

ERCOT CREZ Project

- Perspectives on U.S. Transmission Infrastructure and Renewable Energy Integration Projects;
- CREZ Reactive Study and Technology Overview

ERCOT CREZ Project Conference
Tuesday, January 26, 2009
Taylor, Texas

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Outline

Electric Power & Energy Industries

- Brief Overview: Challenges and Opportunities
- The Role of Transmission System Infrastructure

Comparison of CREZ to U.S. Transmission Projects

- Large U.S. Transmission System Infrastructure Projects
- Transmission Projects for Renewable Energy Integration

Aspects of CREZ Reactive Study and Status Up-date

- Study Progress To-Date
- Remaining Challenges

Series and Shunt Compensation

- Brief Overview: Technology and Applications

Summary, General Comments, and Perspectives

Electric Power & Energy Industries

Electric Power & Energy Industries

A “Perfect Storm” Environment



Challenges and Opportunities

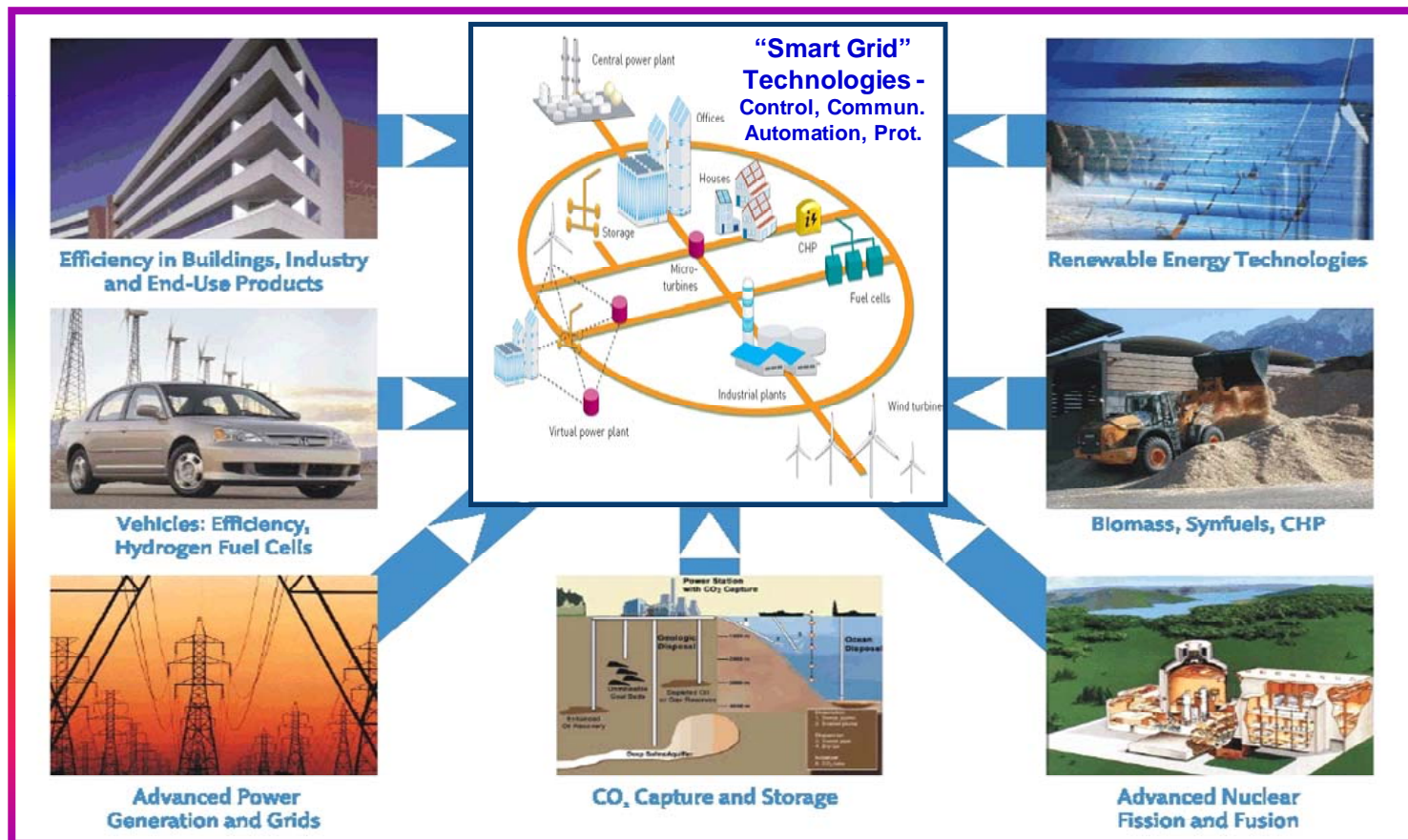
Technology, Infrastructure, R&D, Policy, Workforce, and Education

- Integration of renewable energy resources such as wind, wave, solar, biomass, and geothermal – i.e., going Green;
- Expansion and enhanced reliability of the electric power grid;
- Development of smart grid systems and energy storage technologies;
- Advancement of the nuclear renaissance and clean-coal technologies;
- Growth of transportation electrification – i.e., hybrid/electric vehicles;
- Impacts of global warming and carbon capture & sequestration;
- Effects of government policy, economics, and market drivers;
- Evolution of energy efficiency and demand side management;
- Need for workforce development, training, and education
- To name just a few!!

