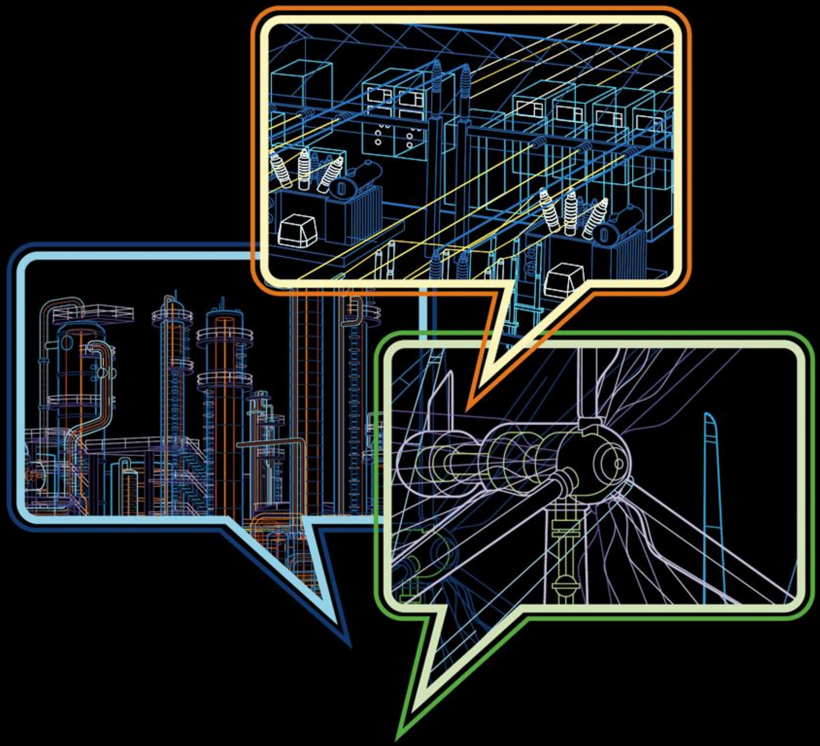

ABB Automation & Power World: April 18-21, 2011

Dynamic Studies for Large Scale Renewable Energy Integration

ERCOT CREZ Case Study

CPS-109-1

Dynamic Studies for Large Scale Renewable Energy Integration

ERCOT CREZ Case Study

- Speaker name: Don Martin
- Company name: ABB Grid System Consulting
- Location: Raleigh, NC

- Speaker name: Ken Donoho
- Company name: ONCOR
- Location: Dallas, TX

Your safety is important to us
Please be aware of these emergency procedures

- In the event of an emergency please dial ext. 55555 from any house phone. Do not dial 9-1-1.
- In the event of an alarm, please proceed carefully to the nearest exit. Emergency exits are clearly marked throughout the hotel and convention center.
- Use the stairwells to evacuate the building and do not attempt to use the elevators.
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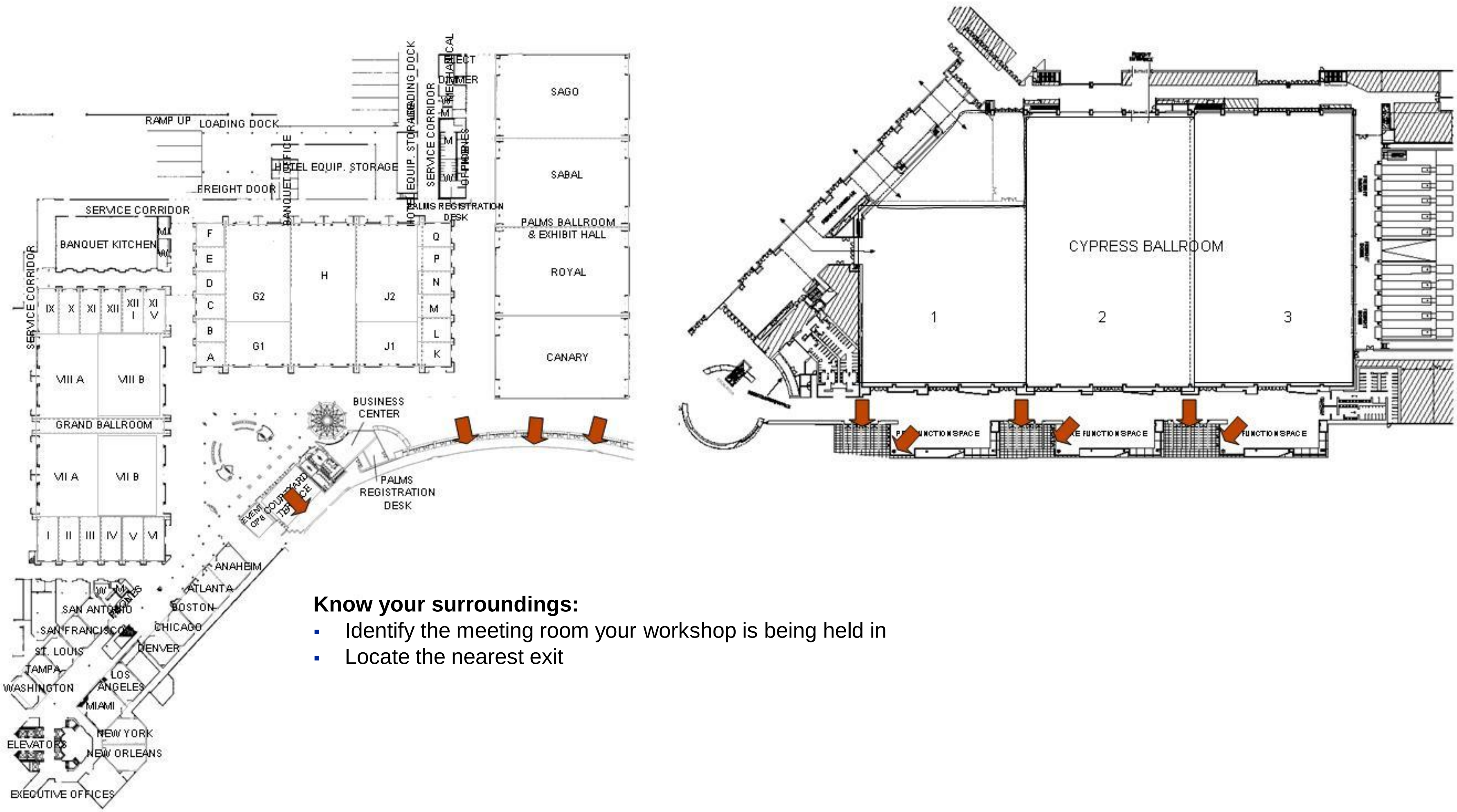
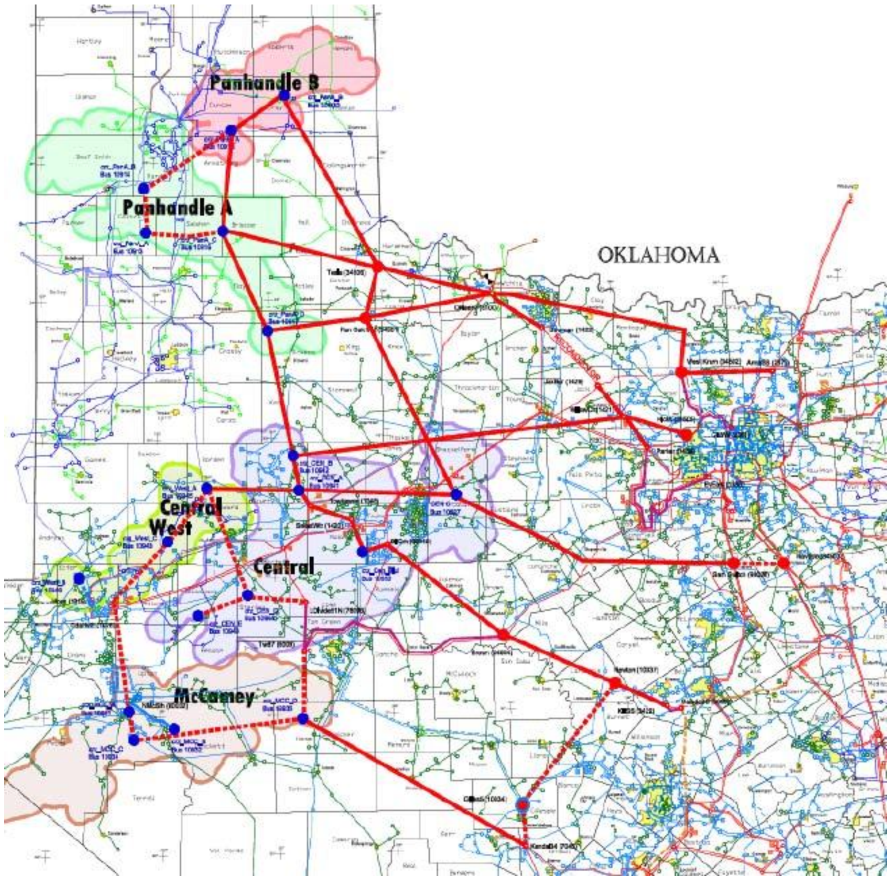
Your safety is important to us
Convention Center exits in case of an emergency



