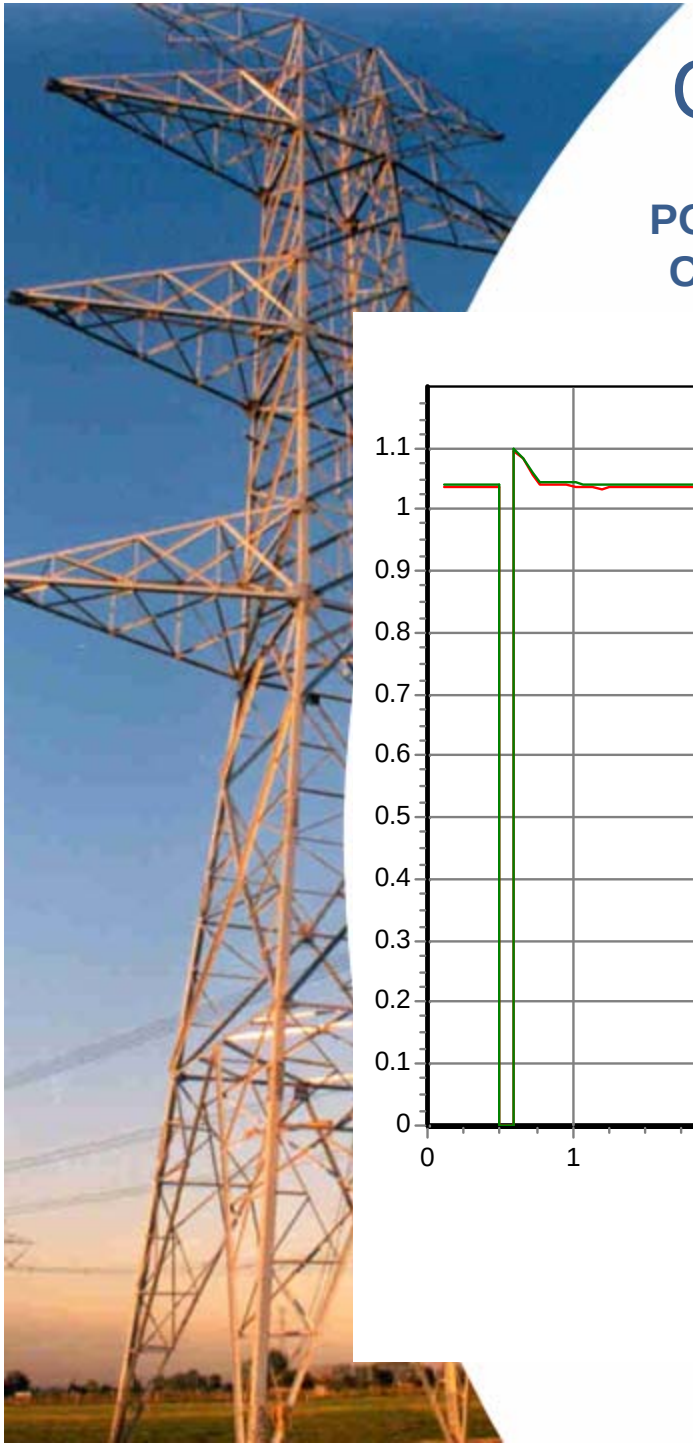
E_{term} for 6 Turbines chosen across Sample WGR Campus



Collection System Aggregation

E_{term} for Two Collector Equivalent Model

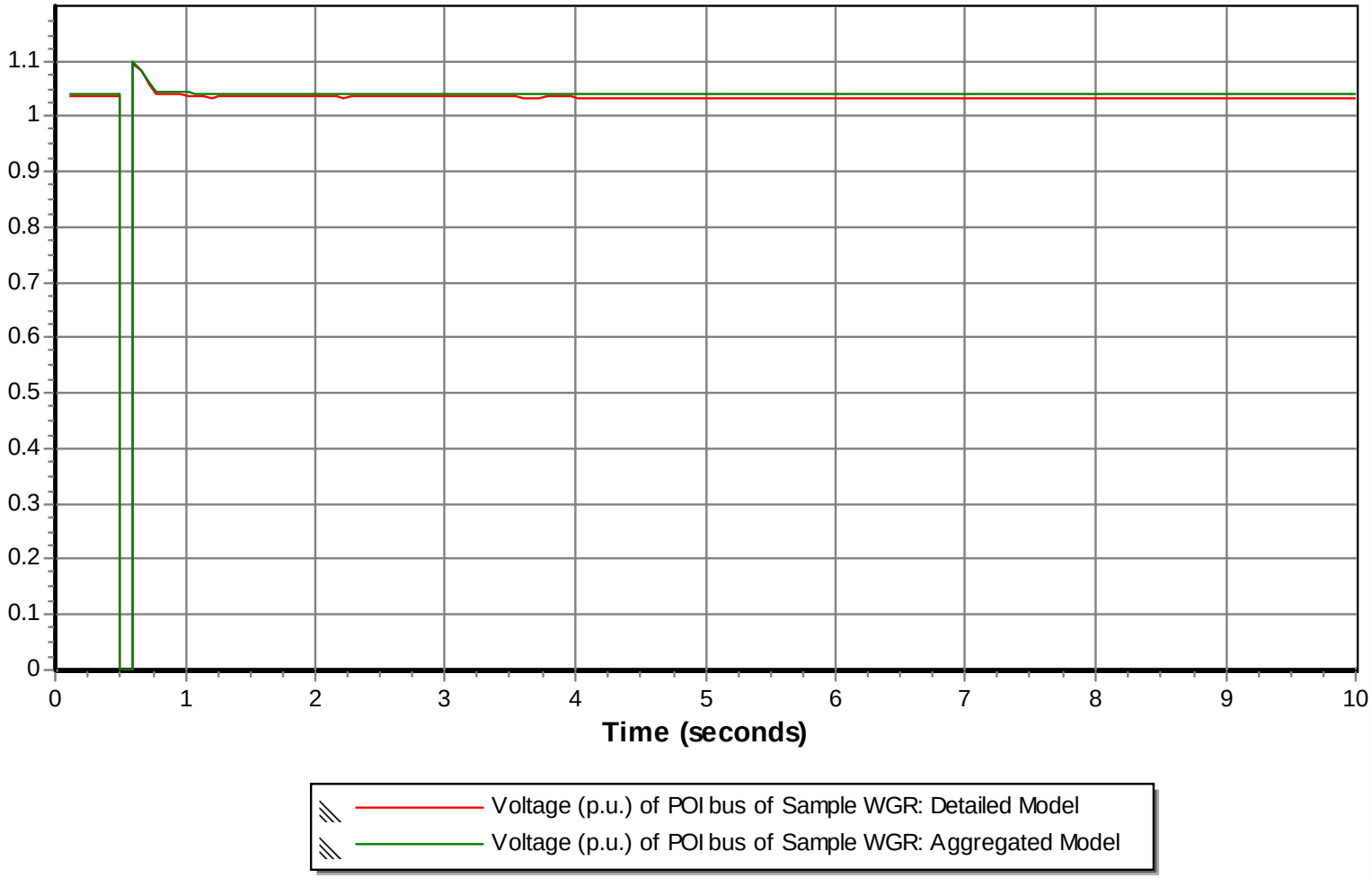


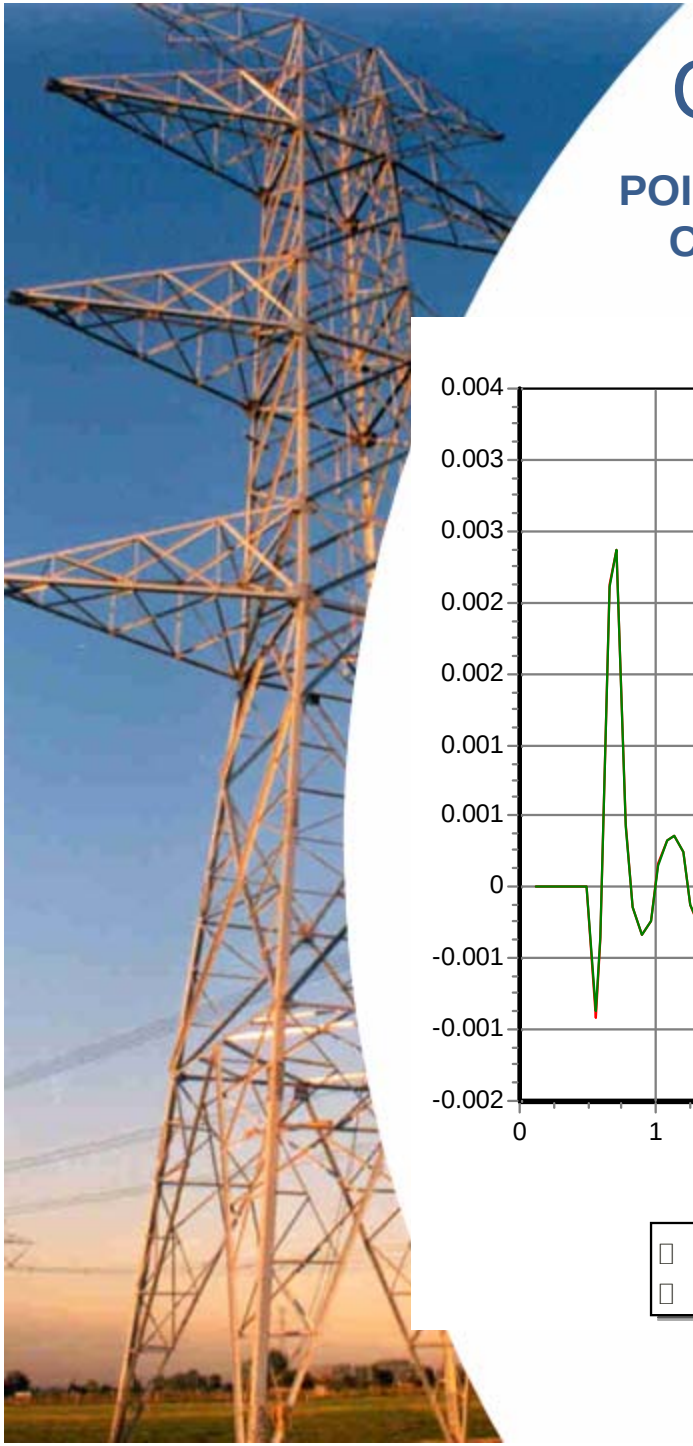


Collection System Aggregation

POI Voltage Response – Comparative Analysis, Detailed Collector System & 2 Collector Equivalent – Sample WGR

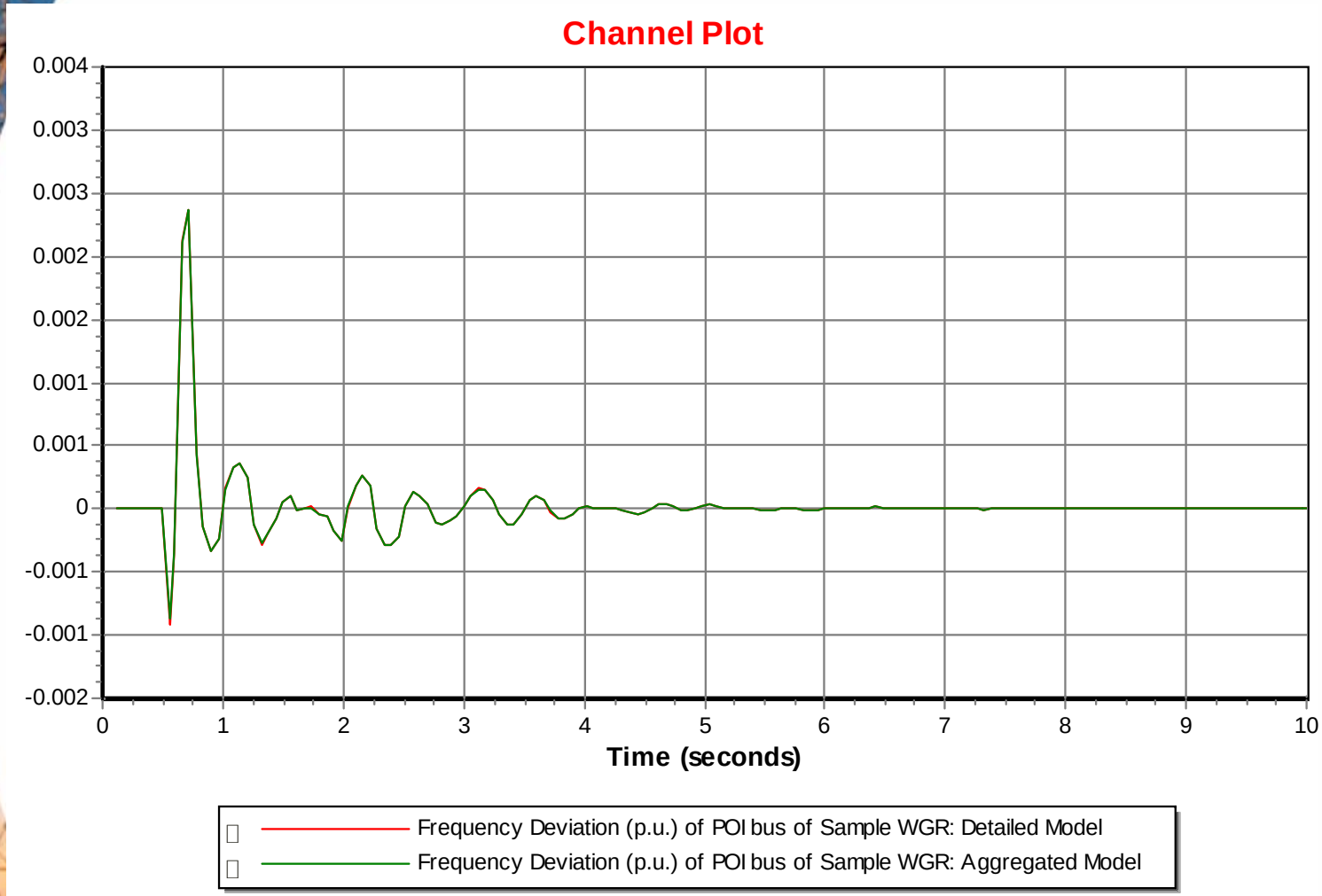
Channel Plot





Collection System Aggregation

POI Frequency Response – Comparative Analysis, Detailed Collector System & 2 Collector Equivalent – Sample WGR