How we meet these challenges in the decades ahead will have imperative societal, environmental, economic, and global implications; and will set the course of energy sustainability for future generations.

Future Development Trends

Smart Grid Technologies for Enhanced Energy Efficiency and Renewable Energy Integration



Comprehensive Strategies are Needed

Renewable Energy Generation and Transmission Infrastructure Expansion are Critical Elements of an Emerging Balanced Energy Portfolio Nationwide

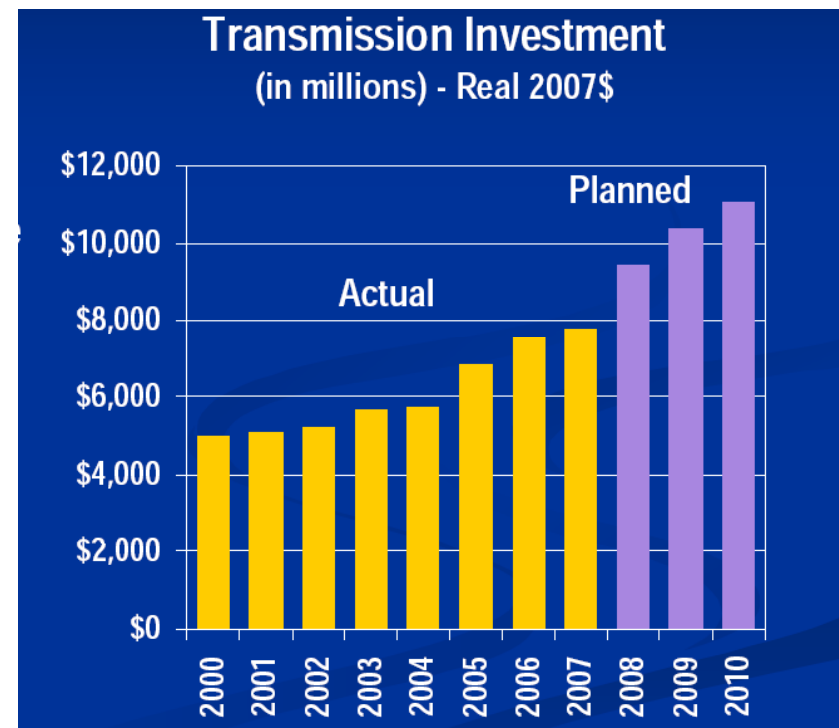
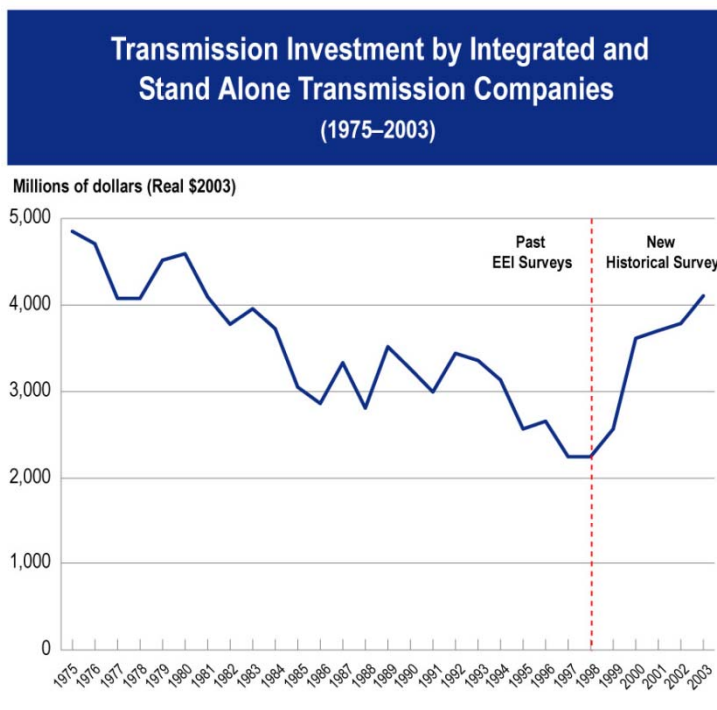