Know your surroundings:

- Identify the meeting room your workshop is being held in
- Locate the nearest exit

ERCOT CREZ Reactive Study Overview

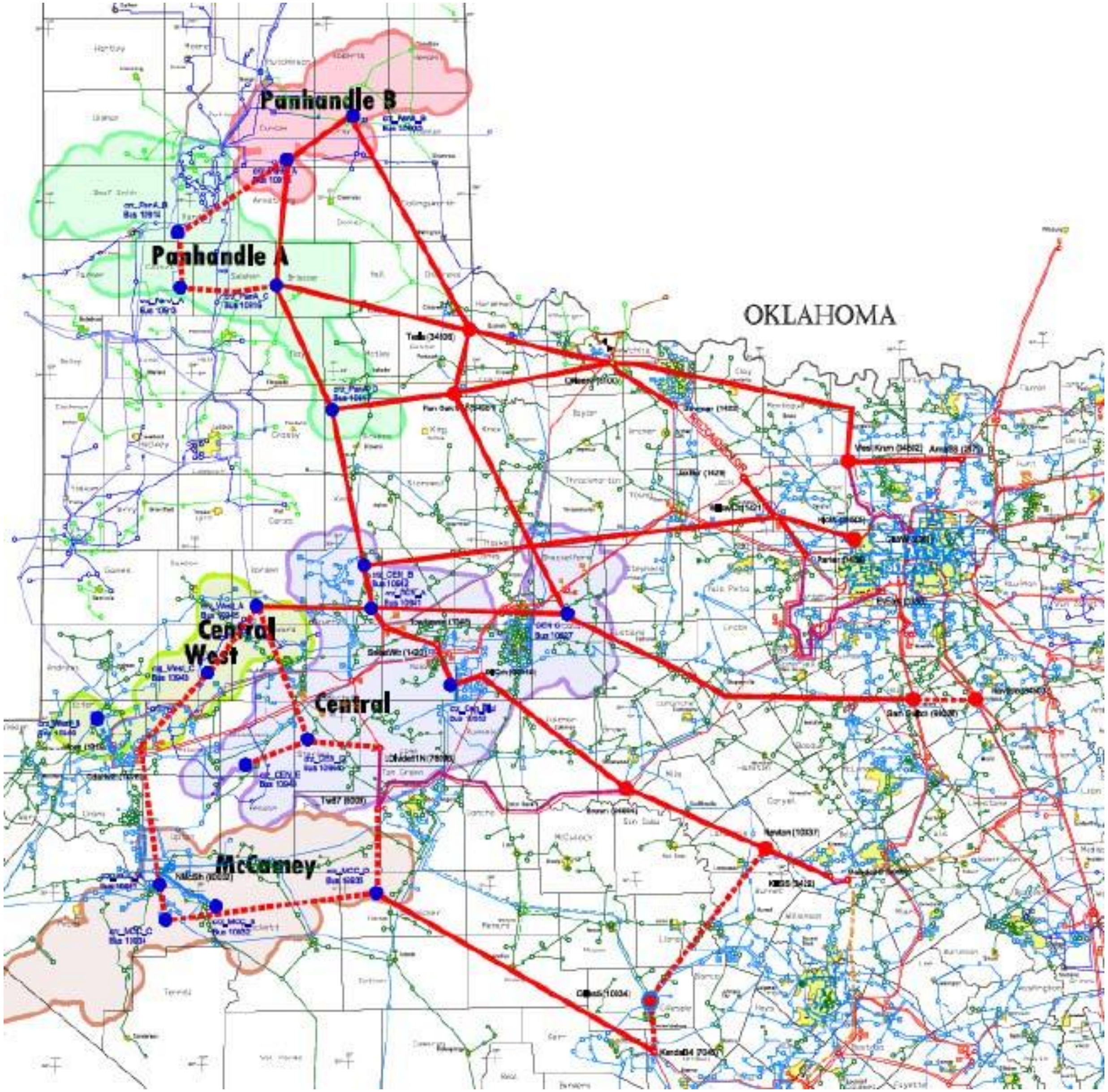


- A large-scale, complex study to determine the reactive compensation needs for the CREZ transmission
- Both shunt and series reactive compensation considered
- Ambitious goals and schedule
- Excellent support from ERCOT and the Transmission Service Providers

CREZ 345-kV System

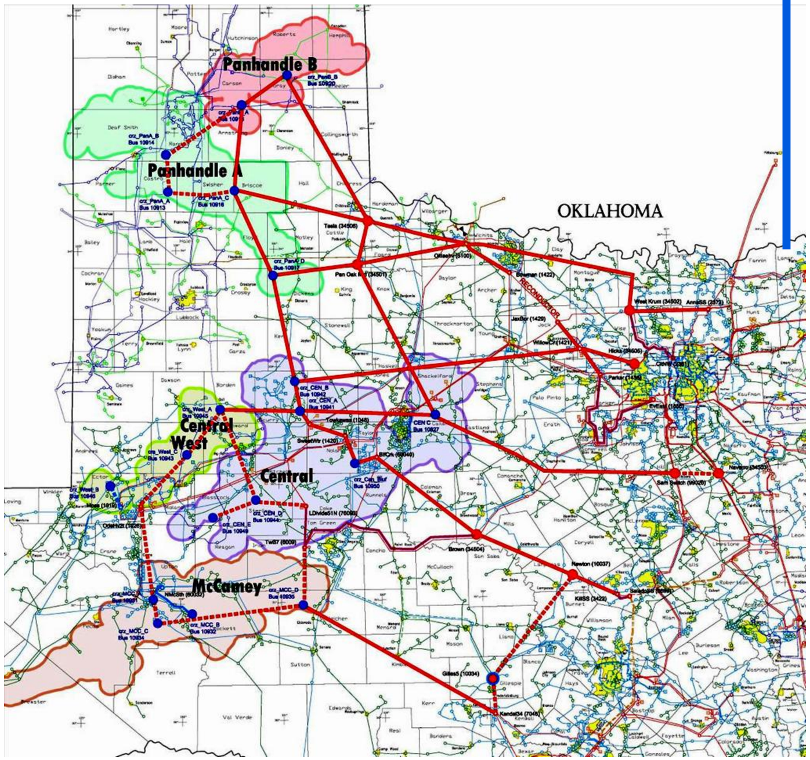
Double Ckt

Single Ckt



ERCOT CREZ Reactive Study Overview

- **The PUCT-selected plan includes**
  - **Long 345kV AC circuits (mostly double circuits) with the sole purpose of integrating the proposed asynchronous generation**
  - **Nine circuits were designed with 50% series compensation**
  - **“Place holder” shunt compensation were included in the plan, with a recommendation for additional study**
- **Study objectives**
  - **Verify or correct ratings and percentage of proposed series compensation**
  - **Identify size, type and location of additional reactive devices required to control system voltages and maintain dynamic stability**
  - **Identify stability-related issues**