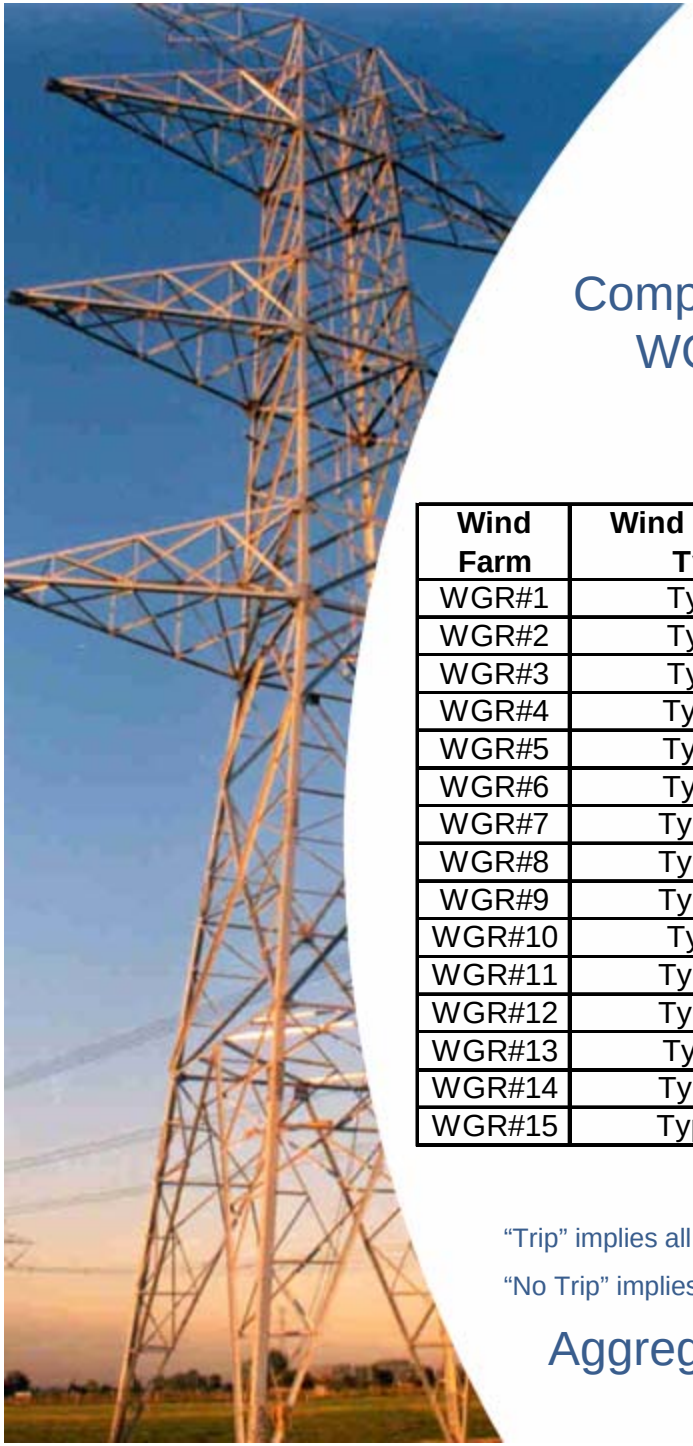


Collection System Aggregation

- WGR campuses with more than 1 turbine type
  - Utilize approach for each wind turbine type group
  - Minimum number of aggregated groups equal to number of turbine types at WGR campus
- Aggregated models developed for all WGR with completed data requests

Collection System Aggregation

- Collection System Aggregated Model Validation
  - Perform dynamic simulation for select normal clearing events
  - Replace aggregated model with detailed WGR collection system model
    - All WGRs tripped for simulated event
    - Select non-tripped WGRs for simulated event
  - Case: Updated ERCOT HWHL case
  - Simulated Event: CTG #9
    - 15 WGRs tripped
    - 1.14 GW lost as per HWHL dispatch
    - 1.71 GW lost as per HWHL capacity



Collection System Aggregation

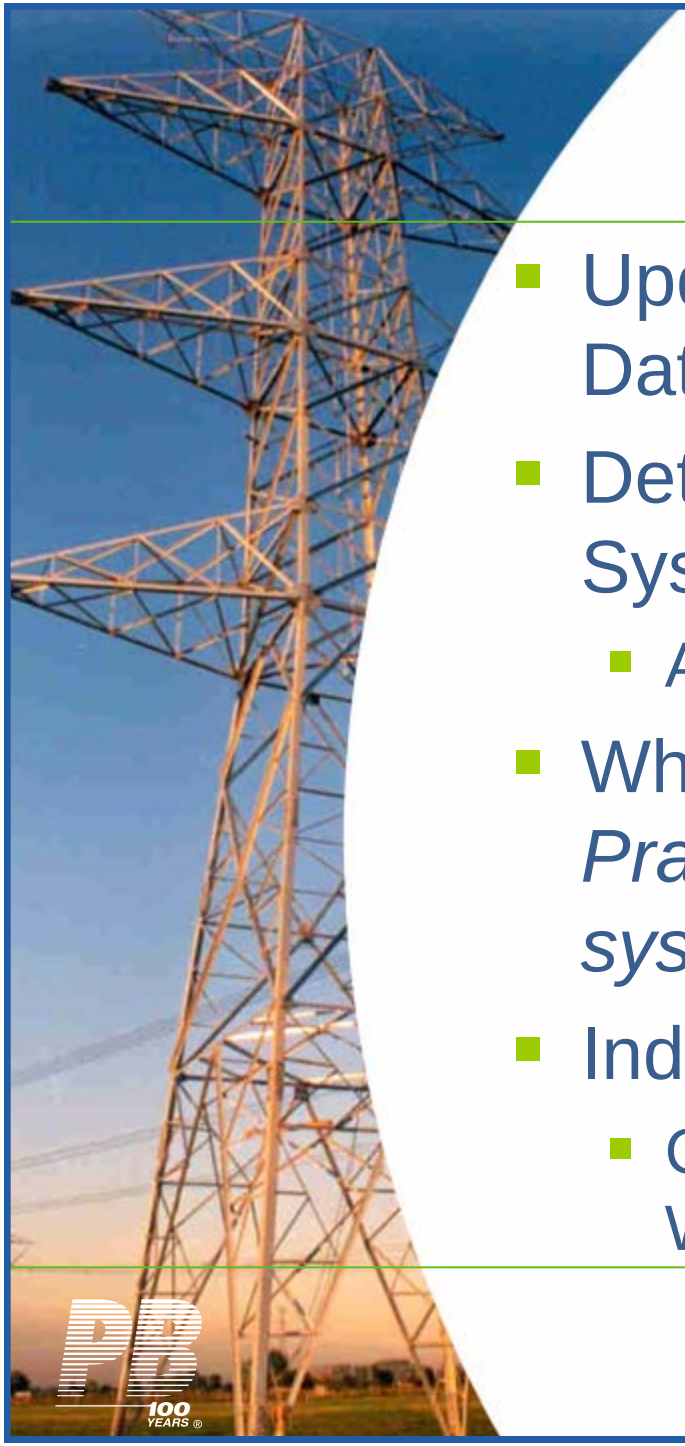
Comparative Analysis for 13 tripped and 2 non-tripped WGR models for CTG #9 – Detailed Vs Aggregated Model

Wind Farm	Wind Turbine Type	Trip Status During Dynamic Simulation - Aggregated Model	Trip Status During Dynamic Simulation - Detailed Model
WGR#1	Type I	Trip	Trip
WGR#2	Type I	Trip	Trip
WGR#3	Type I	Trip	Trip
WGR#4	Type II	Trip	Trip
WGR#5	Type II	Trip	Trip
WGR#6	Type II	Trip	Trip
WGR#7	Type III	Trip	Trip
WGR#8	Type III	Trip	Trip
WGR#9	Type III	Trip	Trip
WGR#10	Type I	Trip	Trip
WGR#11	Type III	Trip	Trip
WGR#12	Type III	Trip	Trip
WGR#13	Type II	Trip	Trip
WGR#14	Type III	No Trip	No Trip
WGR#15	Type IV	No Trip	No Trip

"Trip" implies all turbines tripped for detailed model

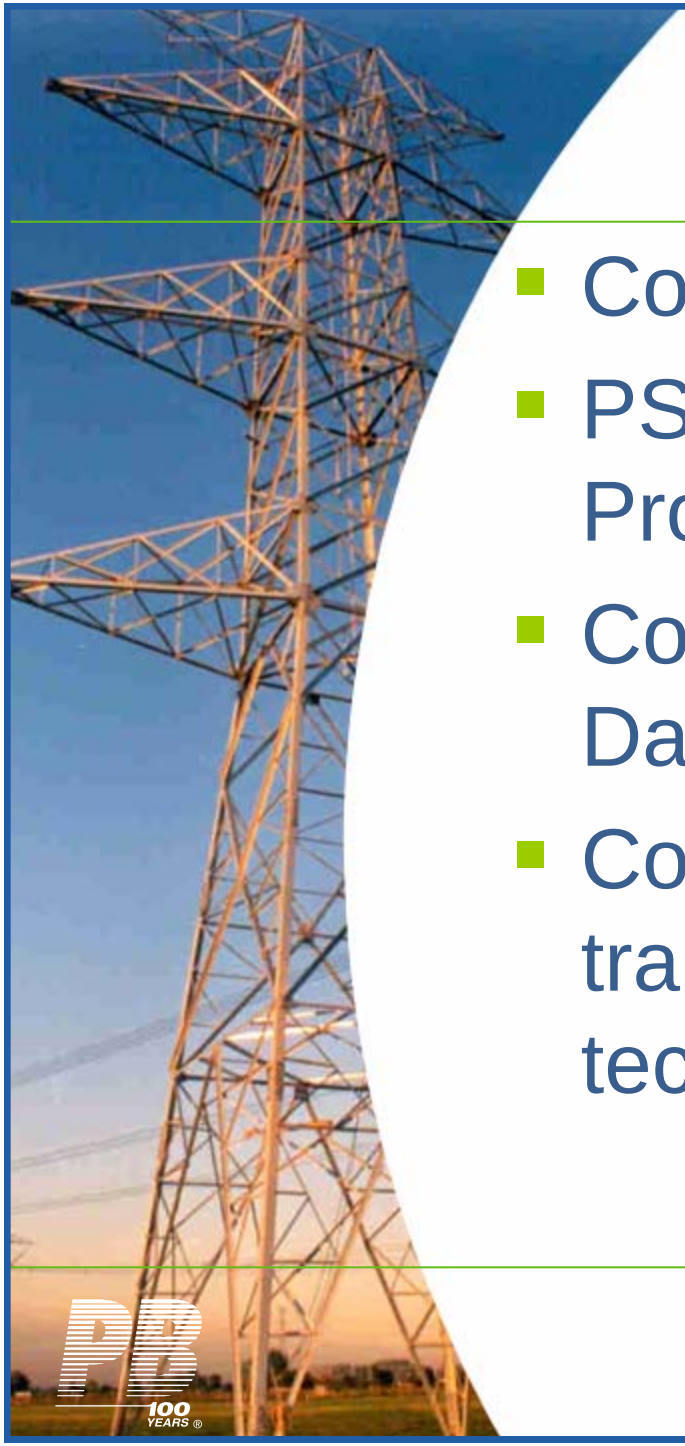
"No Trip" implies no turbines tripped for detailed model

Aggregated Model adequately represents Detailed model in terms of WGR trips



Phase II Deliverables

- Updated HWHL & HWLL Dynamic Datasets
- Detailed & Aggregated Collector System Models
  - All ERCOT WGRs modeled in study
- White Paper on "*Recommended Practices for developing collection system aggregated models for WGRs*"
- Individual PowerPoint Presentation
  - Collector System Aggregation for each WGR Campus



Phase II Deliverables

- Comprehensive WGR Database
- PSS/E Version 31 Wind Flat Start Procedural Guide
- Comprehensive Phase II WGR Data organized by campus
- Comprehensive knowledge transfer sessions for aggregation techniques to ERCOT personnel

PB Contribution

- Novel Methodology for WGR Collection System Aggregation
  - An Industry First
- Accurate & practically feasible approach
  - 65 WGR detailed & aggregated models developed from scratch
- Accurate representation of WGR from steady state & dynamic standpoint
- WGR Consensus on data collection & modeling approach
- Validation of modeling approach & effort
  - Majority of WGRs
  - Individual Web & Tele-conference calls

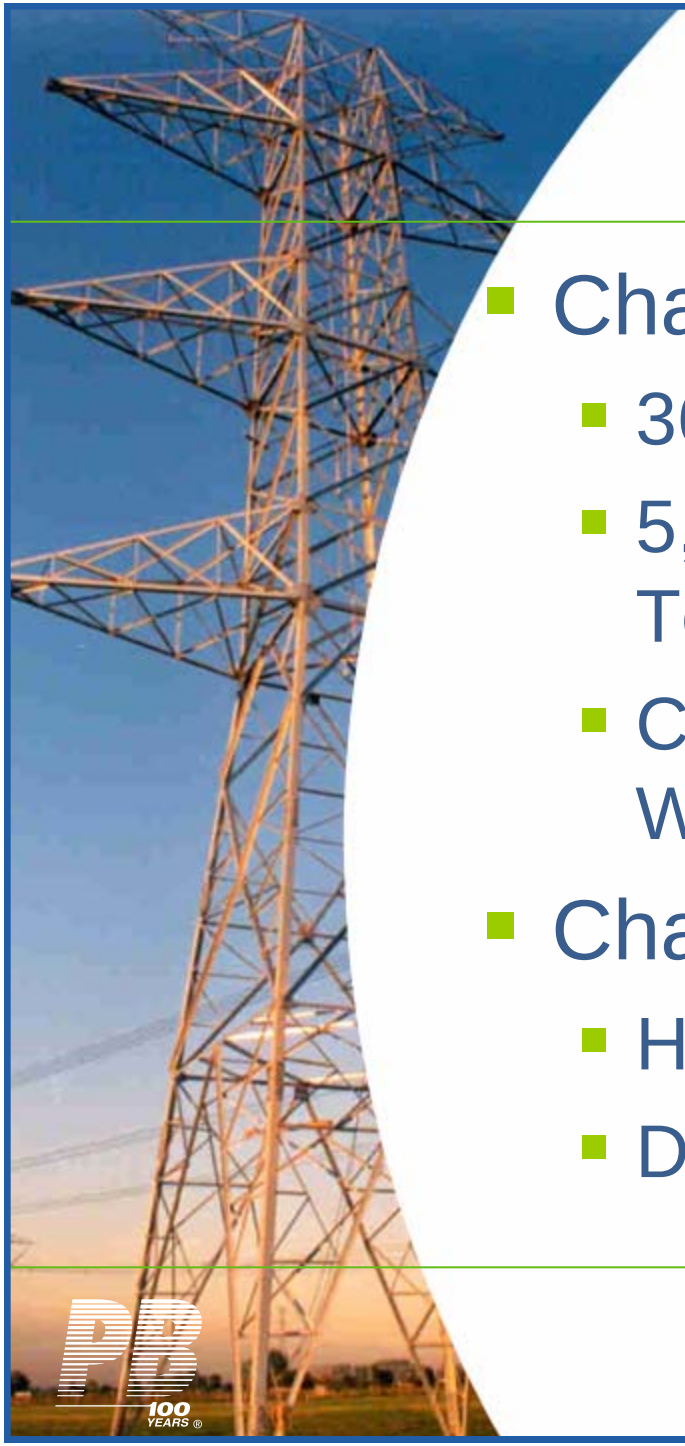
Phase III

Objectives

- Development of updated dynamic datasets in PSS/E Version 31
  - HWHL
  - HWLL
- Assessment of reliability risks due to lack of WGR VRT capability
  - Normal Clearing Events
  - Breaker Failure Events
- 6 Additional Change Case Assessments
- Mitigation Options & Recommendations

Case Definitions

- HWHL Case
  - 58,000 MW ERCOT System Load
  - 4,800 MW of WGR output, West Texas
  - N-1 Secure Dispatch
- HWLL Case
  - 36,000 MW ERCOT System Load
  - 4,300 MW of WGR output, West Texas
  - N-1 Secure Dispatch