Comparison of CREZ to Other Major U.S. Transmission Projects

Major U.S. Transmission System Investment

History and Present Market Environment

- Under-investment in T&D from 1970's through 1999
- Increasing investment trend from 1999 through present



Major U.S. Transmission System Projects

Major Project Criteria

- Minimum investment of \$20 million; 100 kV or higher
- Projects completed, underway, or proposed from 2007 to 2022 (2 yr. backlog, 15 yrs. Forward)

63 Projects Nationwide

- 7 Projects in excess of \$1.0 Billion (project estimates)
- Total est. project costs = \$17.5 Billion
- Largest at \$3.0 Billion and 1,000 miles of transmission (APS TransWest Express)

Source: EEI, Transmission Projects: At-a-Glance, January 2008

Major Transmission for Renewable Energy

Major Project Criteria

- Minimum investment of \$20 million; 100 kV or higher
- Projects to be completed by 2015

Projects specifically in support of:

- Solar, Wind, Geothermal and Biomass renewable energy

34 Projects Nationwide

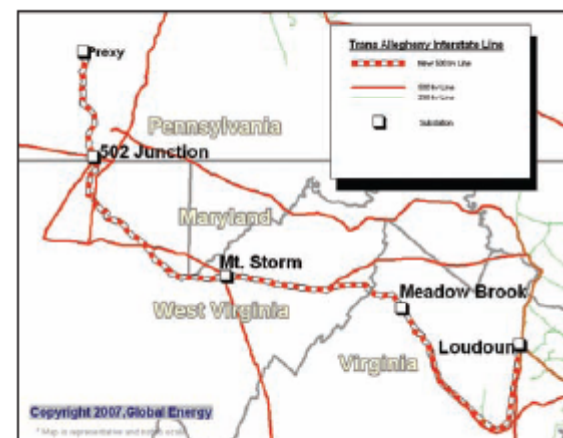
- 13 projects in excess of \$500 Million (project estimates)
- Total est. project costs = \$20.7 Billion
- Largest at \$3.0-\$7.0 Billion / 1,000 miles of transmission (PG&E California – Pacific Northwest Project)

Source: EEI, Transmission Projects Supporting Renewable Resources, February 2009

Allegheny Power / Dominion TRAIL

Project Summary

- **Project Need: Reliability and Load/Congestion Relief**
- **Voltage: 500 kV (primarily) and some 138 kV**
- **Distance: 294 miles over 3 states**
- **Cost Est.: \$1.063 Billion**



Arizona Public Service TransWest Express

Project Summary

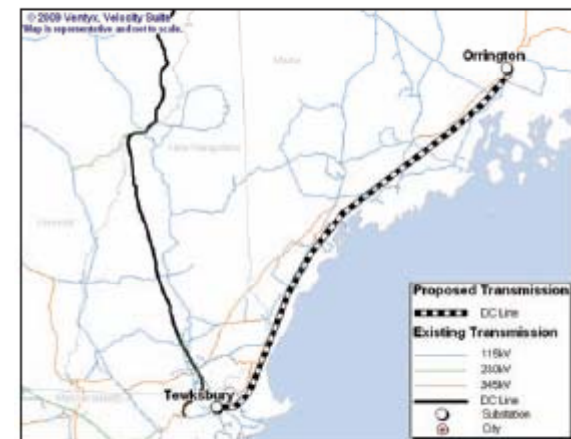
- **Project Need: Reliability, Demand Growth, and Renewable Integration**
- **Voltage: 500 kV**
- **Distance: 1,000 miles over 4 states**
- **Cost Est.: \$3.0 Billion**



National Grid Northeast Energy Link

Project Summary

- **Project Need: Renewable Energy Integration**
- **Capacity: 600 MW HVDC**
- **Distance: 220 miles**
- **Cost Est.: \$2.0 Billion**



NU/UI Middletown-Norwalk OH/UG Project

Project Summary

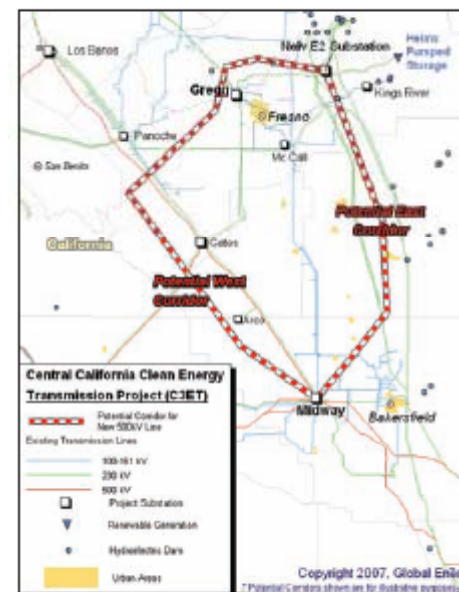
- **Project Need: Reliability and Transmission Capacity**
- **Voltage: 345 kV and 115 kV**
- **Distance: 45 miles Overhead / 24 miles Underground**
- **Cost Est.: \$1.05 Billion**