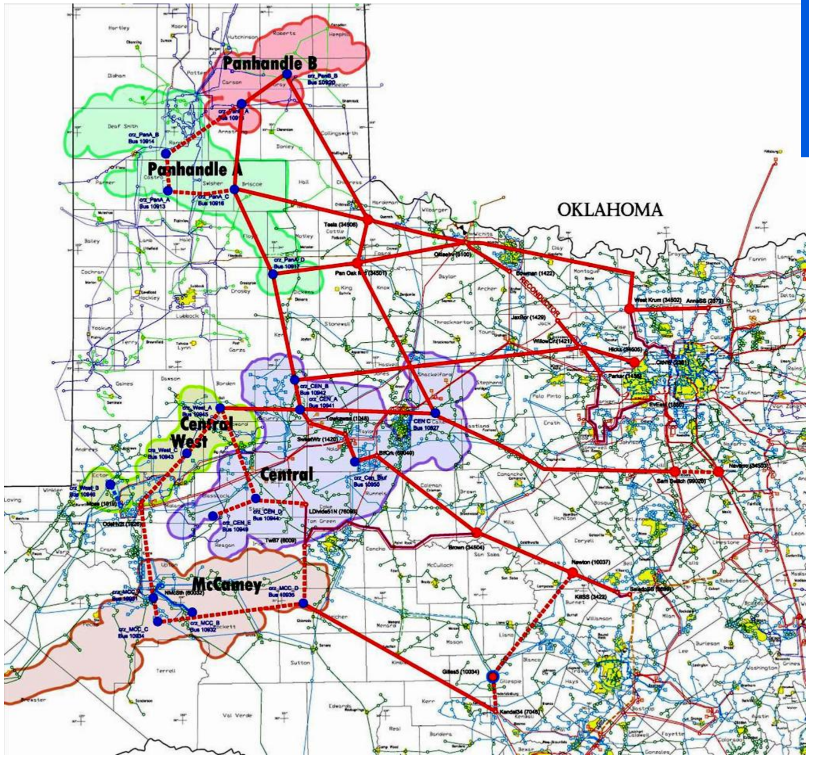


CREZ 345-kV System

ERCOT CREZ Reactive Study Results

Results for Initial Wind of 16,200 MW

- **Study plan modifications included:**
  - **New 345-kV Substation with 8 lines by looping in 4 lines – Needed for dynamic stability performance**
  - **Ultimately 12 circuits were designed with 50% series compensation**

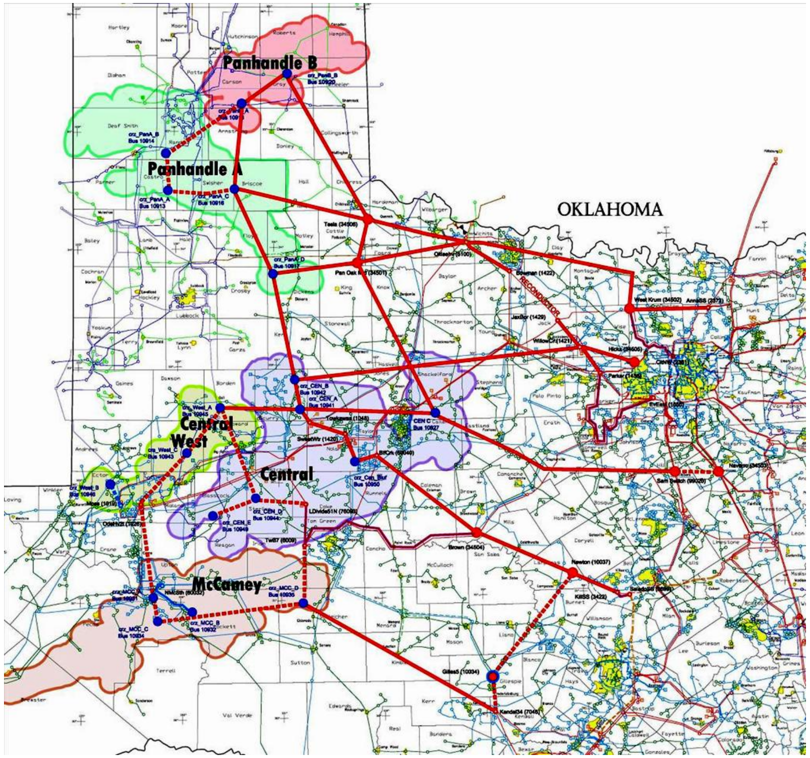


- **Study Results Identified:**
  - **3,930 MVARS Shunt Reactors**
  - **1,860 MVARS of Shunt Capacitors**
  - **Total SVC capacity of +1,400 MVARS / -450 MVARs**

ERCOT CREZ Reactive Study Results

Results for Ultimate Wind of 20,375 MW

- **Study plan modifications included:**
  - **Synchronous Condensers to increase short circuit strength in Panhandle in order to operate wind turbines (2 x 350 MVA)**
- **Study Results Identified:**
  - **276 Additional MVARS of Shunt Capacitors**
  - **Additional SVC capacity of +3,900 MVARS / -1,300**



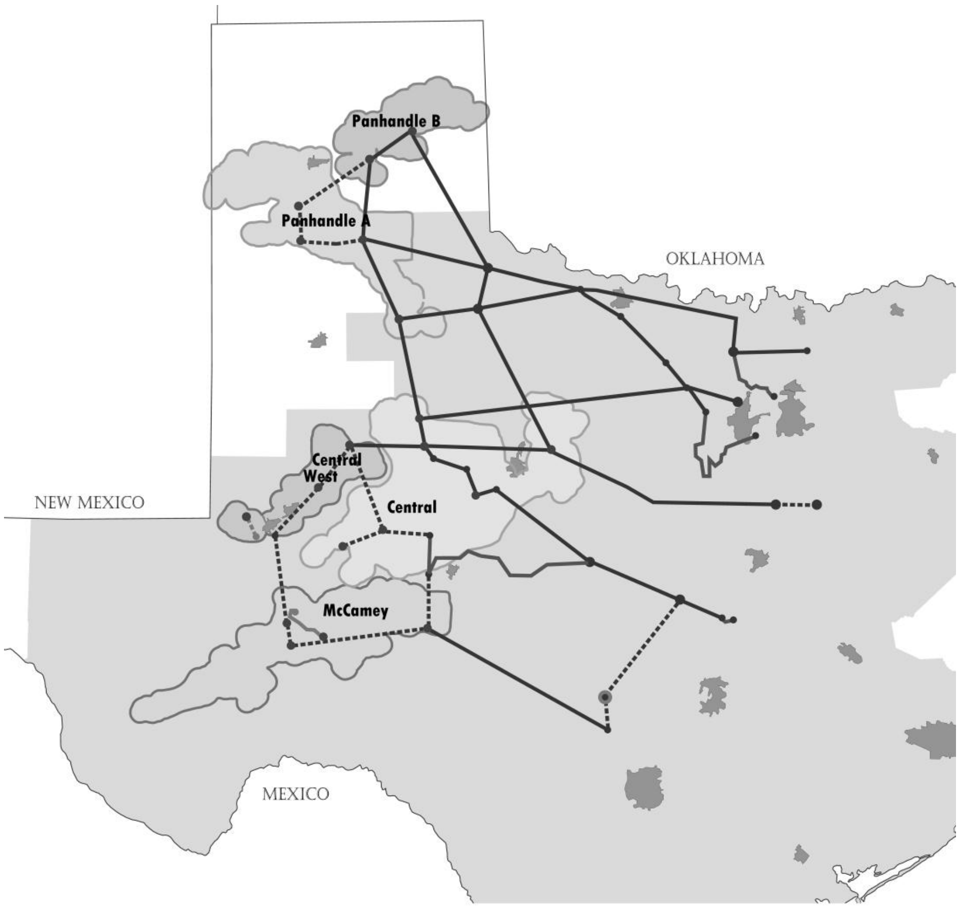
ERCOT CREZ Reactive Study Results

SUMMARY OF REACTIVE POWER REQUIREMENTS

	TOTAL REQUIREMENT		
	Min Export	Initial Build	Max Export/Edison
Series Capacitor	50% - 12 Lines	50% - 12 Lines	50% - 12 Lines
Shunt Reactors	3930 MVArs	3930 MVArs	3930 MVArs
Shunt Capacitors	0	860 MVARs	1136 MVARs
SVCs or STATCOMs:	0	1400 MVARs	5300 MVArs
Synchronous Condensers	0	0	700 MVA