Case Definitions

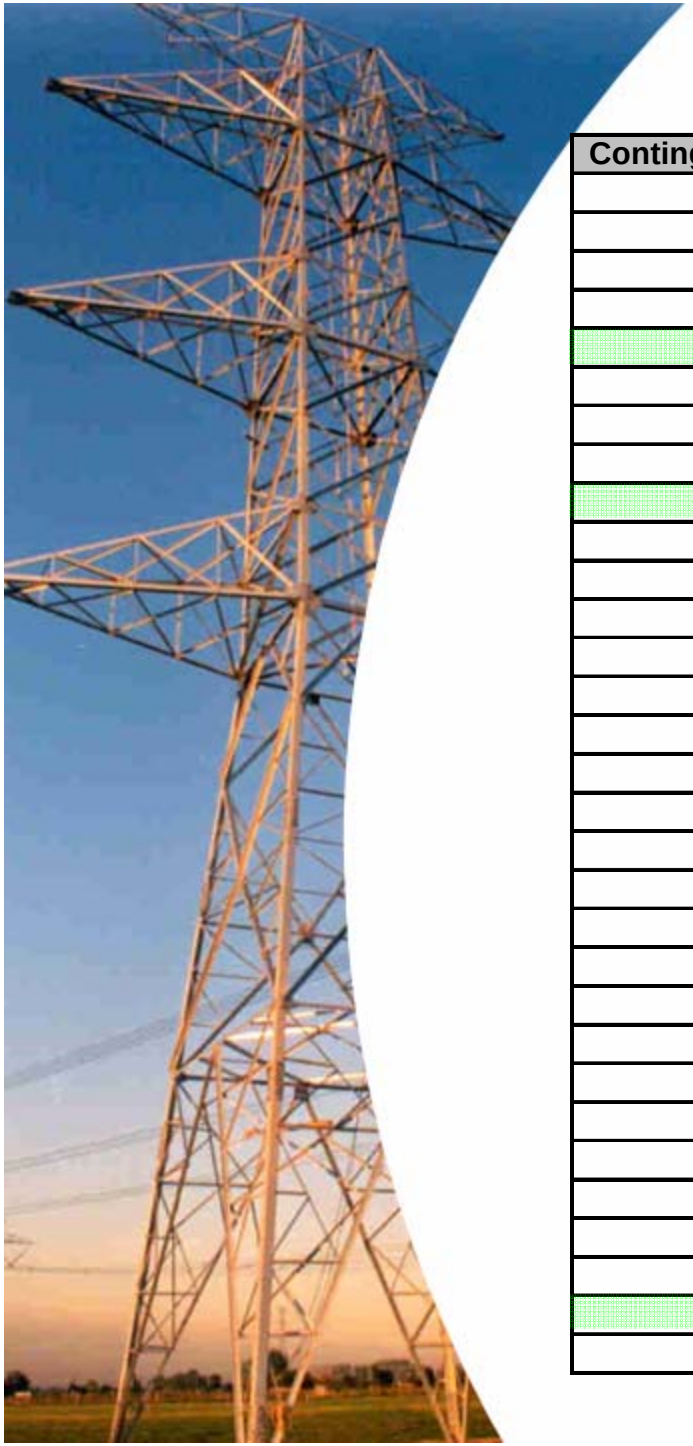
- Change Case 1
  - 36,000 MW ERCOT System Load
  - 5,100 MW of WGR output, West Texas
  - Conventional Generation Units in West Texas off-line
- Change Case 2
  - HWHL Case
  - Dynamic Load Models, West Texas

Case Definitions

- Change Case 3
  - Change Case 1
  - Dynamic Load Models, West Texas
- Change Case 4
  - Sensitivity Analysis
    - Low pre-fault WGR terminal voltage
    - WGR Terminal Vs Remote voltage control
- Change Case 5
  - Detailed investigation for events posing reliability risks
  - HWHL/HWLL Cases & Change Cases 1-3

Event Definitions & Reliability Metrics

- 65 normal clearing & 31 breaker failure events – Phase I
- Reliability Metrics
  - WGR trips as per case dispatch vis-à-vis ERCOT RRS requirement i.e. 2300 MW
  - WGR trips as per WGR capacity vis-à-vis ERCOT RRS requirement i.e. 2300 MW
  - System frequency response & post-event frequency deviations
    - With & Without LaaR models
  - Voltage Recovery & post-event voltage levels

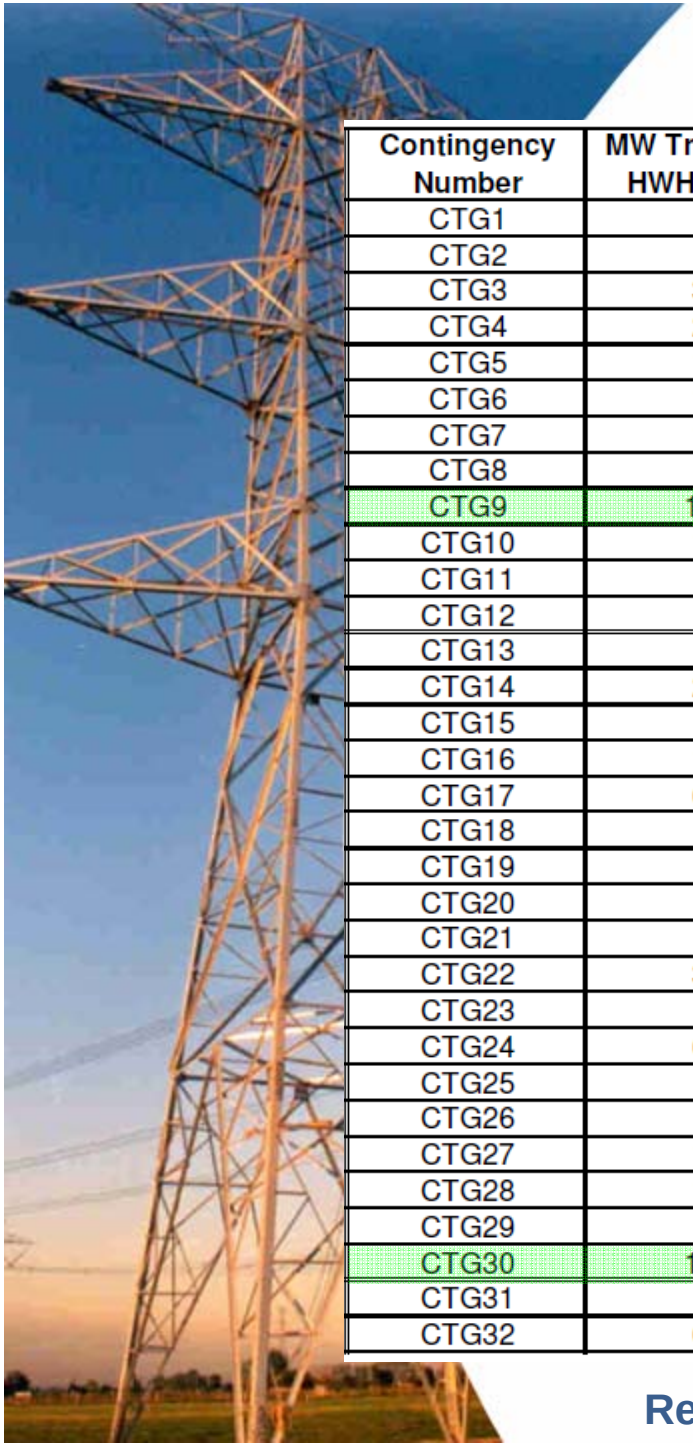


Event Definitions

Contingency Number	NERC Category
CTG1	D
CTG2	D
CTG3	D
CTG4	D
CTG5	D
CTG6	D
CTG7	D
CTG8	B
CTG9	D
CTG10	B
CTG11	B
CTG12	B
CTG13	B
CTG14	D
CTG15	D
CTG16	B
CTG17	B
CTG18	B
CTG19	B
CTG20	B
CTG21	D
CTG22	D
CTG23	D
CTG24	B
CTG25	B
CTG26	B
CTG27	B
CTG28	B
CTG29	B
CTG30	D
CTG31	D

Contingency Number	NERC Category
CTG32	D
CTG33	D
CTG34	B
CTG35	B
CTG36	B
CTG37	B
CTG38	B
CTG39	B
CTG40	B
CTG41	B
CTG42	D
CTG43	B
CTG44	B
CTG45	B
CTG46	B
CTG47	B
CTG48	B
CTG49	B
CTG50	B
CTG51	B
CTG52	B
CTG53	B
CTG54	B
CTG55	B
CTG56	B
CTG57	B
CTG58	D
CTG59	D
CTG60	B
CTG61	B
CTG62	B
CTG63	D
CTG64	B
CTG65	B

Normal Clearing Events, Phase III – NERC Category



Results – HWHL Case

Contingency Number	MW Tripped as per HWHL Dispatch	MW Capacity Lost
CTG1	63.74	258.00
CTG2	44.10	63.00
CTG3	398.13	800.10
CTG4	228.09	528.60
CTG5	171.00	180.90
CTG6	161.16	226.86
CTG7	182.40	251.28
CTG8	0.00	0.00
CTG9	1140.75	1706.20
CTG10	105.00	150.00
CTG11	0.00	0.00
CTG12	0.00	0.00
CTG13	65.55	142.50
CTG14	217.35	310.50
CTG15	0.00	0.00
CTG16	155.40	222.00
CTG17	610.31	991.42
CTG18	65.55	142.50
CTG19	0.00	0.00
CTG20	0.00	0.00
CTG21	0.00	0.00
CTG22	398.13	800.10
CTG23	0.00	0.00
CTG24	610.31	991.42
CTG25	65.55	142.50
CTG26	0.00	0.00
CTG27	198.60	295.50
CTG28	155.40	222.00
CTG29	0.00	0.00
CTG30	1140.75	1706.20
CTG31	0.00	0.00
CTG32	610.31	991.42

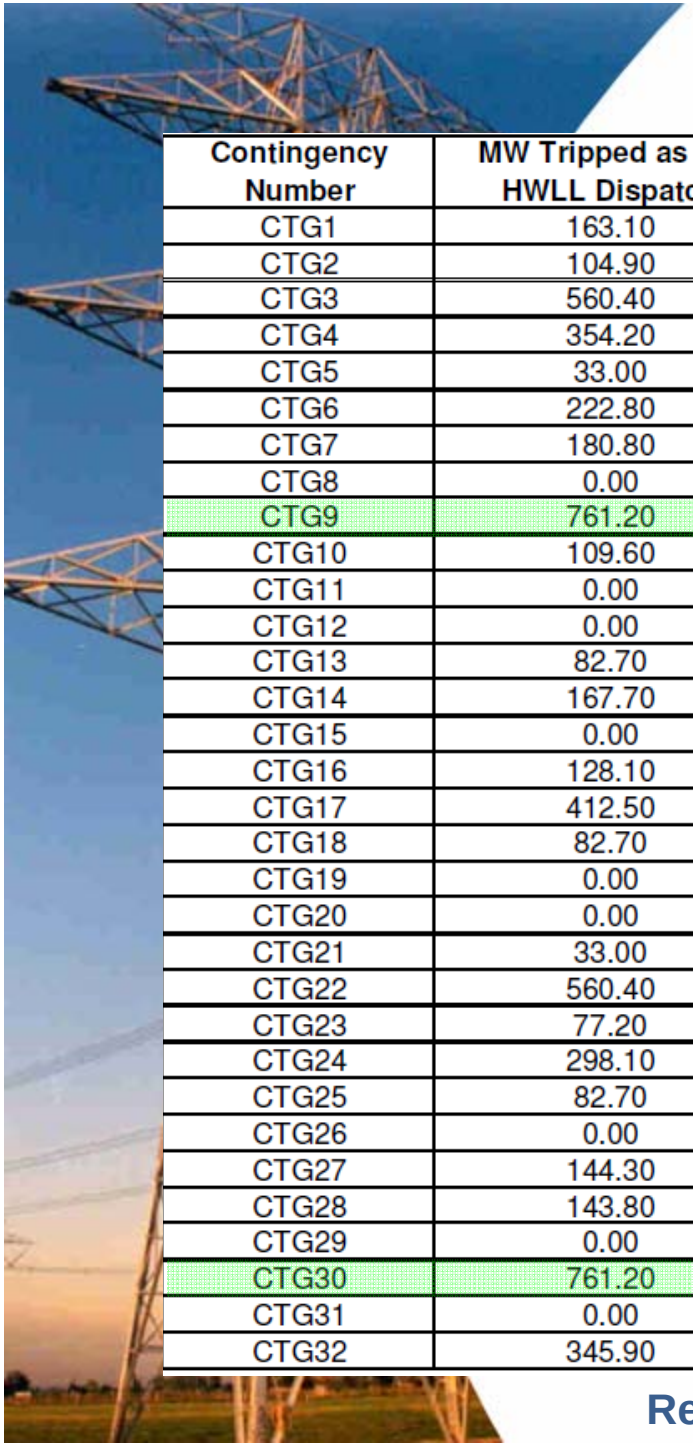
Contingency Number	MW Tripped as per HWHL Dispatch	MW Capacity Lost
CTG33	37.49	220.50
CTG34	70.35	100.50
CTG35	70.35	100.50
CTG36	155.40	222.00
CTG37	0.00	0.00
CTG38	0.00	0.00
CTG39	0.00	0.00
CTG40	65.55	142.50
CTG41	33.30	38.28
CTG42	79.80	114.00
CTG43	0.00	0.00
CTG44	499.29	832.82
CTG45	610.31	991.42
CTG46	610.31	991.42
CTG47	0.00	0.00
CTG48	155.40	222.00
CTG49	0.00	0.00
CTG50	0.00	0.00
CTG51	171.00	180.90
CTG52	171.00	180.90
CTG53	155.40	222.00
CTG54	610.31	991.42
CTG55	208.55	309.72
CTG56	362.60	552.72
CTG57	304.85	470.22
CTG58	610.31	991.42
CTG59	65.55	142.50
CTG60	114.39	378.60
CTG61	114.39	378.60
CTG62	0.00	0.00
CTG63	244.44	316.50
CTG64	44.10	63.00
CTG65	44.10	63.00

Results for WGR Trips, Normal Clearing Events – HWHL Case

Results – HWHL Case

Breaker Failure Event	MW Tripped as per HWHL	MW Capacity Lost
BF1	0.00	0.00
BF2	0.00	0.00
BF3	0.00	0.00
BF4	0.00	0.00
BF5	148.53	186.30
BF6	148.53	186.30
BF7	0.00	0.00
BF8	514.01	830.92
BF9	0.00	0.00
BF10	0.00	0.00
BF11	0.00	0.00
BF12	178.70	313.50
BF13	0.00	0.00
BF14	338.46	416.76
BF15	338.46	416.76
BF16	167.46	235.86
BF17	326.40	402.90
BF18	155.40	222.00
BF19	155.40	222.00
BF20	338.46	416.76
BF21	338.46	416.76
BF22	105.00	150.00
BF23	105.00	150.00
BF24	0.00	0.00
BF25	105.00	150.00
BF26	105.00	150.00
BF27	410.46	671.20
BF28	464.51	748.42
BF29	105.00	150.00
BF30	105.00	150.00
BF31	105.00	150.00

Results for WGR Trips, Breaker Failure Events – HWHL Case

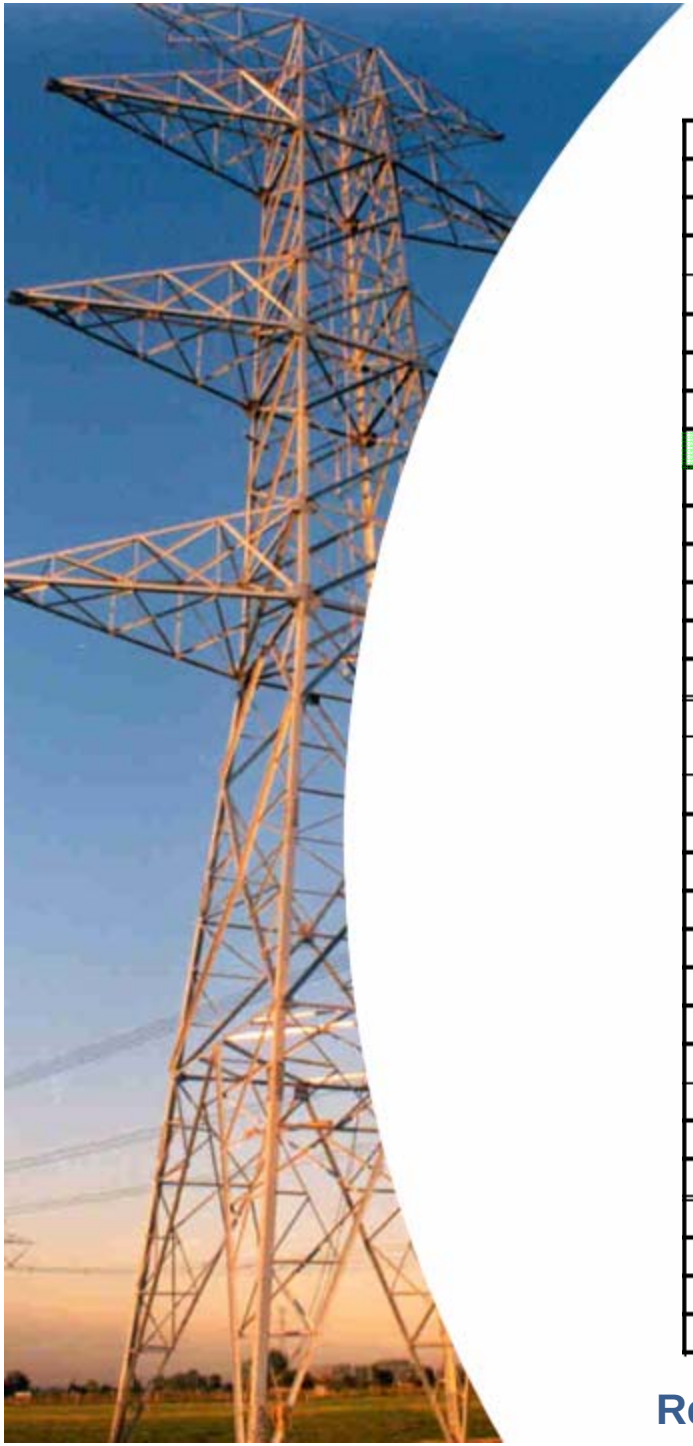


Results – HWLL Case

Contingency Number	MW Tripped as per HWLL Dispatch	MW Capacity Lost
CTG1	163.10	258.00
CTG2	104.90	177.00
CTG3	560.40	838.38
CTG4	354.20	542.46
CTG5	33.00	37.50
CTG6	222.80	531.00
CTG7	180.80	411.00
CTG8	0.00	0.00
CTG9	761.20	1274.70
CTG10	109.60	265.50
CTG11	0.00	0.00
CTG12	0.00	0.00
CTG13	82.70	142.50
CTG14	167.70	341.28
CTG15	0.00	0.00
CTG16	128.10	222.00
CTG17	412.50	991.42
CTG18	82.70	142.50
CTG19	0.00	0.00
CTG20	0.00	0.00
CTG21	33.00	37.50
CTG22	560.40	838.38
CTG23	77.20	188.28
CTG24	298.10	713.22
CTG25	82.70	142.50
CTG26	0.00	0.00
CTG27	144.30	348.00
CTG28	143.80	260.28
CTG29	0.00	0.00
CTG30	761.20	1274.70
CTG31	0.00	0.00
CTG32	345.90	832.82