PG&E California Clean Energy Project

Project Summary

- **Project Need: Reliability, Renewable Energy Integration, Increase Path 15 Transfer, other...**
- **Voltage: 500 kV**
- **Distance: 150 miles and 500/230 kV S/S**
- **Cost Est.: \$1.0 Billion**



PG&E California Pacific Northwest Project

Project Summary

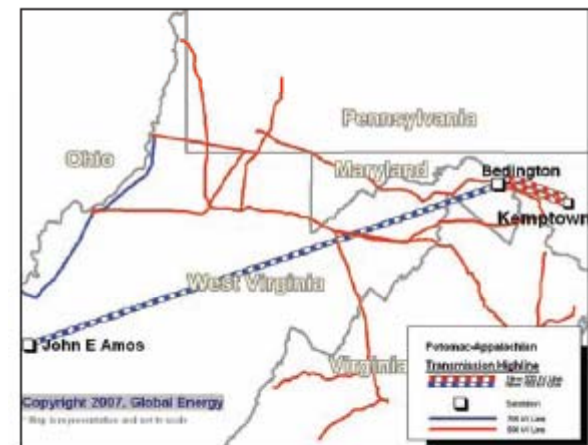
- **Project Need: Facilitate 3,000 MW of Renewable Energy Integration from BC to PN/CA**
- **Voltage: 500 kV AC and HVDC**
- **Distance: 1,000 miles**
- **Cost Est.: \$3.0 - \$7.0 Billion**



PATH Project (Allegheny Power and AEP)

Project Summary

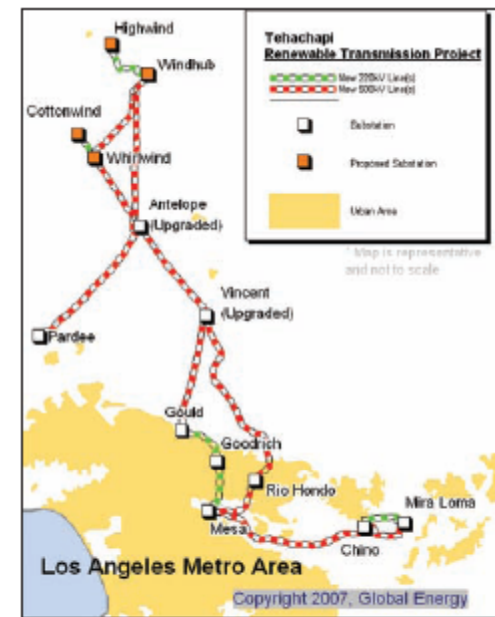
- **Project Need: Reliability**
- **Voltage: 765 kV and 500 kV**
- **Distance: 290 miles**
- **Cost Est.: \$1.8 Billion**



SCE Tehachapi Renewable Project

Project Summary

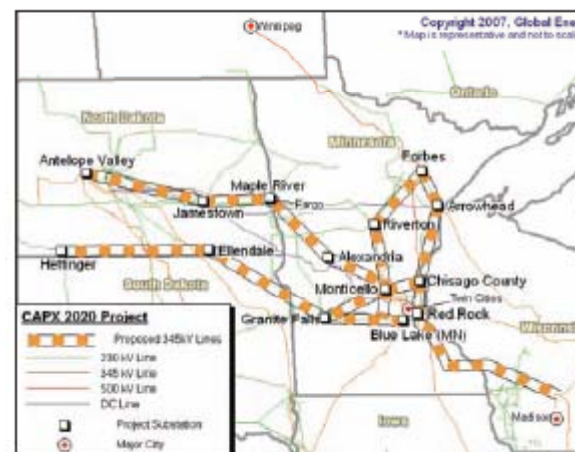
- **Project Need: Reliability, Renewable Energy Integration, Increase PATH 26 Transfer, other**
- **Voltage: 500 kV and 230 kV**
- **Includes Series Compensation**
- **Distance: 250 miles**
- **Cost Est.: \$2.0 Billion**