CREZ Reactive Power Study Results

- **To address the study objectives several areas were evaluated including**
  - **Coordinate System Performance Criteria**
  - **Fundamental frequency concerns**
    - **Conventional powerflow**
    - **Optimal powerflow**
    - **Dynamic stability**
    - **Chronological loading analysis**
  - **Sub-synchronous concerns**
    - **SSI (wind generators and series capacitors)**
    - **SSR (thermal generators and series capacitors)**
    - **SSTI (thermal generators and dynamic shunt VAR sources)**

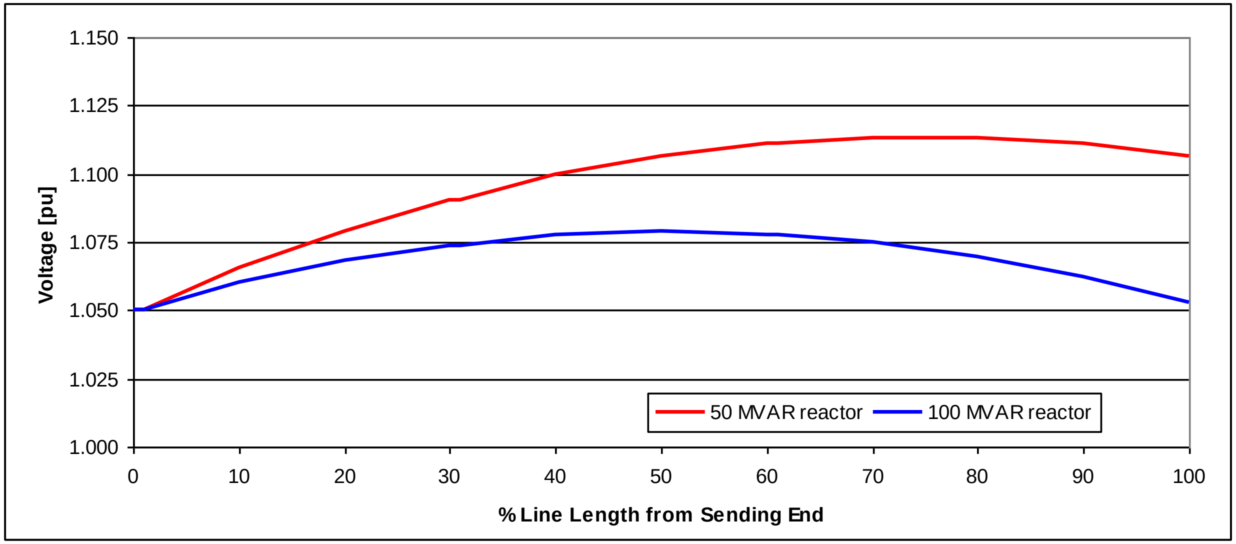


ERCOT CREZ Reactive Study Results

SYSTEM SHUNT LINE REACTOR REQUIREMENTS FOR ENERGIZING LINES

1. Lines between 140 miles and 200 miles a 50 MVAr shunt line reactor will be needed to limit the line voltage to less than 1.10 pu at the open end.

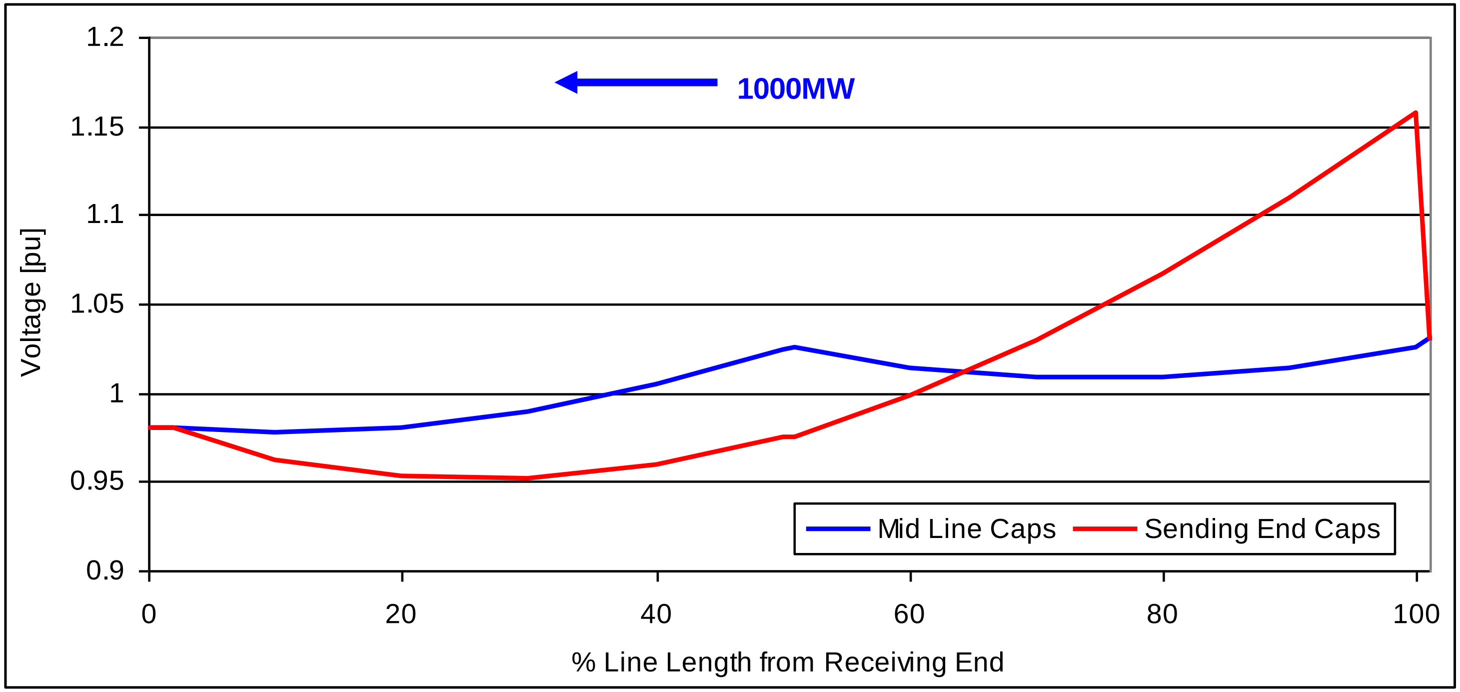
2. Lines over 200 miles a shunt reactor of 100 MVARs will be required to limit the line voltage to 1.10 pu.