Contingency Number	MW Tripped as per HWLL Dispatch	MW Capacity Lost
CTG33	130.10	220.50
CTG34	85.20	138.78
CTG35	85.20	138.78
CTG36	128.10	222.00
CTG37	0.00	0.00
CTG38	0.00	0.00
CTG39	15.70	38.28
CTG40	82.70	142.50
CTG41	15.70	38.28
CTG42	68.40	114.00
CTG43	0.00	0.00
CTG44	345.90	832.82
CTG45	298.10	713.22
CTG46	345.90	832.82
CTG47	0.00	0.00
CTG48	128.10	222.00
CTG49	0.00	0.00
CTG50	0.00	0.00
CTG51	126.00	180.90
CTG52	0.00	0.00
CTG53	128.10	222.00
CTG54	298.10	713.22
CTG55	163.30	392.22
CTG56	345.90	832.82
CTG57	232.30	552.72
CTG58	364.70	871.82
CTG59	82.70	142.50
CTG60	235.40	378.60
CTG61	235.40	378.60
CTG62	0.00	0.00
CTG63	405.40	575.28
CTG64	85.20	138.78
CTG65	120.60	215.28

Results for WGR Trips, Normal Clearing Events – HWLL Case



Results – HWLL Case

Breaker Failure Event	MW Tripped as per HWLL	MW Capacity Lost
BF1	0.00	0.00
BF2	0.00	0.00
BF3	68.40	114.00
BF4	0.00	0.00
BF5	163.90	186.30
BF6	163.90	186.30
BF7	0.00	0.00
BF8	276.90	672.32
BF9	0.00	0.00
BF10	0.00	0.00
BF11	0.00	0.00
BF12	125.40	313.50
BF13	0.00	0.00
BF14	143.80	260.28
BF15	143.80	260.28
BF16	143.80	260.28
BF17	143.80	260.28
BF18	143.80	260.28
BF19	143.80	260.28
BF20	143.80	260.28
BF21	143.80	260.28
BF22	61.50	150.00
BF23	61.50	150.00
BF24	0.00	0.00
BF25	127.30	310.50
BF26	127.30	310.50
BF27	127.30	310.50
BF28	127.30	310.50
BF29	127.30	310.50
BF30	175.10	430.10
BF31	175.10	430.10

Results for WGR Trips, Breaker Failure Events – HWLL Case

Results

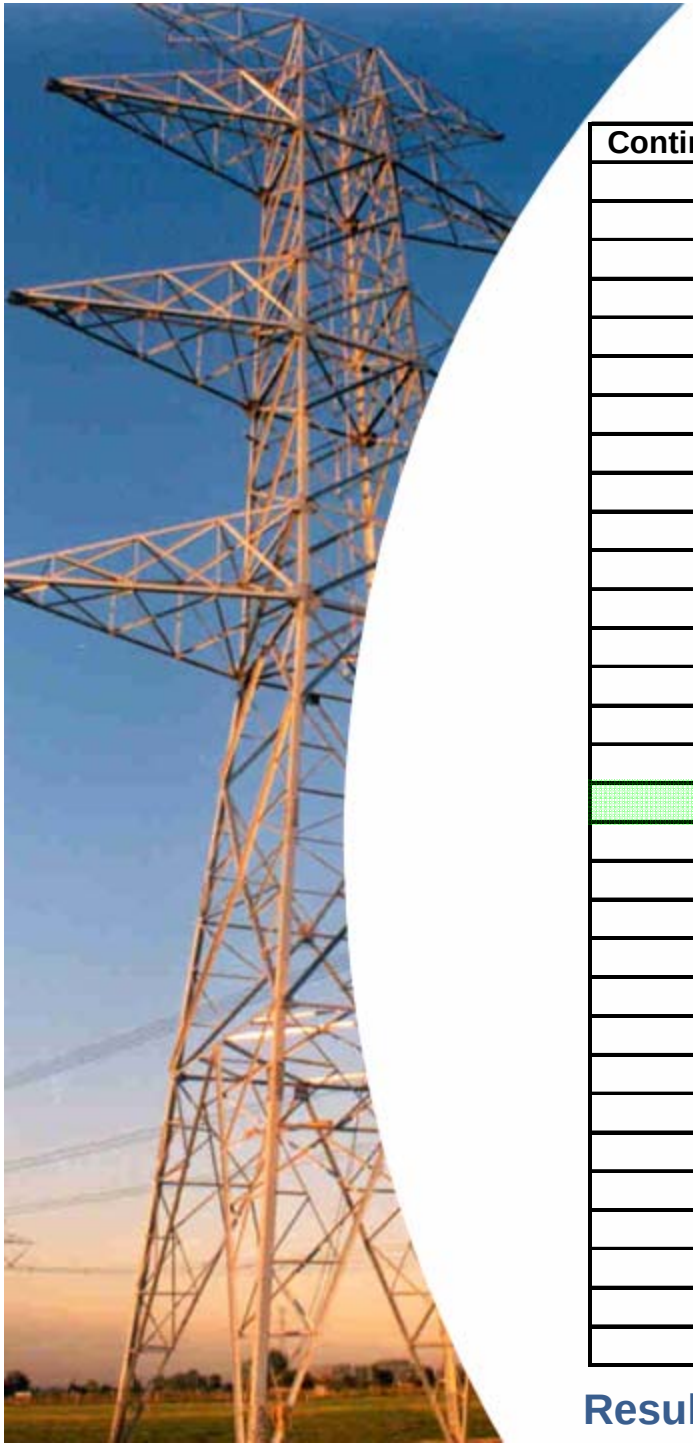
- HWHL Case
  - No reliability risks due to lack of WGR VRT capability for events simulated
- HWLL Case
  - No reliability risks due to lack of WGR VRT capability for events simulated
- Evaluation of reliability risks based on outlined reliability metrics

Results – Change Case 1

Contingency Number	MW Tripped as per Change Case 1	MW Capacity Lost
CTG1	69.50	100.50
CTG2	432.80	535.50
CTG3	531.90	679.50
CTG4	531.90	679.50
CTG5	734.60	977.90
CTG6	98.00	213.00
CTG7	131.00	250.50
CTG8	0.00	0.00
CTG9	725.50	1065.00
CTG10	98.00	213.00
CTG11	0.00	0.00
CTG12	82.70	142.50
CTG13	82.70	142.50
CTG14	510.70	687.00
CTG15	0.00	0.00
CTG16	128.10	222.00
CTG17	487.50	991.42
CTG18	82.70	142.50
CTG19	0.00	0.00
CTG20	0.00	0.00
CTG21	483.60	597.00
CTG22	531.90	679.50
CTG23	98.00	213.00
CTG24	334.90	713.22
CTG25	82.70	142.50
CTG26	0.00	0.00
CTG27	98.00	213.00
CTG28	128.10	222.00
CTG29	0.00	0.00
CTG30	725.50	1065.00
CTG31	0.00	0.00

Contingency Number	MW Tripped as per Change Case 1	MW Capacity Lost
CTG32	487.50	991.42
CTG33	69.50	100.50
CTG34	449.20	537.00
CTG35	449.20	537.00
CTG36	128.10	222.00
CTG37	0.00	0.00
CTG38	0.00	0.00
CTG39	0.00	0.00
CTG40	82.70	142.50
CTG41	52.20	101.28
CTG42	259.10	321.00
CTG43	0.00	0.00
CTG44	401.90	832.82
CTG45	334.90	713.22
CTG46	487.50	991.42
CTG47	0.00	0.00
CTG48	70.90	123.00
CTG49	0.00	0.00
CTG50	0.00	0.00
CTG51	171.00	180.90
CTG52	171.00	180.90
CTG53	128.10	222.00
CTG54	401.90	832.82
CTG55	61.50	150.00
CTG56	487.50	991.42
CTG57	487.50	991.42
CTG58	420.50	871.82
CTG59	82.70	142.50
CTG60	259.10	321.00
CTG61	259.10	321.00
CTG62	0.00	0.00
CTG63	531.90	679.50
CTG64	427.90	668.28
CTG65	427.90	668.28

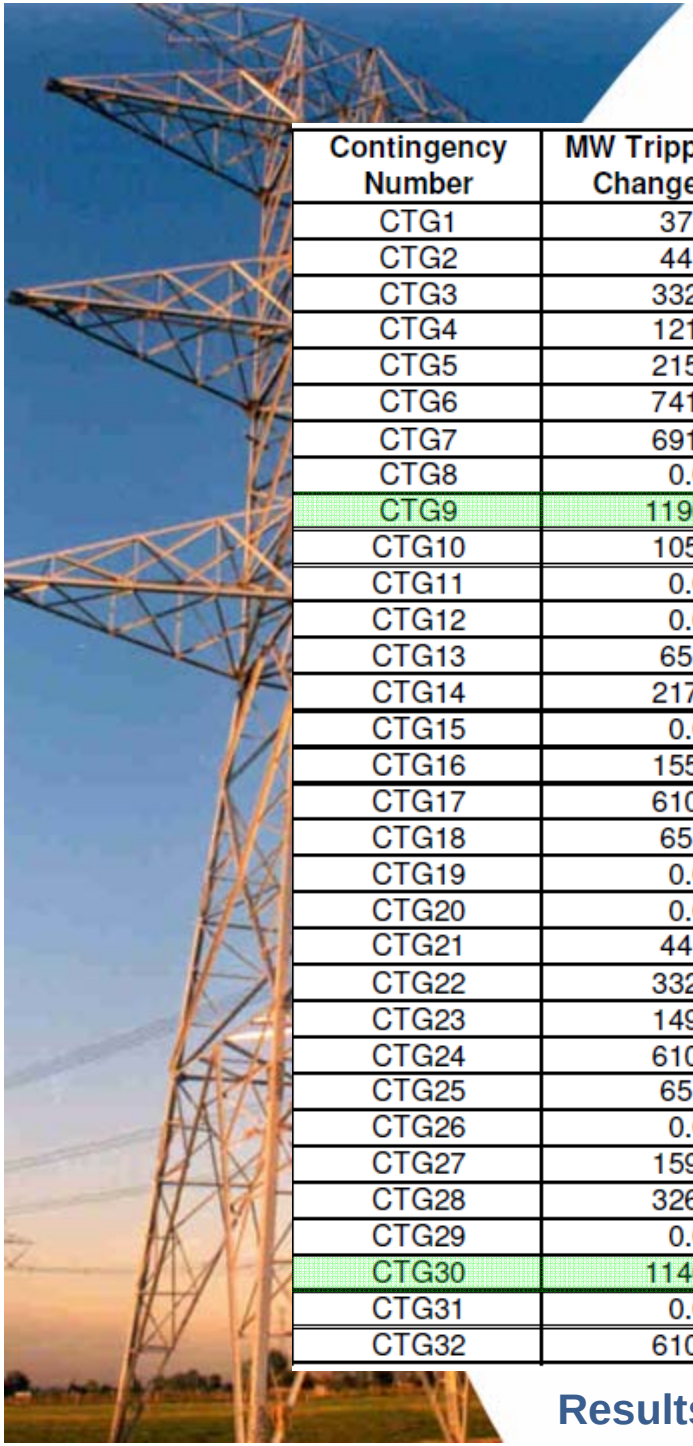
Results for WGR Trips, Normal Clearing Events – Change Case 1



Results – Change Case 1

Contingency Number	MW Tripped as per Change Case 1	MW Capacity Lost
BF1	539.40	680.60
BF2	539.40	680.60
BF3	273.50	301.50
BF4	378.30	421.10
BF5	163.90	186.30
BF6	163.90	186.30
BF7	0.00	0.00
BF8	316.90	672.32
BF9	0.00	0.00
BF10	196.20	282.60
BF11	171.00	180.90
BF12	256.60	313.50
BF13	0.00	0.00
BF14	601.10	976.12
BF15	791.50	1256.44
BF16	767.20	1271.60
BF17	835.00	1307.58
BF18	644.60	1029.38
BF19	644.60	1029.38
BF20	732.50	1189.10
BF21	597.00	1031.00
BF22	127.30	310.50
BF23	279.90	588.70
BF24	218.40	438.70
BF25	313.60	648.00
BF26	313.60	648.00
BF27	267.10	560.58
BF28	312.50	643.08
BF29	267.10	560.58
BF30	127.30	310.50
BF31	127.30	310.50

Results for WGR Trips, Breaker Failure Events – Change Case 1



Results – Change Case 2

Contingency Number	MW Tripped as per Change Case 2	MW Capacity Lost
CTG1	37.49	220.50
CTG2	44.10	63.00
CTG3	332.58	657.60
CTG4	121.00	221.10
CTG5	215.10	243.90
CTG6	741.17	1088.68
CTG7	691.67	1006.18
CTG8	0.00	0.00
CTG9	1190.25	1788.70
CTG10	105.00	150.00
CTG11	0.00	0.00
CTG12	0.00	0.00
CTG13	65.55	142.50
CTG14	217.35	310.50
CTG15	0.00	0.00
CTG16	155.40	222.00
CTG17	610.31	991.42
CTG18	65.55	142.50
CTG19	0.00	0.00
CTG20	0.00	0.00
CTG21	44.10	63.00
CTG22	332.58	657.60
CTG23	149.10	213.00
CTG24	610.31	991.42
CTG25	65.55	142.50
CTG26	0.00	0.00
CTG27	159.05	227.22
CTG28	326.40	402.90
CTG29	0.00	0.00
CTG30	1140.75	1706.20
CTG31	0.00	0.00
CTG32	610.31	991.42