Xcel Energy CAPX 2020 Project

Project Summary

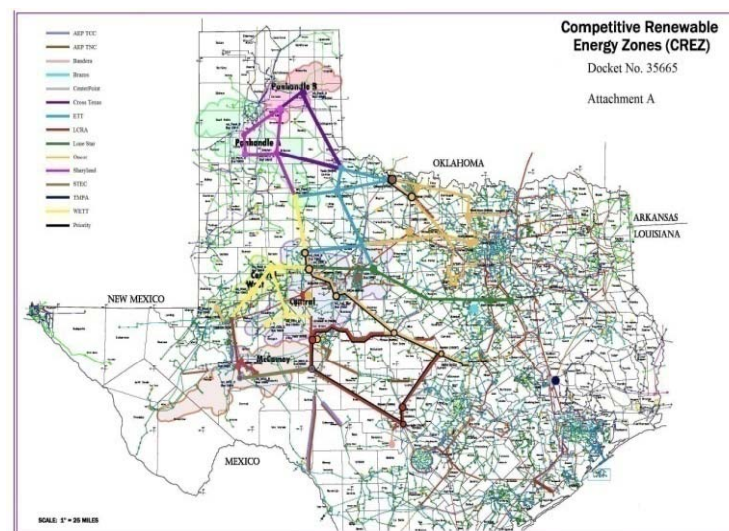
- **Project Need: Facilitate 8 GW of New Generation for demand growth of 6.3 GW by 2020**
- **Voltage: 345 kV**
- **Distance: 1,620 miles over 4 states**
- **Cost Est.: \$1.6 Billion**



ERCOT CREZ Project

ERCOT and 7 Transmission Services Providers

- **Facilitate 11.5 GW of Additional Wind Energy in Texas**
 - ~ 20 GW total wind in Texas by 2013 (~ 9 GW existing)
 - Voltage: 345 kV AC
 - Distance: 2,300 miles of new 345-kV AC
 - Includes Series and Shunt Compensation
 - Cost Est.: \$4.9 Billion



ERCOT CREZ Project

Unprecedented Transmission Up-grade Project for Support of Renewable Energy Integration in the U.S.

- National model for renewable energy integration
- Approx. 25% of the total investment of all reported U.S. transmission infrastructure projects to support renewable energy growth and integration
- Implications of CREZ project success will have national significance and will help to establish methodologies, procedures, technology developments and applications, and potentially standards regarding renewable energy penetration capabilities

Aspects of CREZ Reactive Study and Status Up-date

ERCOT CREZ Reactive Study

Study Categories

1. Reactive Compensation Requirements
2. SSR (Subsynchronous Resonance) Analysis
3. SSI (Subsynchronous Interaction) Study
4. Equipment Specifications

**Study is being conducted by ABB,
with support from ERCOT and the TSPs**

ERCOT CREZ Reactive Study – Status Update

1. Reactive Compensation Requirements

Work Completed or Currently Underway:

- **Conducting steady-state analyses of three scenarios provided by ERCOT:**
 - Maximum Exports; Minimum Exports and Peak Load.Thus far, most of the efforts have concentrated on the Maximum Exports Scenario.
- **Identified the critical contingencies and utilizing OPF; PV and QV Curve techniques**
- **Determined additional reactive requirements (and their locations) that would be necessary in order to meet voltage and voltage stability criteria following those contingencies.**
These are not negligible; in the order of 800 MVAR in additional shunt compensation.
- **Dynamic studies will likely shed additional insight as to the type (e.g., SVC/STATCOM or mechanically switched compensation), location, and size of such compensation.**
Investigating trade-offs between these shunt compensation requirements and changes in series compensation levels.
- **Determining steady-state series capacitor rating requirements; including how such requirements could vary as a function of different wind generation patterns.**
- **Working on putting together the dynamic model; which includes modeling of existing and new wind generation, and also modeling of load dynamics.**

ERCOT CREZ Reactive Study – Status Update

1. Reactive Compensation Requirements

Work Remaining:

- Completion of steady-state analyses, including analyses of Minimum Exports and Peak load conditions, which may shed additional light on reactive requirements, in particular those of the inductive type, as those cases examine lighter loadings of the CREZ transmission system.
- Full dynamic analyses of all scenarios

Challenges Ahead:

- One of the challenges thus far observed has been the previously-mentioned significant additional shunt compensation requirements highlighted by the studies.
Such requirements may grow even further once considering system and load dynamics.
- One of the reasons for such significant compensation requirements is the extensive use in the CREZ transmission of double circuit 345 kV lines, and the consequent need to consider their outage as NERC Category B contingencies.

ERCOT CREZ Reactive Study – Status Update

2. SSR (Subsynchronous Resonance) Analysis

Work Completed or Currently Underway:

- The preliminary screening evaluations have been completed to identify the minimum number of outages for which the generators may become susceptible to SSR.
This can help plant owners and ERCOT and ABB decide how to focus remaining SSR screening work.
- An additional item that can help in this regard is to compare the screening results to the calculated torsional modes of the generators.
The torsional information for the plants is being collected, processed and, if sufficient, compared to the screening results to more fully identify torsional modes that may be at risk.
Several plants have indicated difficulty in readily obtaining the necessary torsional information and so it may take some time to fully evaluate them.
The Willow Creek and Oklaunion plants are nearly complete in regards to the torsional mode comparisons and initial results should be ready within the next week.
- In the mean time, the preliminary screening results can be re-processed from the perspective of induction generator effects to determine if there is any concern anticipated from that phenomenon.