Line voltage profile for 215 mi. line, 50 or 100 MVAr reactor at open end

ERCOT CREZ Reactive Study Results

LINE VOLTAGE PROFILES TO ASSIST IN OPTIMUM LOCATION FOR SERIES CAPACITORS



LINE VOLTAGE PROFILES FOR LINES WITH SERIES CAPACITORS AT THE END AND MIDDLE OF A LINE

ERCOT CREZ Reactive Study Results

REQUIREMENTS FOR RATING THE SERIES CAPACITOR BANKS

- **Rated capacitor reactive impedance (ohms)**
- **Continuous capacitor current requirements (amperes)**
- **30 minute overload current requirements (amperes)**
- **Maximum swing current following system disturbances**
- **Maximum fault current for external faults**
- **Maximum fault current for internal faults**

ERCOT CREZ Reactive Study Results

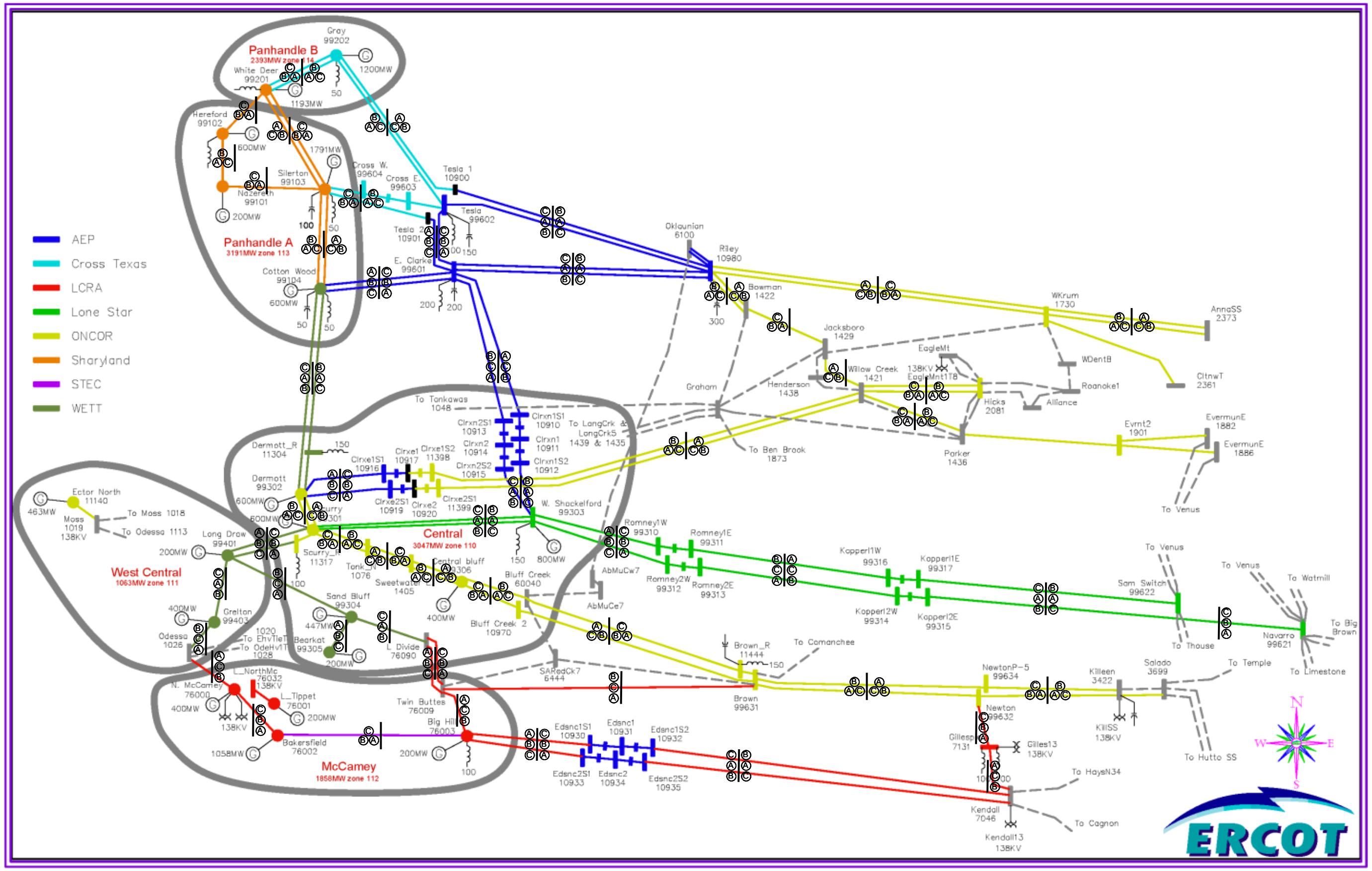
REQUIREMENTS FOR RATING THE SHUNT CAPACITOR BANKS AND REACTOR BANKS

- **Largest MVAR that can be switched at each station**
- **Estimate of number of switching (breaker open and close) operations per year**

ERCOT CREZ Reactive Study Results

SYSTEM UNBALANCE SIMULATIONS

- **Voltage Unbalance**
- **Negative Sequence Generator Currents**



ERCOT CREZ Reactive Study Results

DYNAMIC SHUNT REACTIVE POWER

- **SVC and STATCOM both can provide the needed dynamic MVARs**
- **General evaluation modeled units of +300 / -100 MVAR SVC**
- **Dynamic MVARs identified to prevent voltage collapse following faults and loss on lines**

ERCOT CREZ Reactive Study Results

SHORT CIRCUIT REQUIREMENTS

- **For high wind generation, control oscillations occurred in the WTG models in the Panhandle areas**
- **WTGs have minimum short circuit operating levels and may vary with type and manufacturer**
- **Study solutions was to add two 350 MVA synchronous condensers**
  - **Sync Condenser can use some MVAR for steady-state reactive power control**
  - **Sync Condenser can reserve some MVAR for dynamic voltage recovery**

CREZ Reactive Power Study Results

- **To address the study objectives several areas were evaluated including**
  - **Coordinate System Performance Criteria**
  - **Fundamental frequency concerns**
    - **Conventional powerflow**
    - **Optimal powerflow**
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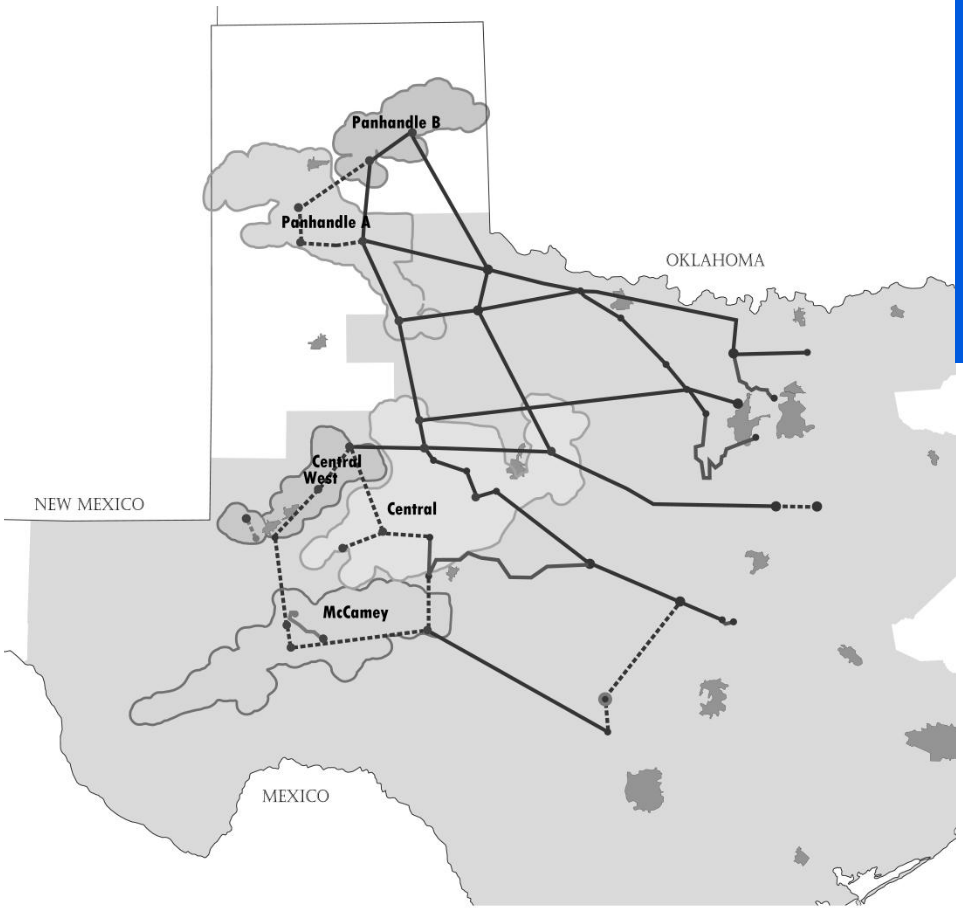
    - **SSTI (thermal generators and dynamic shunt VAR sources)**