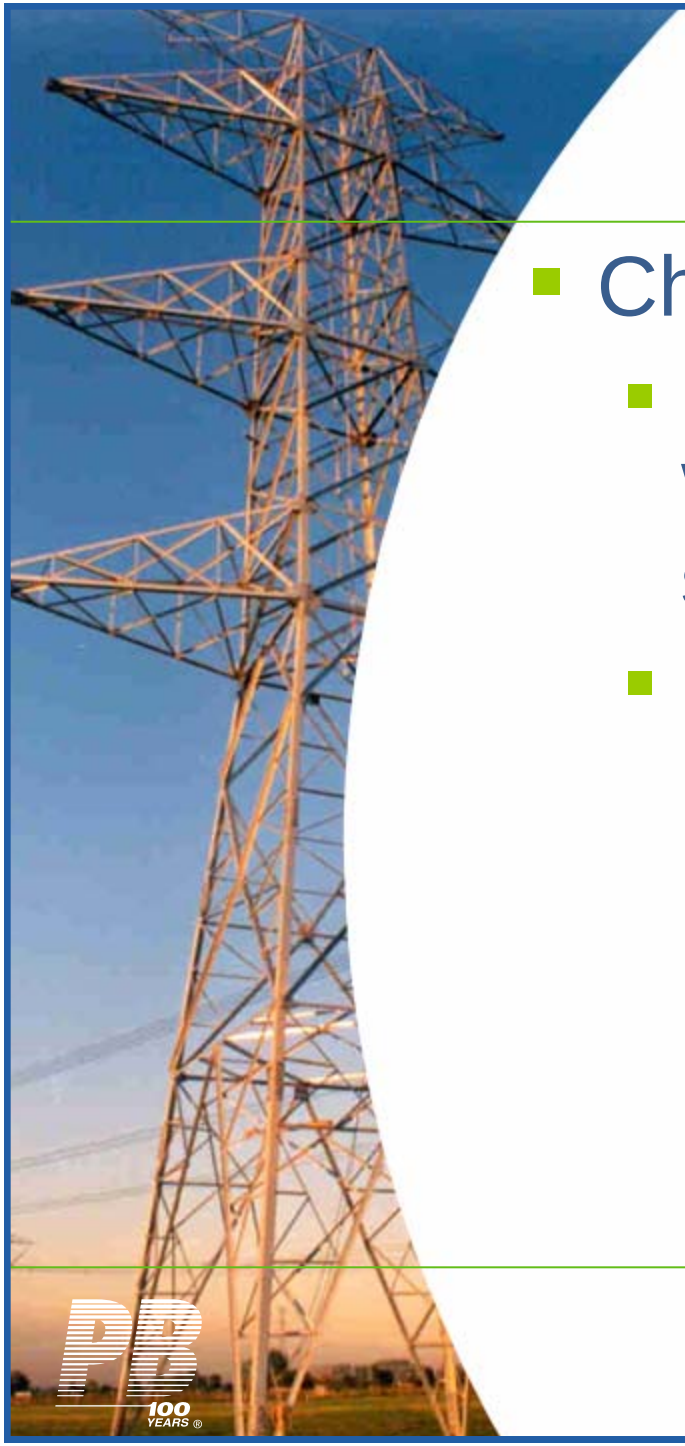
Contingency Number	MW Tripped as per Change Case 2	MW Capacity Lost
CTG33	0.00	0.00
CTG34	86.10	123.00
CTG35	44.10	63.00
CTG36	326.40	402.90
CTG37	0.00	0.00
CTG38	0.00	0.00
CTG39	0.00	0.00
CTG40	65.55	142.50
CTG41	33.30	38.28
CTG42	79.80	114.00
CTG43	0.00	0.00
CTG44	499.29	832.82
CTG45	610.31	991.42
CTG46	610.31	991.42
CTG47	0.00	0.00
CTG48	155.40	222.00
CTG49	0.00	0.00
CTG50	0.00	0.00
CTG51	171.00	180.90
CTG52	171.00	180.90
CTG53	155.40	222.00
CTG54	610.31	991.42
CTG55	159.05	227.22
CTG56	362.60	552.72
CTG57	362.60	552.72
CTG58	610.31	991.42
CTG59	65.55	142.50
CTG60	88.14	341.10
CTG61	88.14	341.10
CTG62	0.00	0.00
CTG63	244.44	316.50
CTG64	44.10	63.00
CTG65	44.10	63.00

Results for WGR Trips, Normal Clearing Events – Change Case 2

Results – Change Case 2

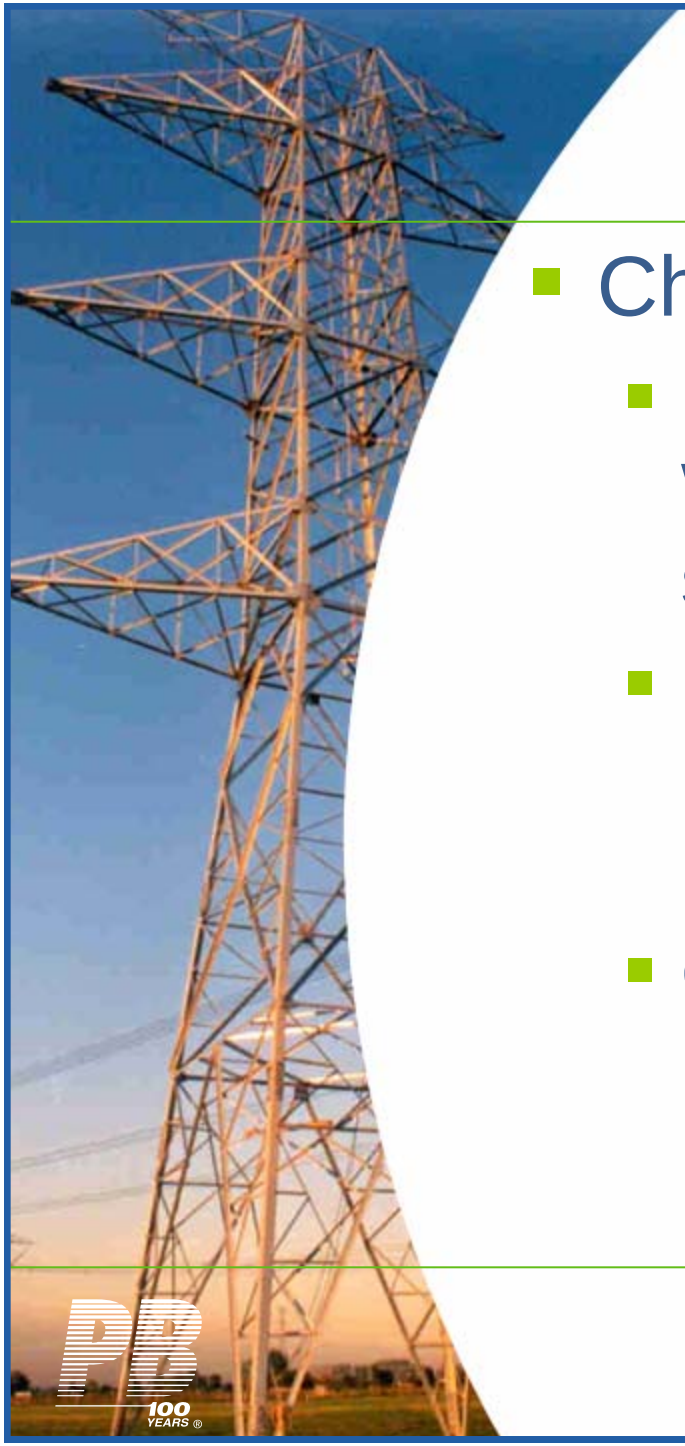
Contingency Number	MW Tripped as per Change Case 2	MW Capacity Lost
BF1	0.00	0.00
BF2	0.00	0.00
BF3	0.00	0.00
BF4	0.00	0.00
BF5	148.53	186.30
BF6	148.53	186.30
BF7	0.00	0.00
BF8	514.01	830.92
BF9	0.00	0.00
BF10	0.00	0.00
BF11	0.00	0.00
BF12	178.70	313.50
BF13	0.00	0.00
BF14	338.46	416.76
BF15	802.97	1165.18
BF16	338.46	416.76
BF17	338.46	416.76
BF18	338.46	416.76
BF19	338.46	416.76
BF20	824.21	1189.60
BF21	802.97	1165.18
BF22	105.00	150.00
BF23	105.00	150.00
BF24	0.00	0.00
BF25	635.51	929.32
BF26	635.51	929.32
BF27	635.51	929.32
BF28	635.51	929.32
BF29	635.51	929.32
BF30	635.51	929.32
BF31	635.51	929.32

Results for WGR Trips, Breaker Failure Events – Change Case 2



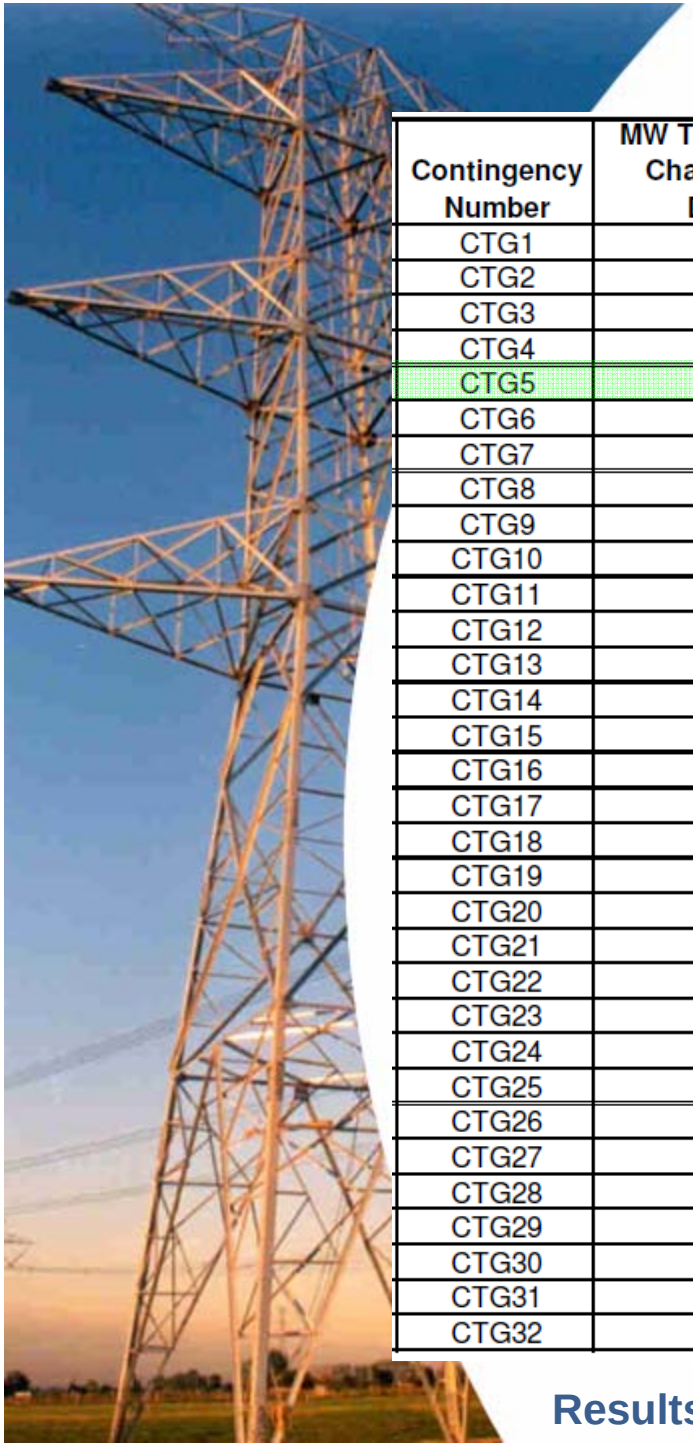
Results

- Change Case 1
  - No reliability risks due to lack of WGR VRT capability for events simulated
  - Key Factors
    - Breaker Failure Event Simulations
      - Adjustment of fault shunt values
      - Reflection of lower 3-Phase and S-L-G contributions in absence of conventional units in West Texas
      - Accurate reflection of zero sequence contribution for WGRs



Results

- Change Case 2
  - No reliability risks due to lack of WGR VRT capability for events simulated
  - Presence of dynamic load models has slight impact on voltage recovery in West Texas
  - Change Case 2 results on similar lines to HWHL case

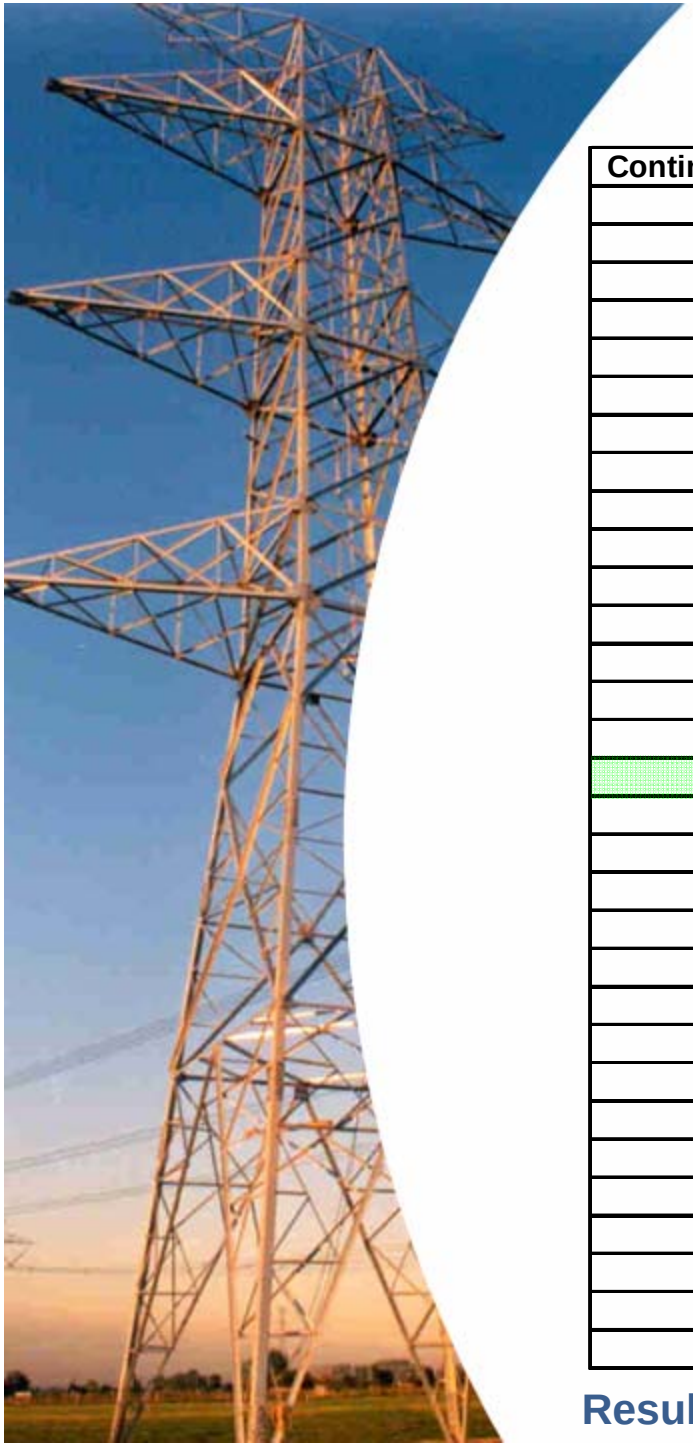


Results – Change Case 3

Contingency Number	MW Tripped as per Change Case 3 Dispatch	MW Capacity Lost
CTG1	69.50	100.50
CTG2	69.50	100.50
CTG3	531.90	679.50
CTG4	449.20	537.00
CTG5	3965.00	6214.00
CTG6	98.00	213.00
CTG7	98.00	213.00
CTG8	0.00	0.00
CTG9	685.00	988.50
CTG10	98.00	213.00
CTG11	0.00	0.00
CTG12	0.00	0.00
CTG13	82.70	142.50
CTG14	207.60	337.50
CTG15	0.00	0.00
CTG16	128.10	222.00
CTG17	487.50	991.42
CTG18	82.70	142.50
CTG19	0.00	0.00
CTG20	0.00	0.00
CTG21	578.00	690.90
CTG22	531.90	679.50
CTG23	98.00	213.00
CTG24	487.50	991.42
CTG25	82.70	142.50
CTG26	0.00	0.00
CTG27	98.00	213.00
CTG28	128.10	222.00
CTG29	0.00	0.00
CTG30	685.00	988.50
CTG31	0.00	0.00
CTG32	487.50	991.42