ERCOT CREZ Reactive Study – Status Update

2. SSR (Subsynchronous Resonance) Analysis

Work Remaining:

- The work still to be done is dependent upon the sensitivity of the stake holders to the preliminary results.
Once the torsional mode data has been received and analyzed for all of the units (work in progress), the torsional modes most likely to be affected will become apparent. If the number of outages necessary to create conditions that are likely to destabilize one or more torsional modes is credible, then additional sensitivity calculations can be performed to better understand the series compensation levels that will lead to concern, the influence of other near-by generation on the frequency of the sub-synchronous resonance, etc.
- If the number of outages is not considered credible the stake holders for a given generation plant may determine that SSR is not a credible problem.
- If it is determined that SSR is an issue, then mitigation measures can be explored.
Such mitigation may be the use of TCSC on the series compensated lines or SSR relays at the generators.
- SSTI between active shunt reactive devices (SVCs and STATCOMs) also still needs to be explored, but the final locations of the shunt devices will need to first be determined.

ERCOT CREZ Reactive Study – Status Update

2. SSR (Subsynchronous Resonance) Analysis

Challenges Ahead:

- The challenges for the SSR effort lie primarily with the changes in the system model, and obtaining adequate torsional data for the generating plants.
For the most part, the system changes will have limited impact on the calculations already performed, but for plants where concern is readily apparent, any sensitivity calculations should be done with the updated system information.
- Torsional data for the turbine-generators has historically been a challenge to obtain. This is proving to also be the case for several of the plants selected.
The torsional data will allow better more tailored conclusions to be drawn and so it is recommended that the effort be made to obtain the information.
- Two plants, TIE Odessa and Hays have also been selected for evaluation, but the formal authorization to proceed has not yet been received from ERCOT.
- This will affect the schedule.

ERCOT CREZ Reactive Study – Status Update

3. SSI (Subsynchronous Interaction) Study

Work Completed or Currently Underway:

- The SSI study has tested two of the wind turbine technologies on a radial system with the third being tested now.
- Two mitigation measures have also been tested. The overall results are as follows:
 - (i) The induction generator wind turbines, Type I, in general do not have SSI if they are near the synchronous frequency. Some models did lock in to an SSI frequency when they were ramped up from zero speed electrically (motor starting) instead of closing the breaker upon synchronizing. One model did experience some SSI with a large disturbance, and some additional analysis will be done on this model.
 - (ii) The DFIG wind turbines (Type 3) experience severe SSI. Two of the potential solutions to this problem were tested as follows:
 - A. Thyristor controlled series capacitor (TCSC) were tested with the DFIG model and eliminated the SSI problem.
 - B. A bypass filter was tested with the DFIG model and it did not prevent the SSI. The filter also had high losses so it may not be a practical solution.

ERCOT CREZ Reactive Study – Status Update

3. SSI (Subsynchronous Interaction) Study

Work Remaining:

- The variable resistor wind turbines (Type 2) are now being tested.
At minimum resistance they are very much like the Type 1 machines.
As they go to higher resistance they have more natural damping so the simulations to date do not show an SSI problem.
Still testing the Type 2 wind turbines.
- The back-to-back wind turbines (Type 4) simulations have not been run on the radial system yet.
They will start this week.
- Develop a much larger system model to include all of the CREZ transmissions to test SSI.

Challenges Ahead:

- Poor response by wind turbine suppliers in providing models will hamper the study effort and potentially limit the conclusions that can be drawn.

ERCOT CREZ Reactive Study – Status Update

4. Equipment Specifications

Work Completed or Currently Underway:

- A line voltage profile report was delivered

Work Remaining:

- Evaluation and specifications for series compensation technologies (FSC and/or TCSC) and shunt compensation technologies (SVC and/or STATCOM and/or synchronous condensers).

ERCOT CREZ Reactive Study

Overall Reactive Study Challenges

1. CREZ is a very large-scale, multi-faceted, complex study with ambitious goals and schedule.
2. It involves a large number of stake holders, including transmission developers. There are many good, but sometimes diverse, ideas that make reaching a consensus a challenge at times.
3. Obtaining the data needed in a timely fashion. The study requires a very large amount of data and information. Items 1 and 2 above make gathering data a big challenge for the ERCOT staff, who have worked diligently to coordinate with the TSPs, plant owners/operators and wind turbine suppliers to provide ABB the needed data. Of course, some of the data availability is outside the control of ERCOT.
4. There will be delay in the study completion due to data issues. The challenge is to get the remaining data and minimize further delay. A major concern is on the criteria to be used to determine the size of the equipment that is acceptable to all stakeholders.