CREZ Reactive Power Study

Subsynchronous Interactions

Sub-synchronous concerns

- **SSI - wind generators (4 types) and series capacitors**
  - **Type 1 Induction Generator**
  - **Type 2 Variable Resistor Induction Generator**
  - **Type 3 Doubly Fed Induction Generator (DFIG)**
  - **Type 4 Full Back-to-back Converters**

CREZ Reactive Power Study

Subsynchronous Interactions

SSI with each type of wind generators with series capacitors

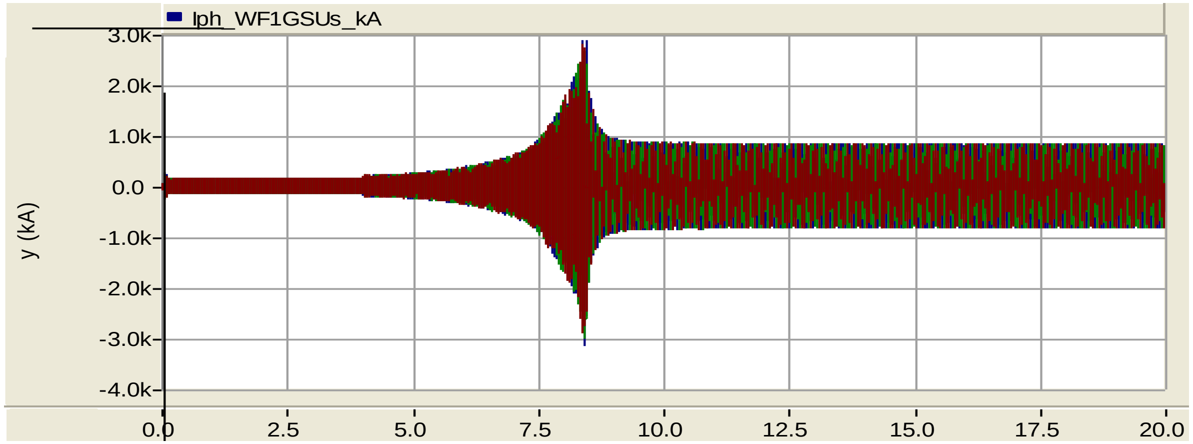
- Classical self-excitation of induction machines possible for Type 1 and Type 2 machines near series-compensated lines
- Type 3 machines near series-compensated lines found to be quite sensitive to subsynchronous interactions.
- Type 4 machines not found in this study to have issues

ERCOT CREZ Reactive Study Results

SUMMARY OF SSI

Problems for WTG Type 1 on CREZ System – Self Excitation

- **Series Capacitors Inserted into the Radial Low Resistance System at 4.0 seconds**

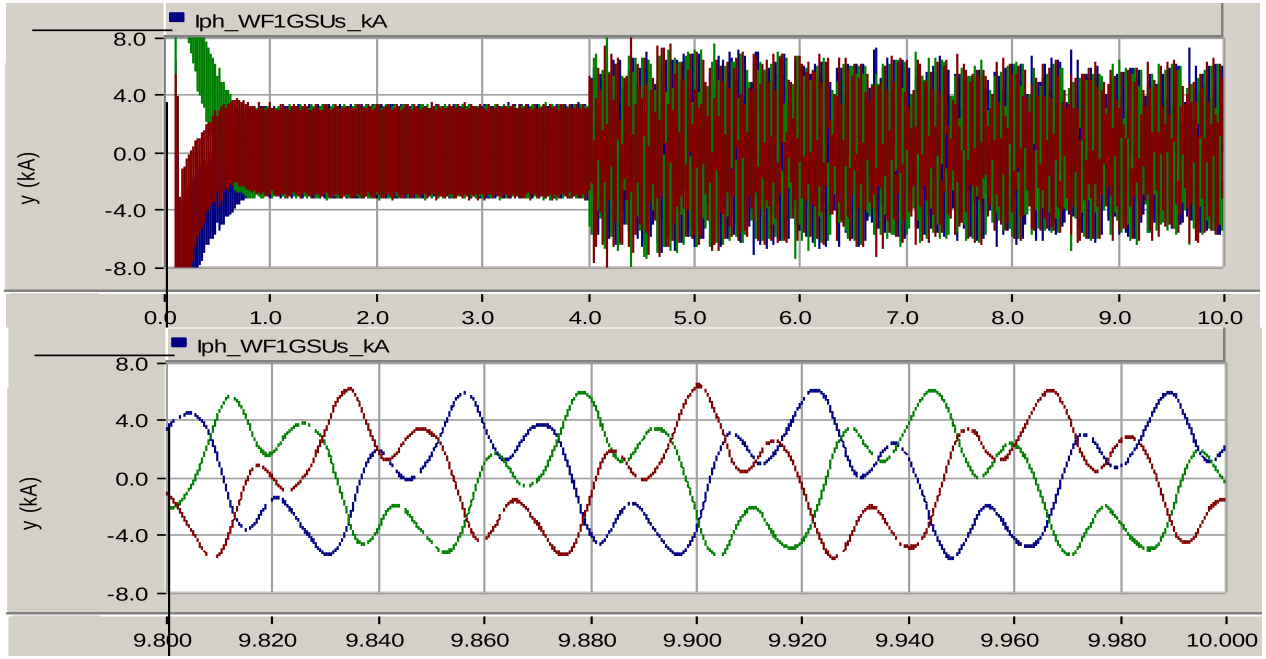


ERCOT CREZ Reactive Study Results

SUMMARY OF SSI

Problems for WTG Type 3 on CREZ System – Control Interaction

- **Series Capacitors Inserted into the Radial System at 4.0 seconds**



ERCOT CREZ Reactive Study Results

SUMMARY OF SSI

Problems for WTG Type 3 on CREZ System

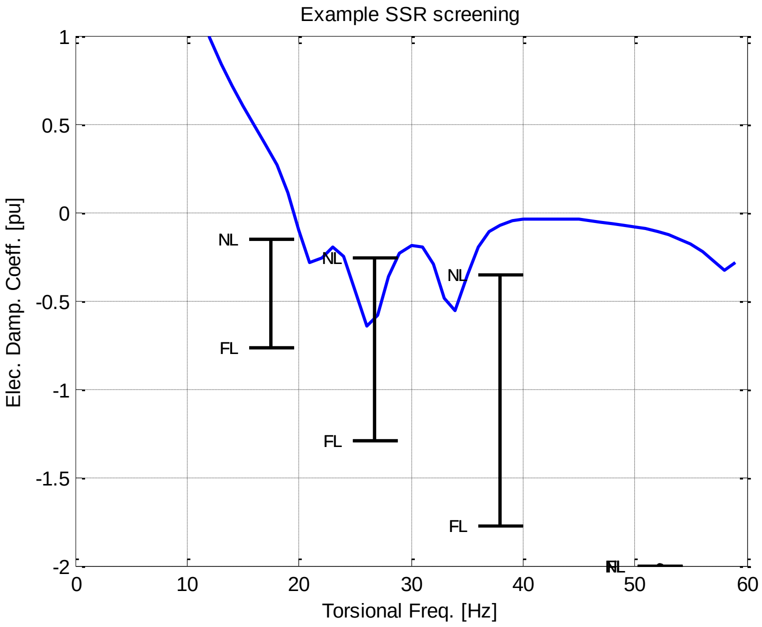
- SSI at one site with no contingencies
- SSI at one site with one uncompensated line out
- SSI at one site with loss of the double circuit lines to Scurry

ERCOT CREZ Reactive Study Results

SUMMARY OF SSR with Thermal Units

Completed SSR Screening Study

- Calculated subsynchronous damping from 1 – 60 Hz
- Identified negative damping modes and frequency of negative modes
- Compare negative modes with generator shaft modes



ERCOT CREZ Reactive Study Results

SUMMARY OF SSR with Thermal Units

SSR Screening Study Results

- Three generating station may begin to see initial indications of SSR with 4 or more outages.
- One generating station has initial indications with 2 or more outages
- Some locations may have negative damping but torsional modes of the units must be checked to verify whether resonances may be an issue