Contingency Number	MW Tripped as per Change Case 3 Dispatch	MW Capacity Lost
CTG33	36.50	63.00
CTG34	146.10	187.50
CTG35	146.10	187.50
CTG36	128.10	222.00
CTG37	0.00	0.00
CTG38	0.00	0.00
CTG39	0.00	0.00
CTG40	82.70	142.50
CTG41	52.20	101.28
CTG42	259.10	321.00
CTG43	0.00	0.00
CTG44	401.90	832.82
CTG45	487.50	991.42
CTG46	487.50	991.42
CTG47	0.00	0.00
CTG48	128.10	222.00
CTG49	0.00	0.00
CTG50	0.00	0.00
CTG51	171.00	180.90
CTG52	171.00	180.90
CTG53	128.10	222.00
CTG54	487.50	991.42
CTG55	61.50	150.00
CTG56	487.50	991.42
CTG57	487.50	991.42
CTG58	487.50	991.42
CTG59	82.70	142.50
CTG60	259.10	321.00
CTG61	259.10	321.00
CTG62	0.00	0.00
CTG63	449.20	537.00
CTG64	427.90	668.28
CTG65	427.90	668.28

Results for WGR Trips, Normal Clearing Events – Change Case 3



Results – Change Case 3

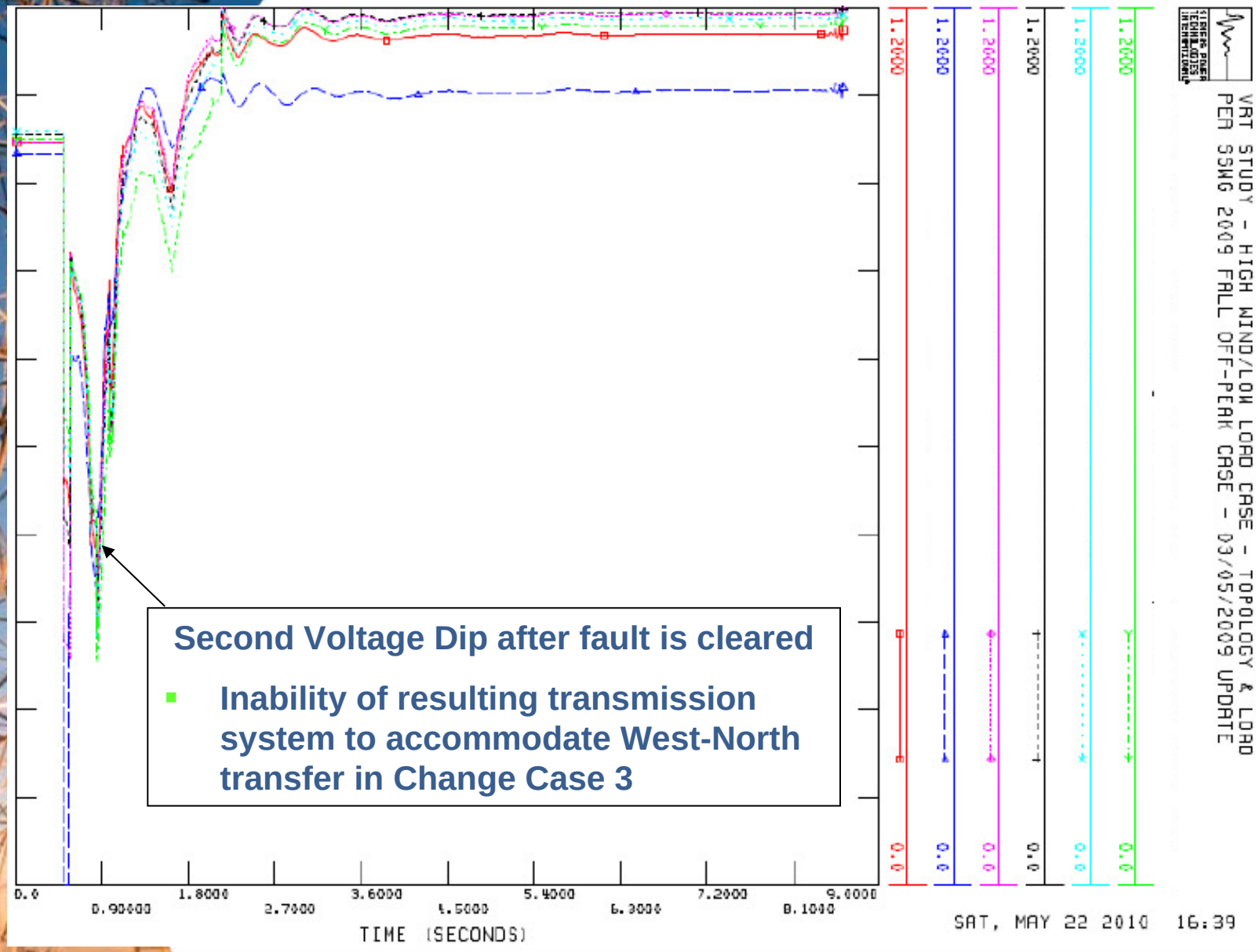
Contingency Number	MW Tripped as per Change Case 3	MW Capacity Lost
BF1	951.00	1236.62
BF2	506.40	643.10
BF3	273.50	301.50
BF4	440.70	641.60
BF5	163.90	186.30
BF6	163.90	186.30
BF7	0.00	0.00
BF8	402.50	830.92
BF9	0.00	0.00
BF10	401.60	523.50
BF11	275.80	300.50
BF12	256.60	313.50
BF13	0.00	0.00
BF14	777.90	1269.48
BF15	860.10	1393.50
BF16	1193.20	1903.56
BF17	1036.40	1586.05
BF18	880.40	1390.08
BF19	922.90	1467.30
BF20	922.90	1467.30
BF21	787.40	1309.20
BF22	127.30	310.50
BF23	325.30	671.20
BF24	218.40	438.70
BF25	682.60	1189.60
BF26	682.60	1189.60
BF27	220.90	484.08
BF28	516.10	883.58
BF29	483.50	823.98
BF30	127.30	310.50
BF31	127.30	310.50

Results for WGR Trips, Breaker Failure Events – Change Case 3

Results – Change Case 3

- Change Case 3
  - CTG5 poses reliability risks
    - 3965 MW of WGR trips in terms of Change Case 3 dispatch
    - 6214 MW of WGR trips in terms of WGR capacity lost
  - Numerous over-frequency WGR trips
  - Post-event frequency deviation greater than 0.3 Hz
  - No other reliability risks from any normal clearing and/or breaker failure events simulated

Results – Change Case 3

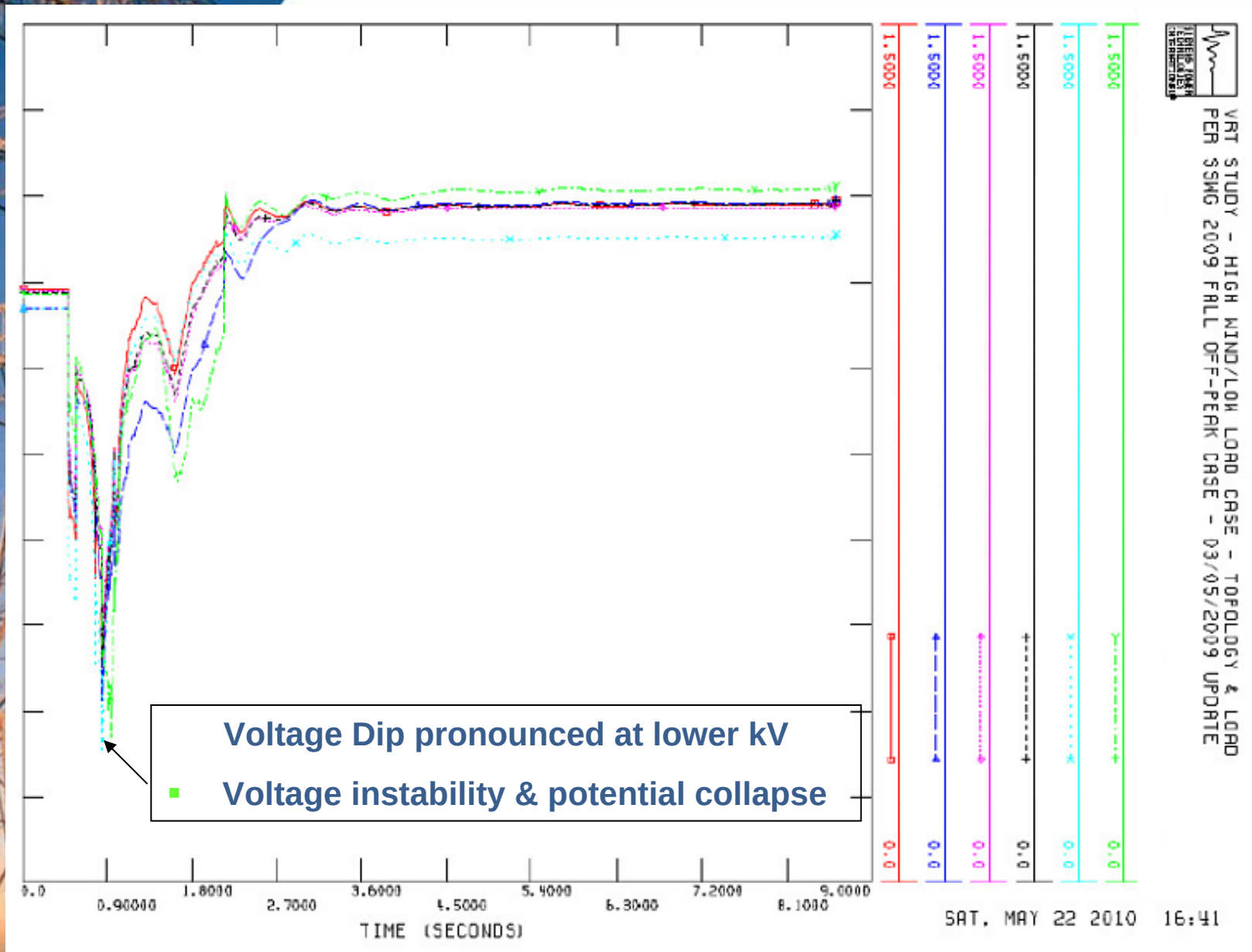


Second Voltage Dip after fault is cleared

- **Inability of resulting transmission system to accommodate West-North transfer in Change Case 3**

Voltage Response, 345kV ERCOT West – CTG5, Change Case 3

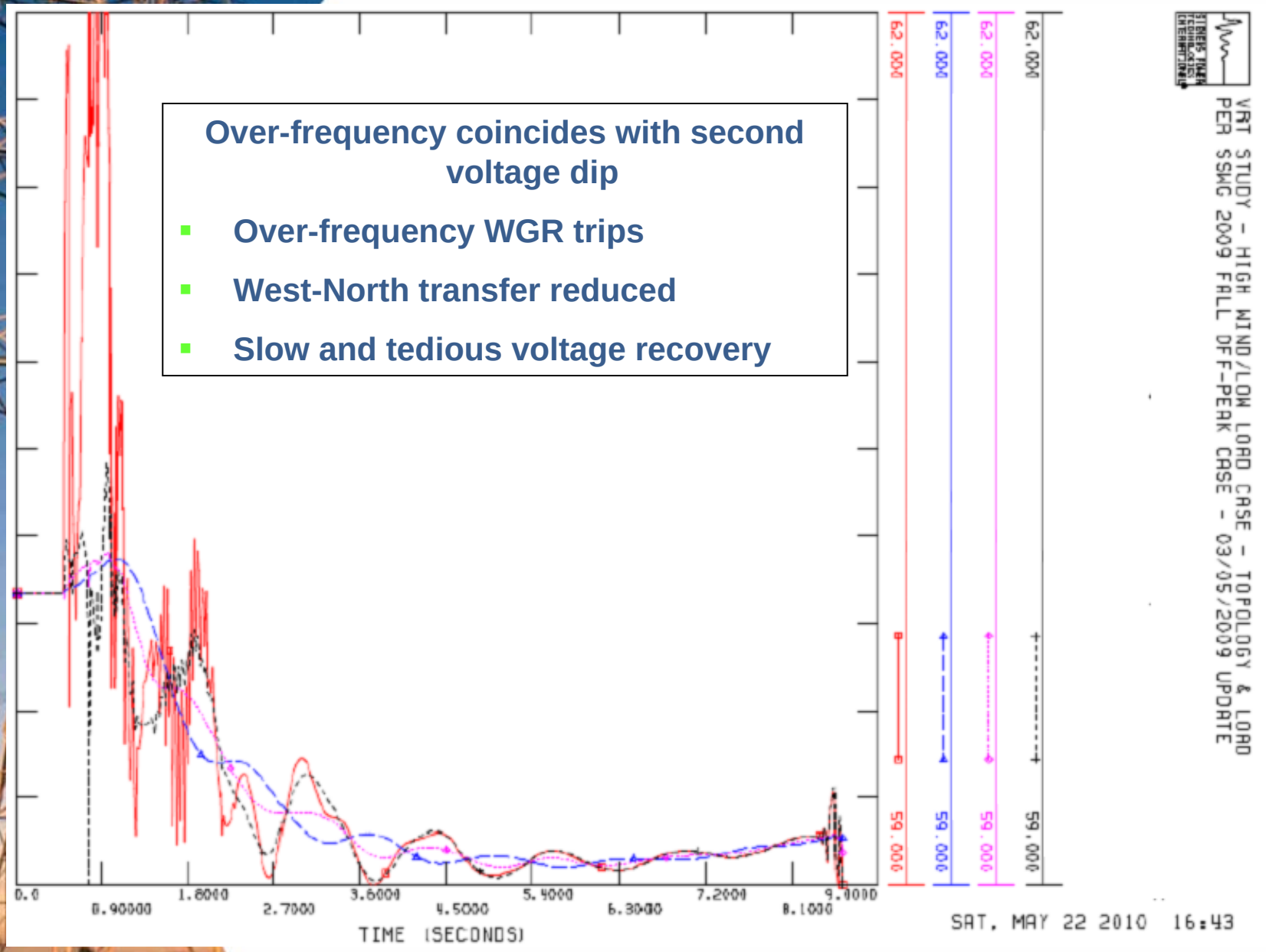
Results – Change Case 3



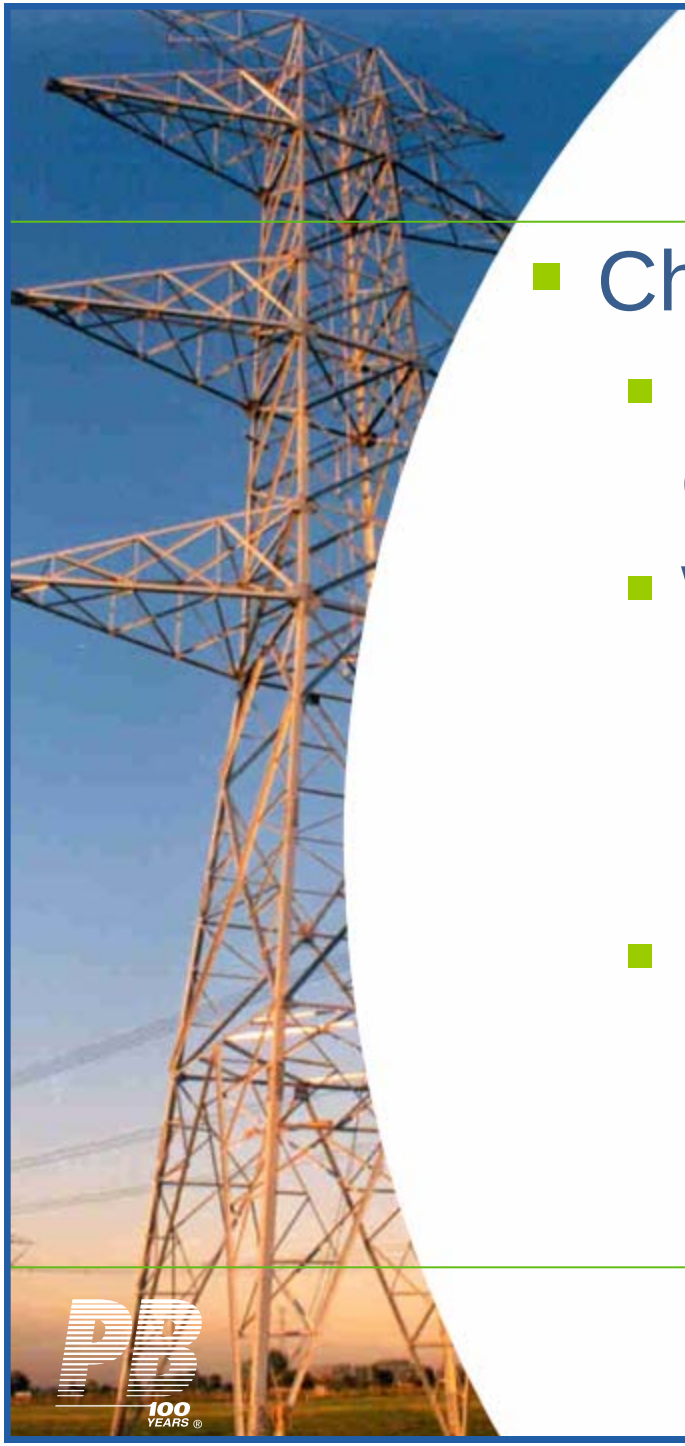
- Voltage Dip pronounced at lower kV
- Voltage instability & potential collapse