Series and Shunt Compensation Technologies

Series Compensation - Overview

Technologies

- Fixed Series Compensator (FSC)
- Thyristor Controlled Series Compensator (TCSC)

Applications

- Increased voltage stability of the grid
- Increased transient (angular) stability of a power corridor
- Improved voltage profile along the power corridor
- Optimized power sharing between parallel circuits
- Damping of low frequency electromechanical oscillations (Subsynchronous Resonance)

Series Compensation - FSC

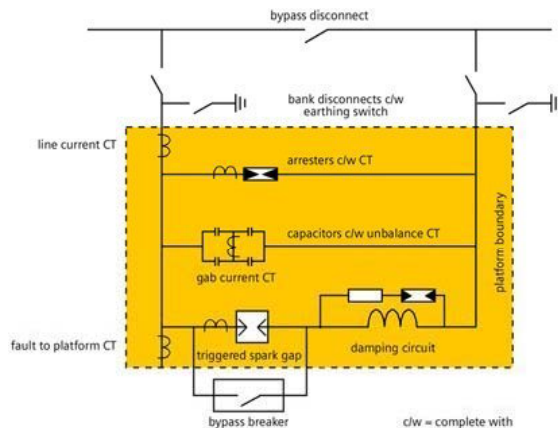
Fixed Series Compensator (FSC)

FSC Technology:

Fixed Series Capacitor installations are installed in series with a transmission line, which means that all the equipment must be installed on a platform that is fully insulated for the system voltage in question. The main capacitor is located together with the overvoltage protection circuits. The overvoltage protection is a key design factor as the capacitor bank must withstand the throughput fault current, even at a severe nearby fault. The primary overvoltage protection typically involves non-linear metal-oxide varistors, a spark gap and a fast bypass switch. Secondary protection is achieved with ground mounted electronics acting on signals from optical current transducers in the high voltage circuit.

FSC Operating Principle:

In a transmission system, the maximum active power transferable over a certain power line is inversely proportional to the series reactance of the line. Thus, by compensating the series reactance to a certain degree, using a Series Capacitor, an electrically shorter line is realized and higher active power transfer is achieved. Since the series capacitor is self-regulated, i.e. its output is directly (without control) proportional to the line current itself, it will also partly balance the voltage drop caused by the transfer reactance. As a result, the voltage stability of the transmission system is raised.



Sources:
ABB, Siemens,
Mitsubishi Electric

Series Compensation - TCSC

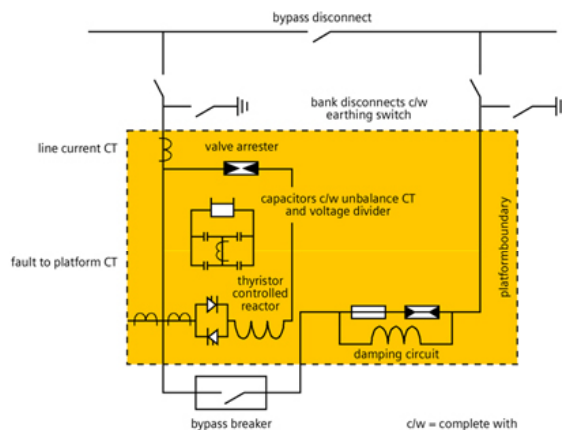
Thyristor Controlled Series Compensator (TCSC)

TCSC Technology:

The TCSC resembles the conventional series capacitor from a technology perspective. All of the power equipment is located on an isolated steel platform, including the thyristor valve that is used to control the behavior of the main capacitor bank. Likewise, the control and protection is located on ground potential together with other auxiliary systems.

TCSC Operating Principle:

There are two main principles of the TCSC concept. First, the TCSC provides electromechanical damping between large electrical systems by changing the reactance of a specific interconnecting power line. That is, the TCSC will provide a variable capacitive reactance. Second, the TCSC changes its apparent impedance (as seen by the line current) for subsynchronous frequencies such that a prospective subsynchronous resonance is avoided. Both these objectives are achieved with the TCSC using control algorithms that work concurrently. The controls function on the thyristor circuit (which is in parallel to the main capacitor bank) such that controlled charges are added to the main capacitor, making it a variable capacitor at fundamental frequency, but a "virtual inductor" at subsynchronous frequencies.