ERCOT CREZ Reactive Study Results

SUMMARY OF SSI

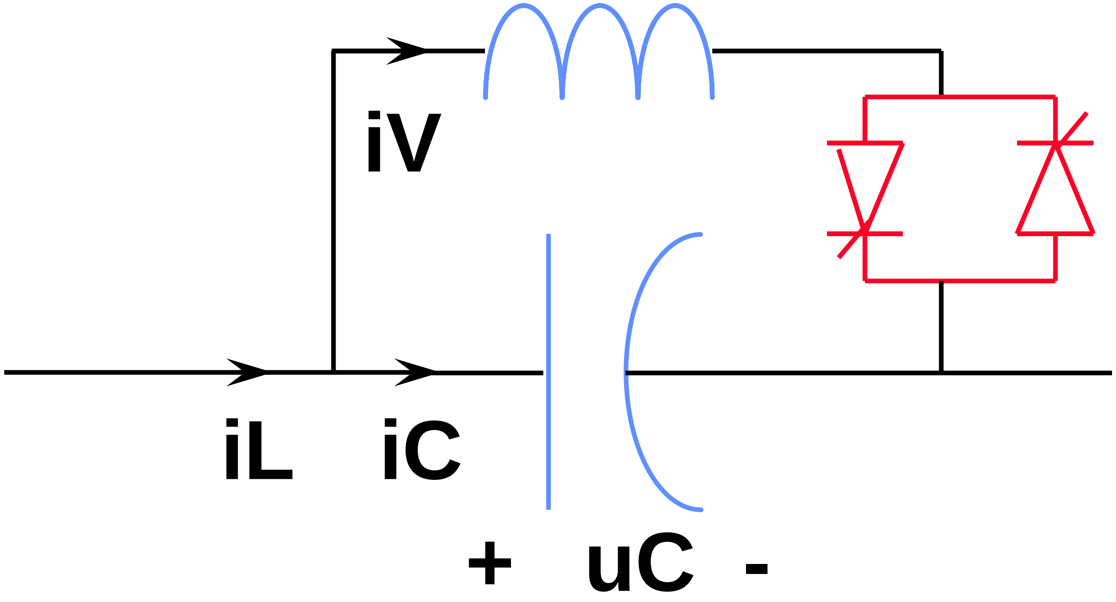
Transmission Solutions for SSI and SSR

- TCSC
- Preventive Bypass Filter
- Modify WTG Controls

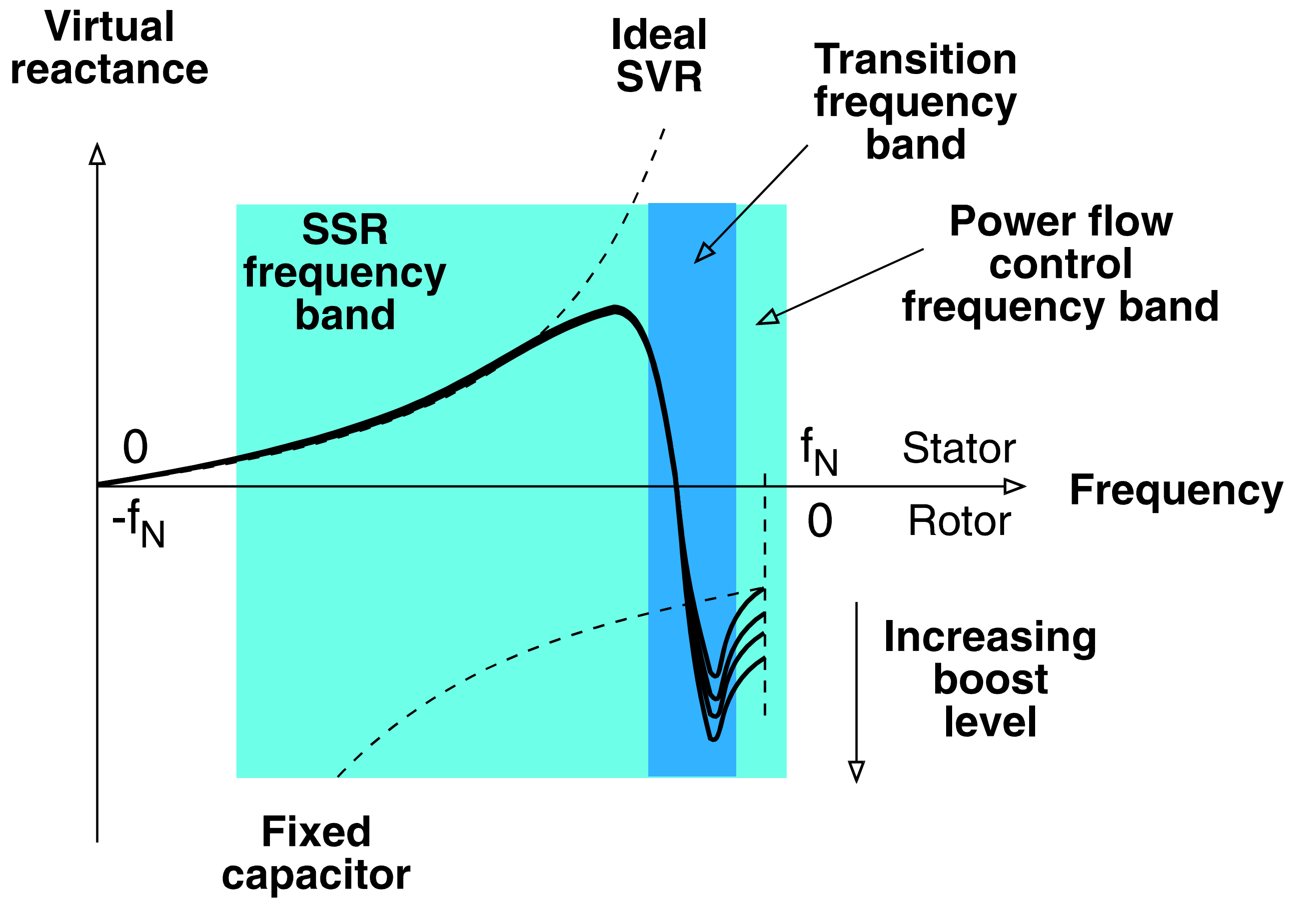
ERCOT CREZ Reactive Study Results

Thyristor Controlled Series Capacitor (TCSC)

- Thyristor fires with controlled timing
- Current circulates to “boost” capacitor voltage
- Larger effective capacitance at fundamental frequency