Voltage Response, 138kV ERCOT West – CTG5, Change Case 3

Results – Change Case 3



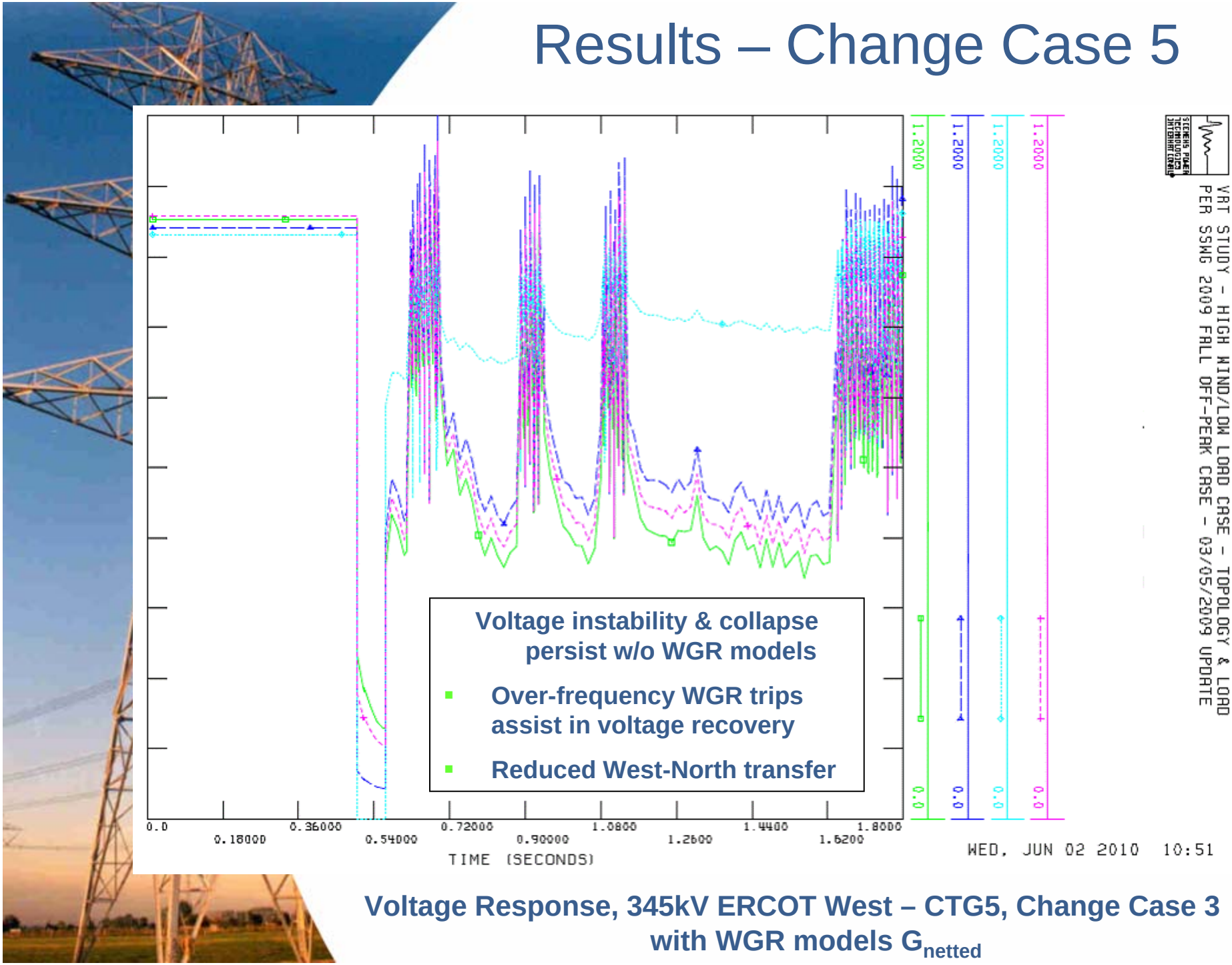
System Frequency Response – CTG5, Change Case 3



Results – Change Case 5

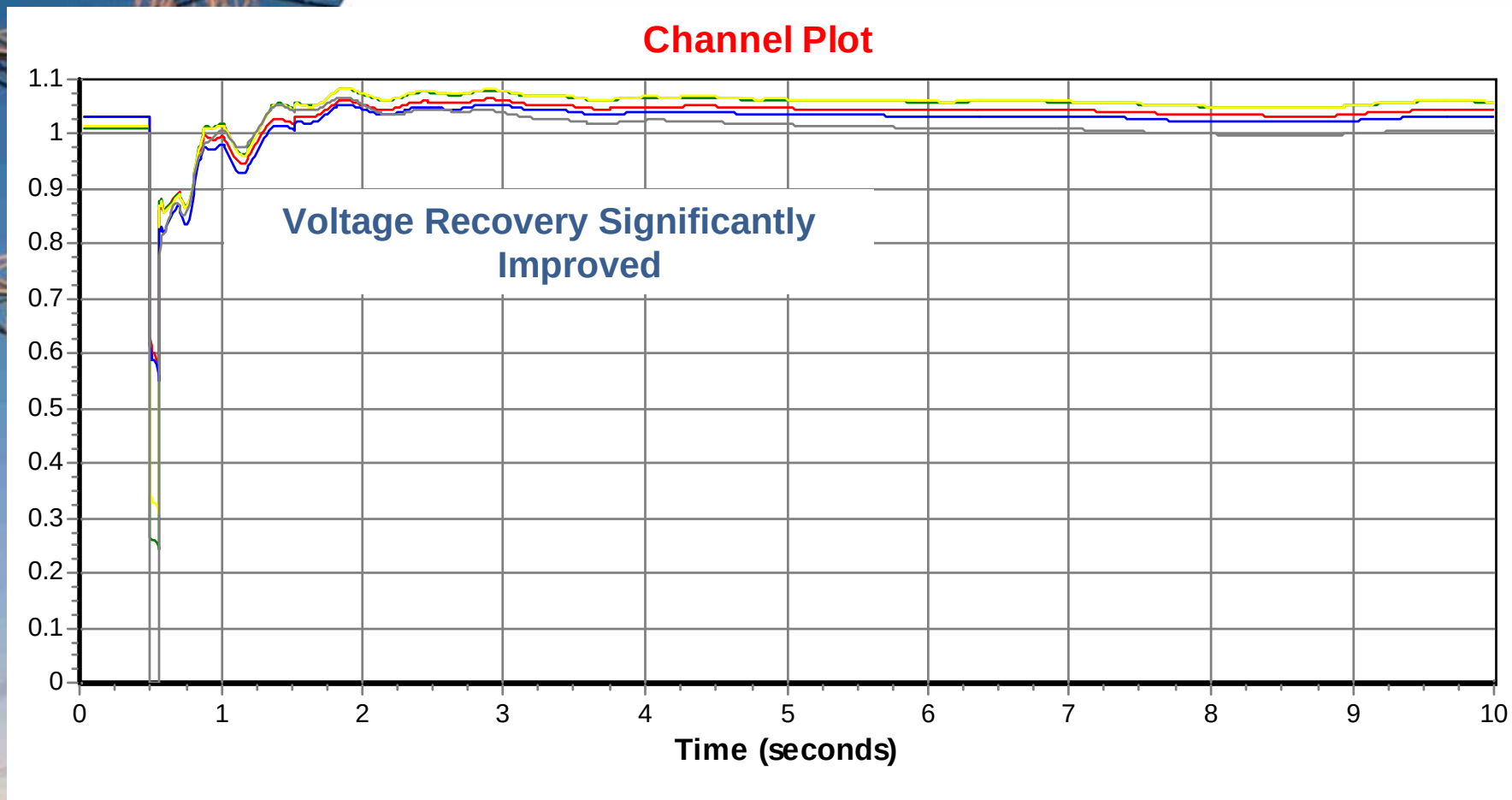
- Change Case 5 Investigation
  - Reliability Risk - CTG5, Change Case 3
  - West-North Voltage Stability Limit
    - Assess CTG5 with WGR models G_{netted}
    - Assess CTG5 with additional reactive support
  - Role of lack of WGR VRT capability
    - Assess WGR trips by virtue of under-voltage

Results – Change Case 5



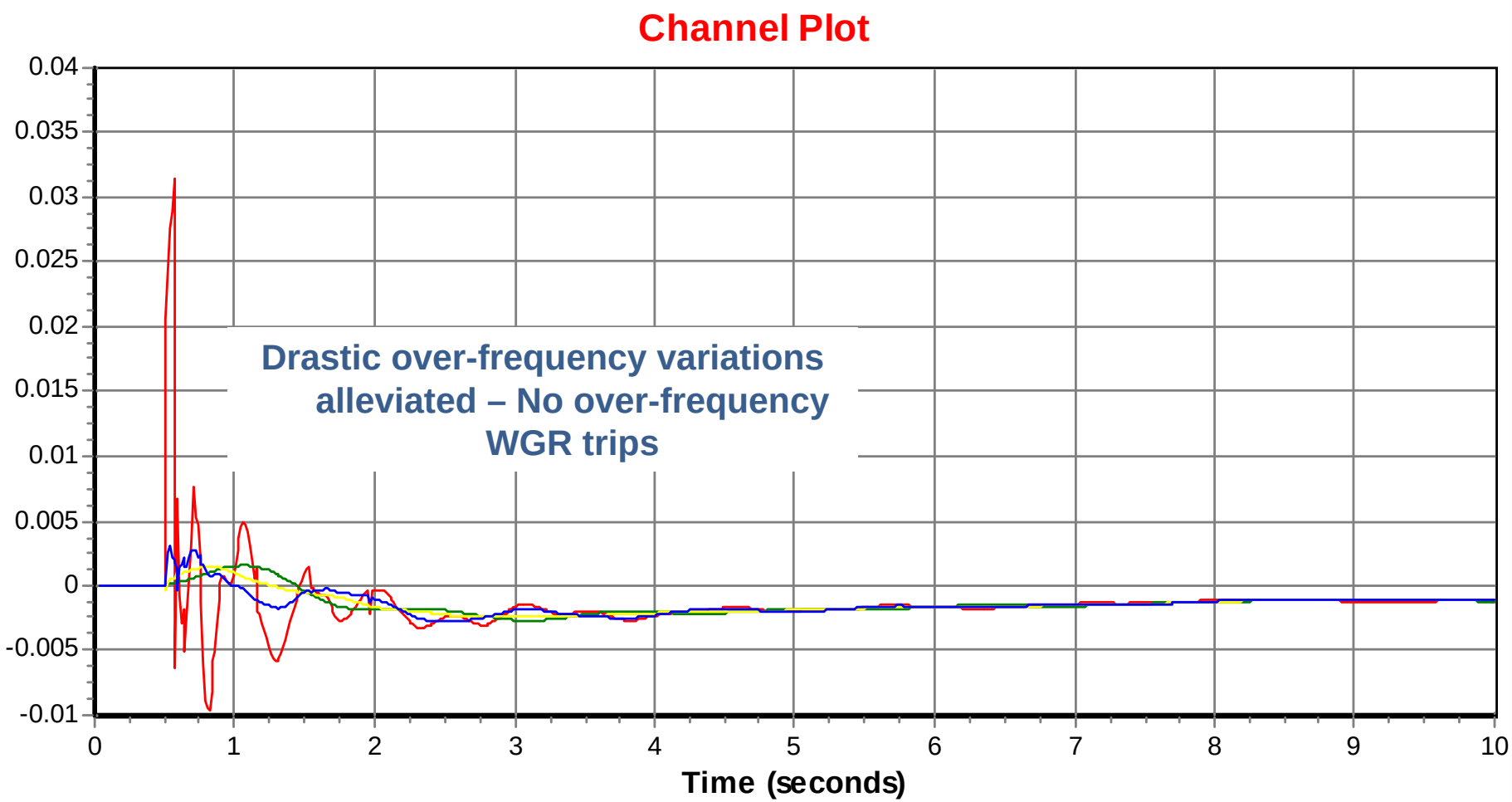
Voltage Response, 345kV ERCOT West – CTG5, Change Case 3 with WGR models G_{netted}

Results – Change Case 5



Voltage Response, 345kV ERCOT West – CTG5, Change Case 3 with WGR models & additional dynamic reactive support

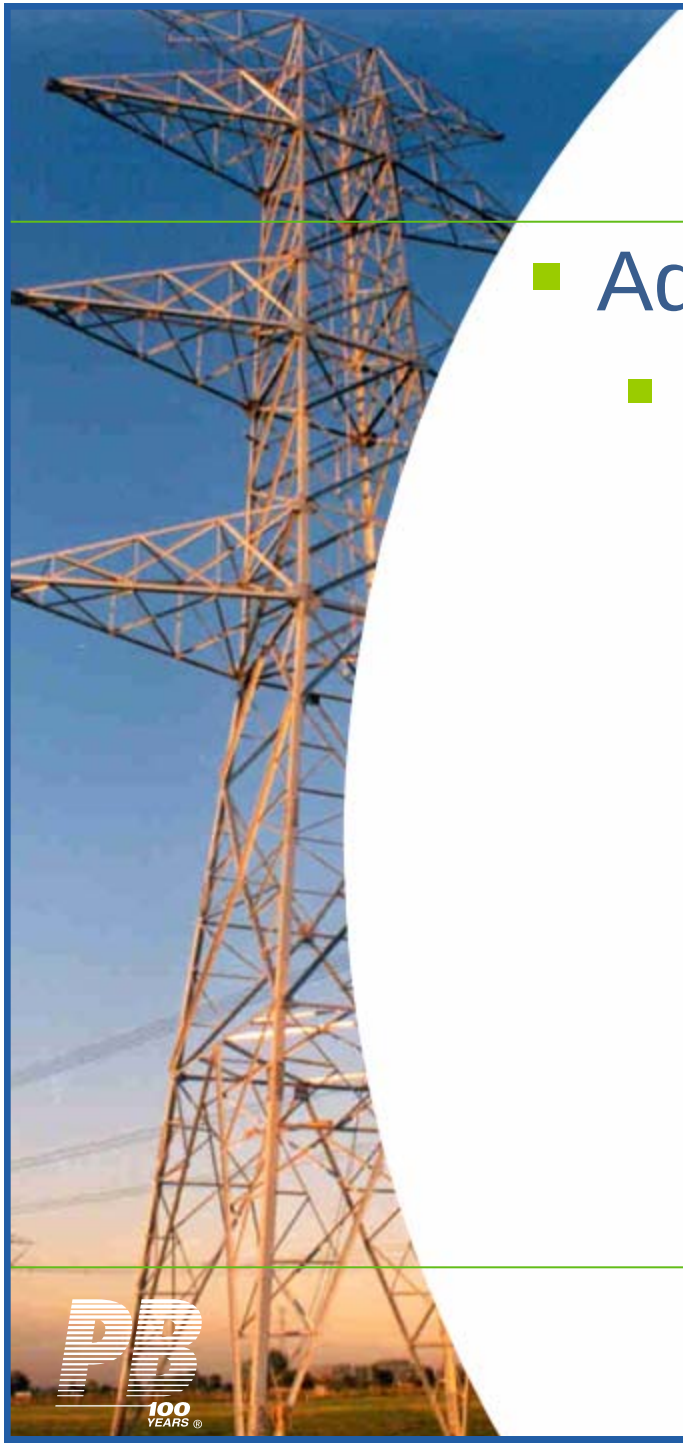
Results – Change Case 5



System Frequency Response – CTG5, Change Case 3 with WGR models & additional dynamic reactive support