Sources:
ABB, Siemens,
Mitsubishi Electric

Shunt Compensation - Overview

Technologies

- **Static Var Compensator (SVC)**
- **Static Reactive Compensator (STATCOM)**

Applications

- **Enhanced Transmission System Reliability & Control**
- **Enhanced Voltage Control and Stability**
- **Improved Power System Stabilization**
- **Increased Power Flow Control**
- **Increased Transmission System Capacity**
- **Higher Levels of Power Quality and Security**

Shunt Compensation - SVC

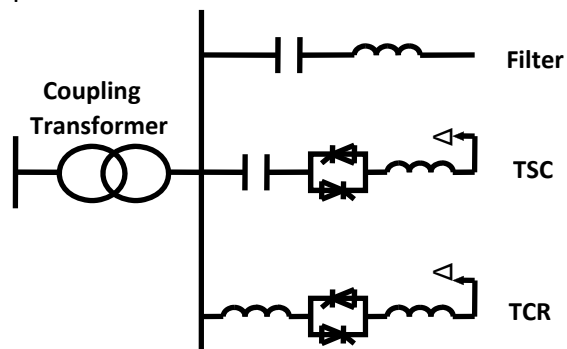
Static Var Compensator (SVC)

SVC Technology:

SVC installations consist of a number of building blocks. The most important is the thyristor valve, i.e. stack assemblies of series connected anti-parallel thyristors to provide controllability. Air core reactors and high voltage AC capacitors are the reactive power elements used together with the thyristor valves. The equipment's step-up connection to the transmission voltage is achieved through a power transformer. The thyristor valves, together with auxiliary systems, are located inside an SVC building, while the air core reactors and capacitors, together with a power transformer, are located outdoors.

SVC Operating Principle:

The SVC is a dynamic source of reactive current having sub-cycle reaction time. Using the thyristor valve as fast switches, capacitor banks can be switched in and out. Also, the thyristor valves can, by means of phase angle modulation, continuously control the current through an air core reactor. This combination of switching capacitors and controlling reactors provides continuous control of the reactive current output between two extremes dictated by component rating selection. SVC's utilizing phase angle control of reactors will produce current harmonics (of odd orders). In order to avoid excessive harmonic distortion in the transmission grid, such SVC's have internal harmonic filters that act as sinks for the harmonic currents. These filters also provide part of the required capacitive range. SVC's in transmission are most often used to control the voltage at the bus where they are connected. The voltage control is typically a closed loop, three-phase symmetrical voltage control with a set droop that allows the voltage to vary a few percent.



Sources:
ABB, Siemens,
Mitsubishi Electric

Shunt Compensation - STATCOM

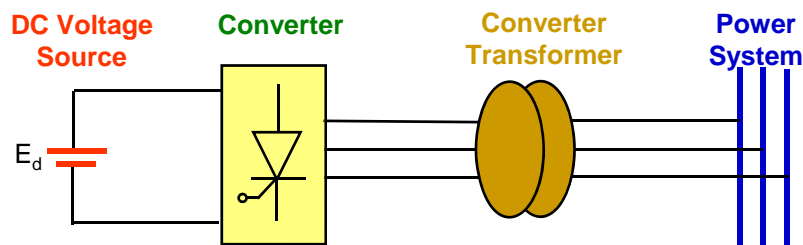
Static Reactive Compensator (STATCOM)

STATCOM Technology:

STATCOM technology is based on the concept of Voltage Source Converter (VSC) designs, equipped with advanced semiconductor devices (IGBTs, GTOs, or GCTs) that are controlled by Pulse Width Modulation (PWM). VSC is capable of both generating and consuming reactive power, over a symmetrical range. If needed, air core reactors and high voltage AC capacitors can be used along with the VSC as additional reactive power elements to achieve any desired range.

STATCOM Operating Principle:

STATCOM can be seen as a voltage source behind a reactance. Physically it is built as a three-level inverter operating on a constant DC-voltage. It provides reactive power generation as well as absorption purely by means of electronic processing of voltage and current waveforms in a voltage source converter (the grid sees it as a synchronous machine without inertia). This means that capacitor banks and shunt reactors are not needed for generation and absorption of reactive power, facilitating a compact design, and thus a small footprint. The high switching frequency of the semiconductors allows extremely fast control, which can be used in areas such as mitigation of voltage flicker caused by electric arc furnaces, voltage balancing, harmonic filtering and robust grid voltage recovery support.



Sources:
ABB, Siemens,
Mitsubishi Electric

Summary, General Comments, and Perspectives

Summary, General Comments, Perspectives

The ERCOT CREZ Project

- The CREZ Project is an unprecedented challenge and a 'national model' for the integration of large scale renewable energy resources in the U.S., with far-reaching implications.
- The CREZ Reactive Study, being conducted by ABB with support from ERCOT and the TSPs, is well-underway with excellent progress to-date, along with some significant challenges to still overcome.
- The selection of transmission technologies, including series and shunt compensation requirements, are a critical aspect of the project and are being studied and investigated thoroughly.
- There are many stakeholders in CREZ, with both common and sometimes divergent perspectives, requiring cooperation and in some cases compromise to realize a successful outcome.

Thank You

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