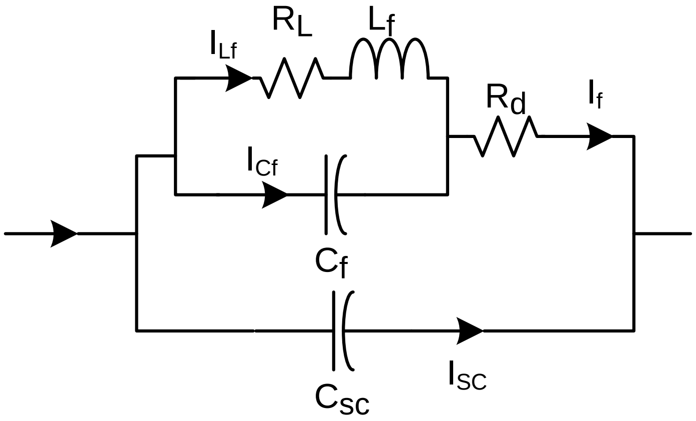


ERCOT CREZ Reactive Study Results
TCSC impedance characteristics



ERCOT CREZ Reactive Study Results

Preventive Bypass Filter was simulated



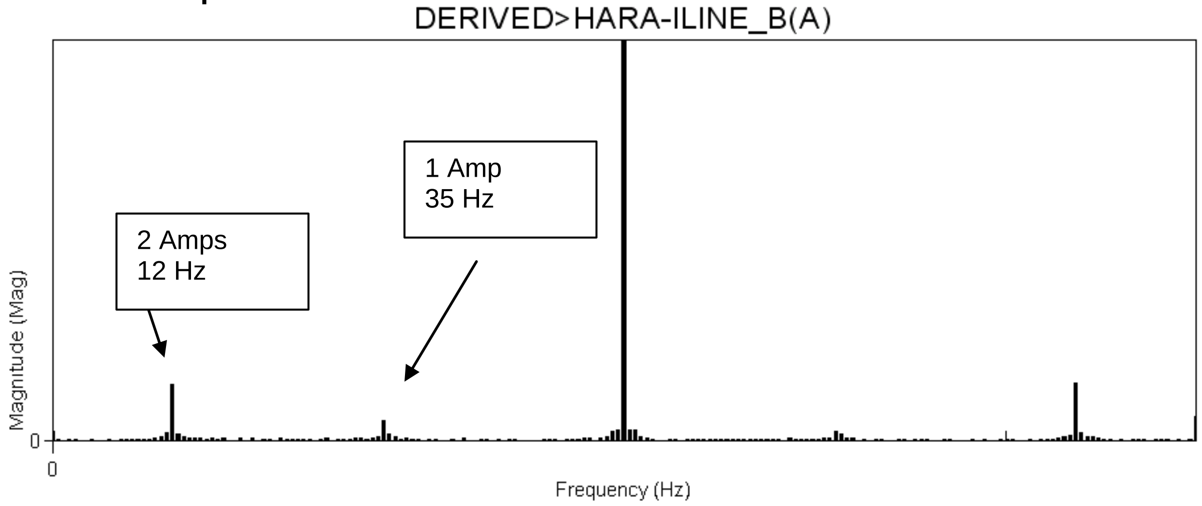
- Developed solution to damp SSI
- Technical feasibility not completely demonstrated and cost to be high

ERCOT CREZ Reactive Study Results

Control modifications was not simulated – proprietary manufacturer

Test results of a wind farm with modified controls shown below

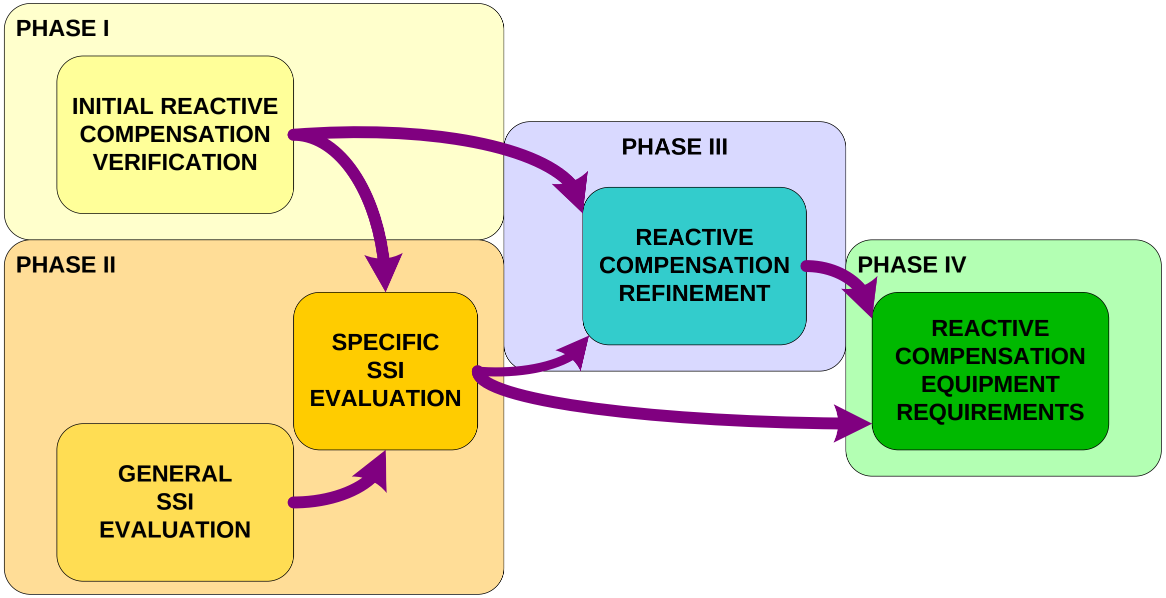
Scale: 10 Amps and 120 Hz



Testing for SSI for a Type 3 DFIG Wind Farm with Modified controls

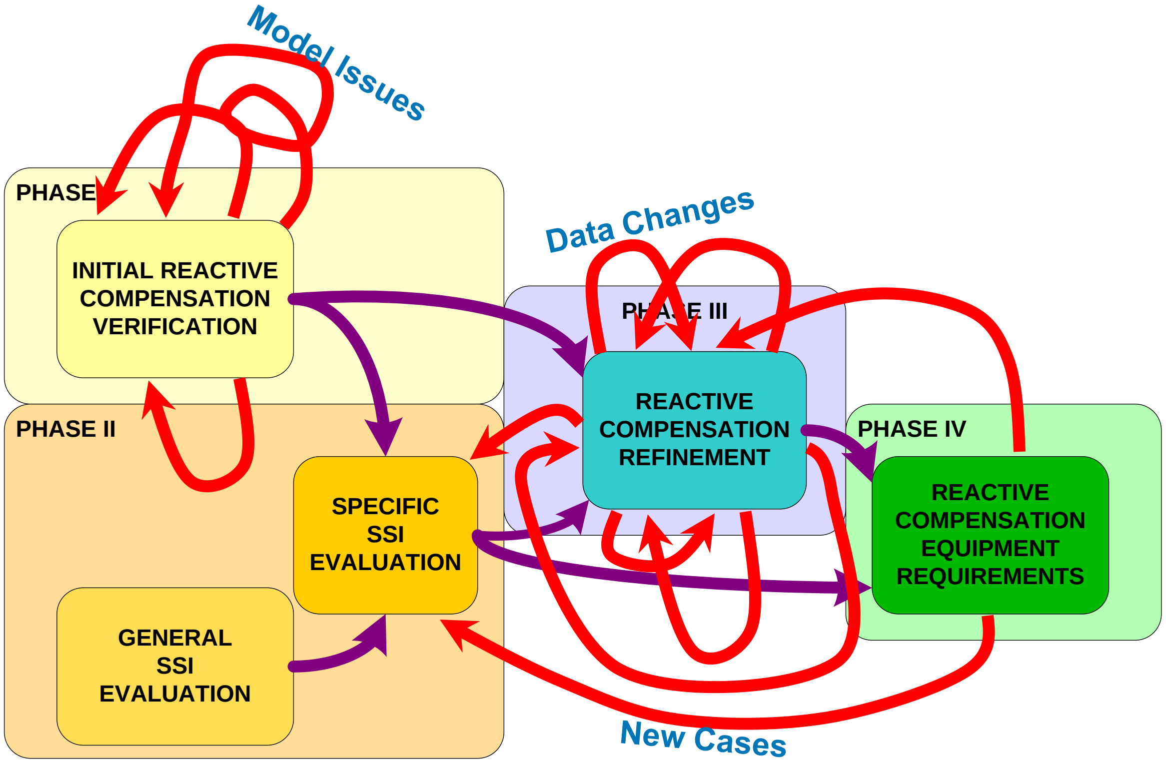
ERCOT CREZ Reactive Study
General Plan

- Address scope in four phases
  - I – Initial reactive compensation verification
  - II – Sub-synchronous Interaction (SSI) evaluation
  - III – Reactive compensation refinement
  - IV – Finalize and compile equipment requirements



ERCOT CREZ Reactive Study
General Appearance

- Address scope in four phases
  - I – Initial reactive compensation verification
  - II – Sub-synchronous Interaction (SSI) evaluation
  - III – Reactive compensation refinement
  - IV – Finalize and compile equipment requirements



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Automation & Power World 2011

- Please be sure to complete the workshop evaluation
- Professional Development Hours (PDHs) and Continuing Education Credits (CEUs):
  - You will receive a link via e-mail to print certificates for all the workshops you have attended during Automation & Power World 2011.
  - BE SURE YOU HAVE YOUR BADGE SCANNED for each workshop you attend. If you do not have your badge scanned you will not be able to obtain PDHs or CEUs.

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