Results – Change Case 5

- Additional Investigation
  - WGR Trips for CTG5, Change Case 3 with additional reactive support
    - 578 MW in terms of Change Case 3 dispatch
    - 690 MW in terms of WGR capacity lost
    - All WGR trips by virtue of under-voltage
  - No over-frequency WGR trips
  - Frequency swings manifestation of unstable system behavior

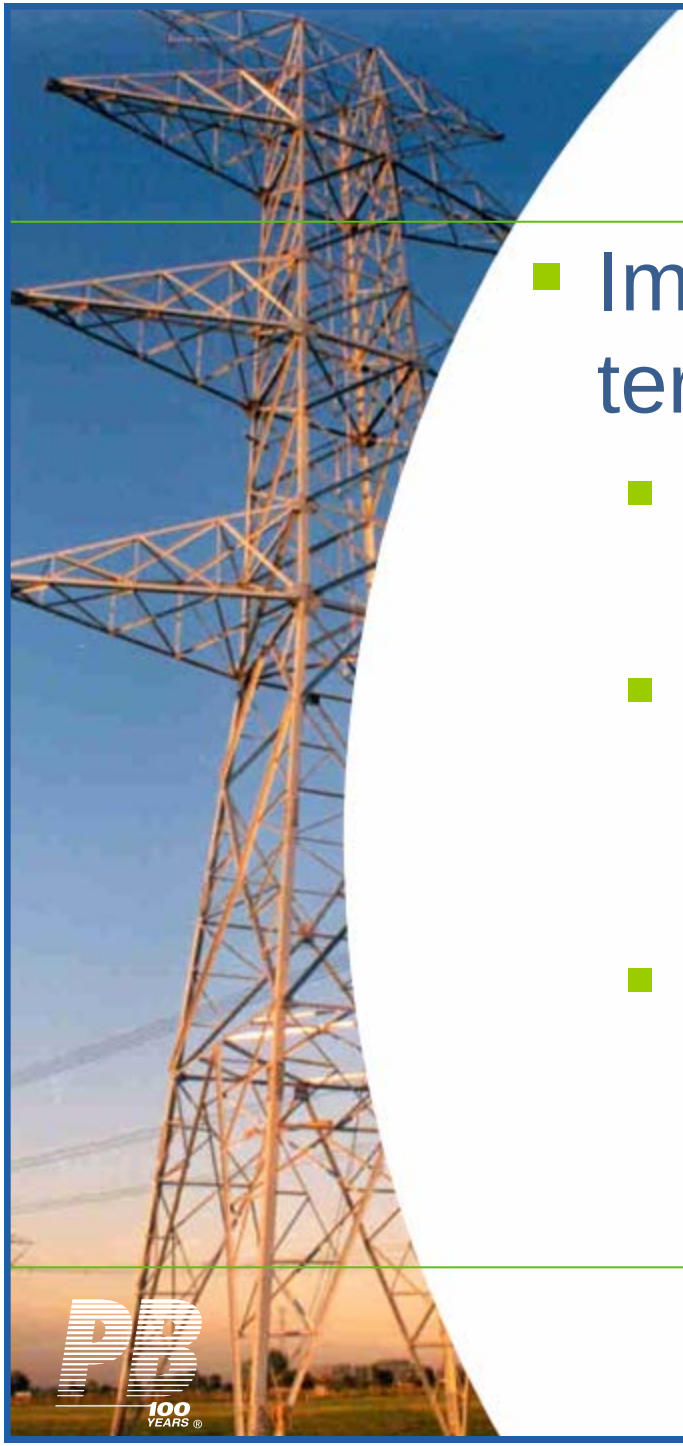


Results – Change Case 5

- Additional Investigation
  - Observations
    - Voltage Instability due to West-North transfer modeled in Change Case 3
    - Frequency deviations & over-frequency WGR trips a manifestation of unstable system behavior
    - Lack of WGR VRT capability not the primary cause for phenomenon
    - Based on dynamic load model representation modeled in Change Case 3

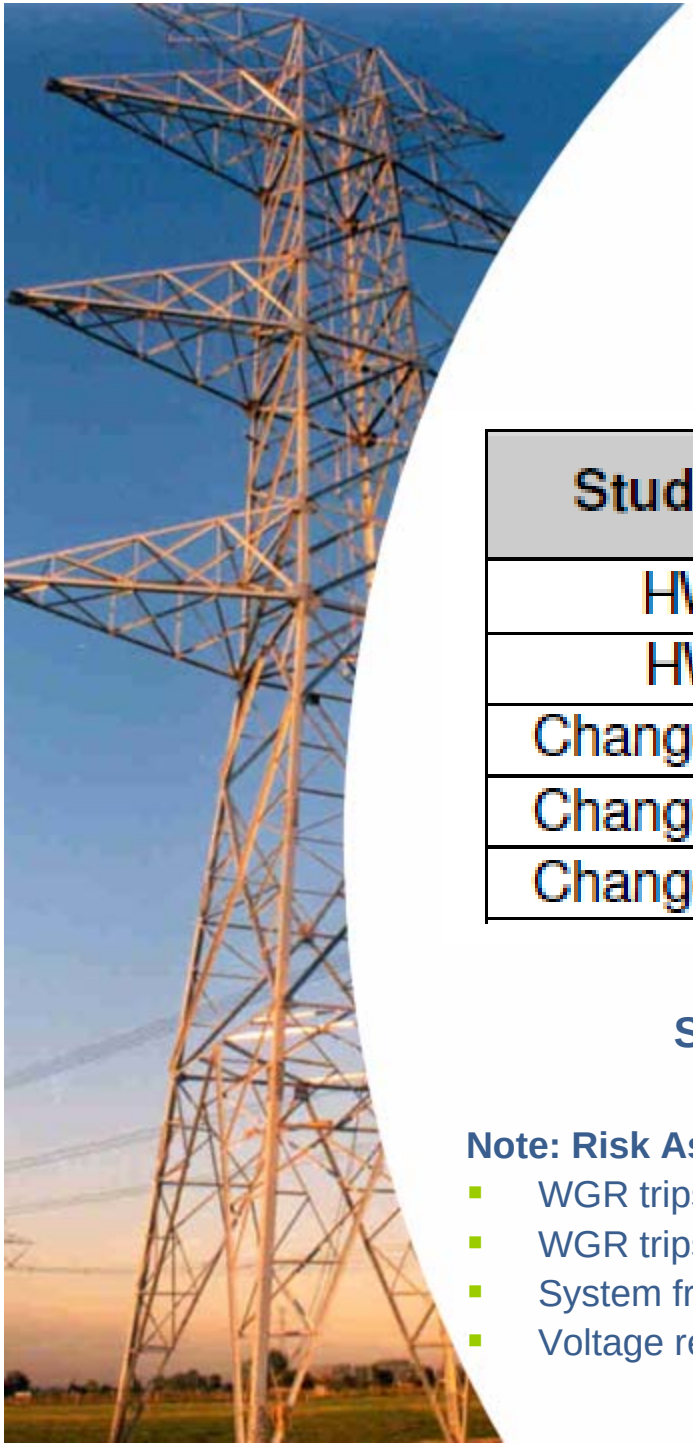
Results – Change Case 4

- Impact of low pre-fault WGR terminal voltages
  - WGR pre-fault terminal voltages lowered
  - Transmission bus voltage maintained within acceptable limits
  - WGRs with no VRT capability focused upon
  - Most severe events for HWHL/HWLL, Change Cases 1 through 3 assessed



Results – Change Case 4

- Impact of low pre-fault WGR terminal voltages
  - Lower pre-fault terminal voltages impact WGRs at margin
  - Impact observed to be more profound for Change Cases 1 & 3
    - Lack of conventional voltage support
  - No reliability risks observed for any of the simulated events by virtue of incremental WGR trips



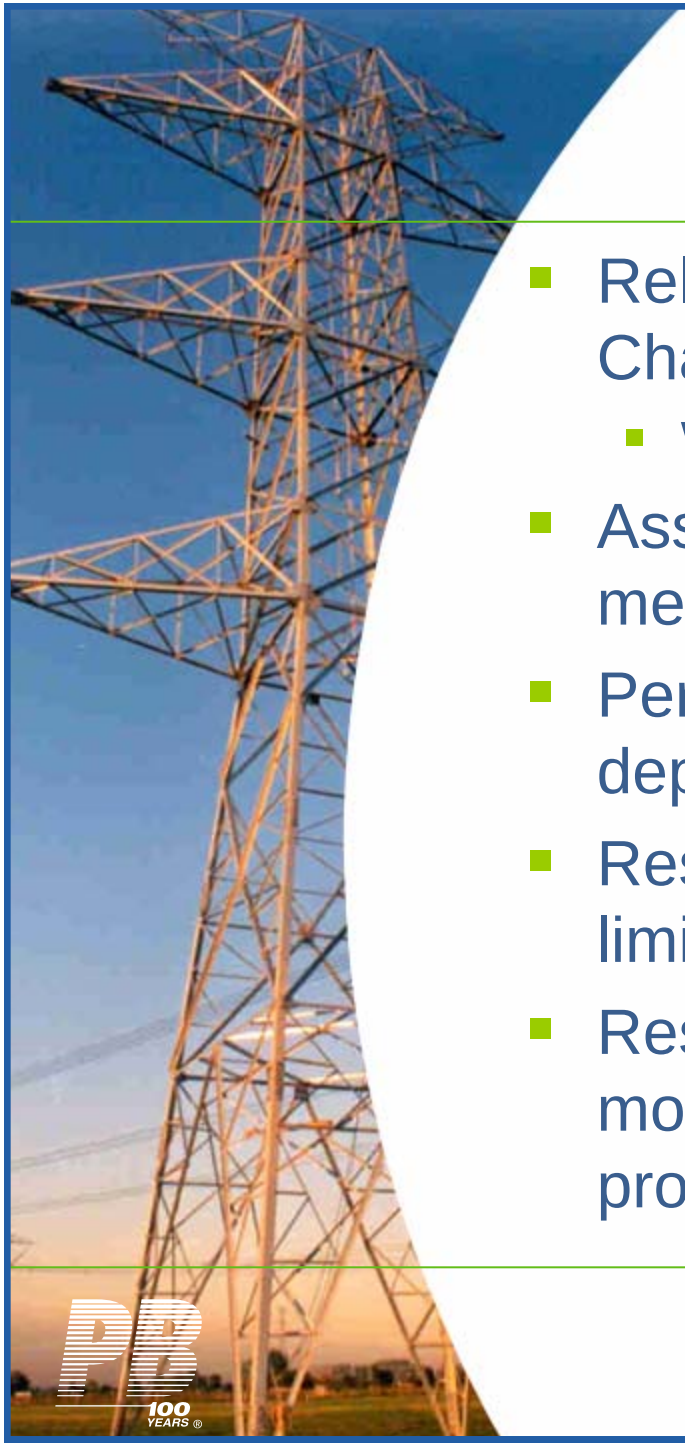
Conclusions

Study Case	Normal Clearing	Breaker Failure
HWHL	No Risk	No Risk
HWLL	No Risk	No Risk
Change Case 1	No Risk	No Risk
Change Case 2	No Risk	No Risk
Change Case 3	Voltage Stability	No Risk

Summary of Reliability Risks – ERCOT VRT Study

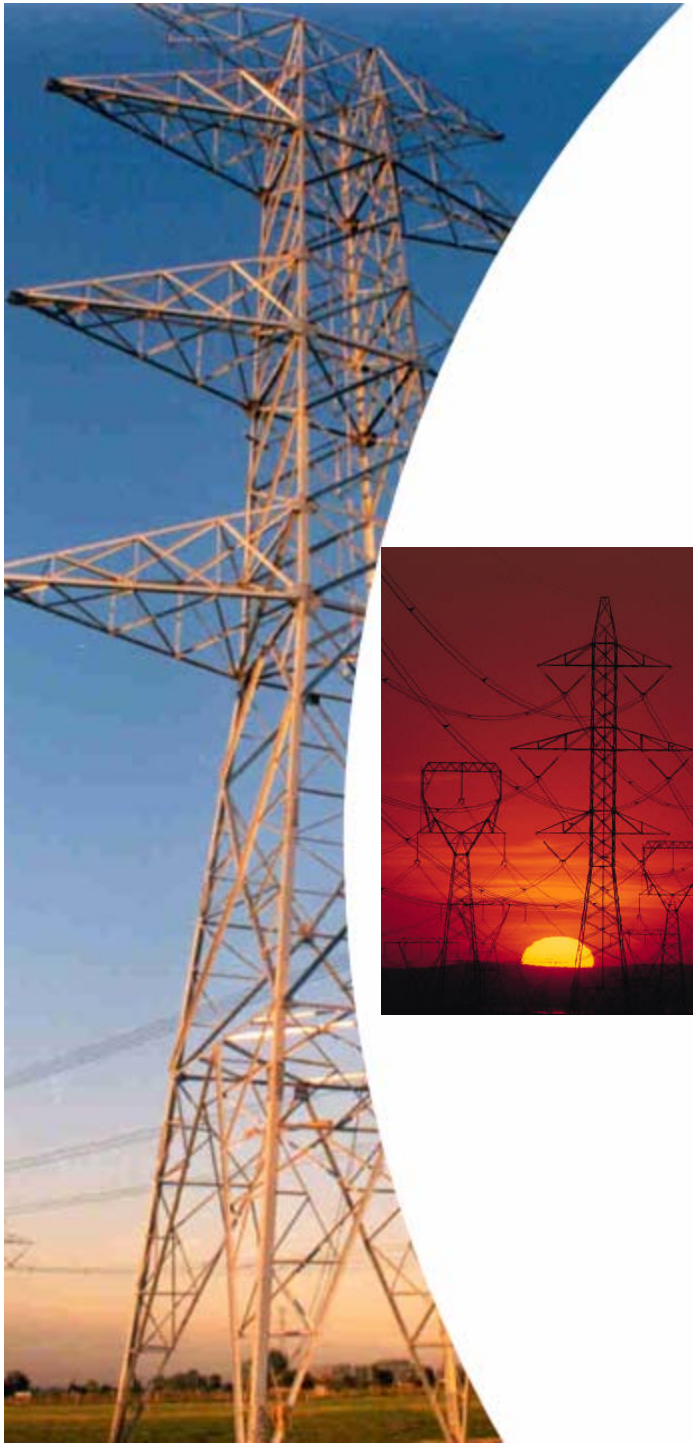
Note: Risk Assessment is based on the reliability metrics used for this study

- WGR trips as per case dispatch vis-à-vis ERCOT RRS requirement (2300 MW)
- WGR trips as per WGR capacity vis-à-vis ERCOT RRS requirement (2300 MW)
- System frequency response & post-event frequency deviations
- Voltage recovery & post-event voltage levels



Conclusions

- Reliability risk associated with CTG5 for Change Case 3
  - West-North Voltage stability limit the primary cause
- Assessment of reliability risks based on metrics outlined in discussion with ERCOT
- Performance of Change Cases 2 & 3 dependent on dynamic load models
- Results based and dependent on PSS/E limitations, if applicable
- Results of study do not indicate a need to modify the ERCOT VRT requirements provided by Operating Guide 3.1.4.6.1



Questions

PB Team