ERCOT SSR Experiences and Challenges

Yunzhi Cheng

November 2019
IEEE Wind SSO Taskforce

About the taskforce

The task force of Modeling Subsynchronous Oscillations in Wind Energy Interconnected Systems ("Wind SSO") was created in 2017 under Modelling and Analysis of System Transients using Digital Programs Working Group, Transient Analysis and Simulations Subcommittee (TASS), Analytic Methods for Power Systems (AMPS) Committee.

Chair: Yunzhi Cheng (ERCOT)
Co-Chair: Lingling Fan (USE)

Documents

2019:
- Task Force Report (Draft), Nov 7, 2019 NEW
- SSO events in China and Impedance network based analysis (Xiaorong Xie)
- ERCOT SSR Study Experiences and Challenges (Yunzhi Cheng)
- Analytical Models and Techniques for Wind Grid Integration Systems (Lingling Fan)
- SSCI study experience: Screening and Detailed Analysis State of the Art (Arunachala Dinakaran)
- Impedance-Based Prediction of SSR-Generated Harmonics in Doubly Fed Induction Generators (Shahil Shab)

2018:
- SOUTH Texas SSR Events In 2017
- China Wind SSO Events (Xiaorong Xie)
- Recent Research Results at USE on Wind Integration System Oscillation Issues (Lingling Fan)

Recent Activities

Panel Session of "Wind Gneration SSO: Event, Modeling and Studies" at 2019 IEEE PES GM, August 7th, 2019, Atlanta, Georgia, USA.
Taskforce Committee Meeting at 2019 IEEE PES GM, August 6th, 2019, Atlanta, Georgia, USA. Meeting Summary

Future Activities

2020 IEEE PES General Meeting, Montreal, Canada

We are going to have a panel session in Montreal
## ERCOT SSR Definition

<table>
<thead>
<tr>
<th>SSR</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Induction Generator Effect (IGE)</strong></td>
<td>An electrical phenomena in which a resonance involving a Generation Resource and a series compensated transmission system results in electrical self-excitation of the Generation Resource at a subsynchronous frequency</td>
</tr>
<tr>
<td><strong>Torsional Interaction (TI)</strong></td>
<td>the interplay between mechanical system of a turbine generator and a series compensated transmission system</td>
</tr>
<tr>
<td><strong>Torsional Amplification (TA)</strong></td>
<td>An interaction between Generation Resources and a series compensated transmission system in which the response results in higher transient torque during or after disturbances than would otherwise occur</td>
</tr>
<tr>
<td><strong>Subsynchronous Control Interaction (SSCI)</strong></td>
<td>The interaction between a series capacitor compensated transmission system and the control system of Generation Resources</td>
</tr>
</tbody>
</table>

Reference: ERCOT Nodal Protocols Section 2, Nov.1, 2019
What is SSCI?

- Subsynchronous Control Interaction (SSCI)
  - the interaction between series capacitors and the control system of generation resources (typically inverter-based)
  - Not mechanical, purely electrical phenomenon
  - Very fast (<1sec)
  - DFIG based wind generation (Type III) is more vulnerable to SSCI because the self excitation of the induction machine could be exacerbated by the converter control, leading to fast un-damped electric oscillation.

Series Capacitors in ERCOT

Challenge #1
Assess hundreds of generation resources (existing + planning) with many series capacitors meshed into the transmission network.
South Texas 2009 Event

- Series capacitor installed on a long 345 kV line in South Texas.
- A cluster of wind farms (DFIG) connected to Ajo.
- In 2009, a fault caused LonHill – Ajo line to trip, leaving wind radially connected to series cap.
- Very high currents resulted in damage.
ERCOT 2017 Events

• Three SSCI events occurred in South Texas in 2017
  – All SSCI events are related to DFIG based wind farms radially connected to series capacitors after outages
  – Both undamped SSCI (20-30Hz) and damped SSCI (20-30Hz) were observed. WTGs were tripped during undamped SSCI events.

Challenge #2
Accurate PSCAD models are important to identify SSCI risk

Challenge #3
Generation resources too close to series cap. Directly connect to series cap terminal

SSR Study Methods

- **EMT Time-domain Simulation (PCAD)**
  - Most accurate and expensive
  - Require a sophisticated EMT level model

- **Eigenvalue Analysis**
  - Accurate when mathematical models of the associated devices are available

- **Frequency Scan (FS)**
  - Balance of accuracy and speed
  - Best SSR (including traditional SSR) screening method
  - **FS Criteria for SSCI:**
    - Negative resistance at the reactance cross-over frequency indicates potential SSCI vulnerability
  - May require at least one EMT time-domain simulation to verify the FS results for SSCI concern
**ERCOT SSR Study Framework**

- **Step 1: Topology Screening**
  - Identify N-x contingency set leading to radial connection

- **Step 2: Frequency Scan (FS)**
  - Run frequency scan and compare with the FS criteria

- **Step 3: EMT analysis**
  - Run PSCAD simulation for limited contingencies as identified in FS

• The classic Ford-Fulkerson max-flow min-cut theorem can be utilized to identify the N-x contingency set leading to radial connection.

How to Run Frequency Scan?

- Measure Thevenin impedance at different frequencies 5 ~ 55 Hz
- Don’t forget to simulate contingencies!
- ERCOT Grid

System-Side Frequency Scan (PSS/e)
Generator-Side Frequency Scan (PSCAD)
How to Run Frequency Scan?
Generator Side Scan (PSCAD)

- PSCAD impedance scan using a perturbation analysis
  - Inject a white noise signal (voltage or current) at subsynchronous frequency spectrum.
  - FFT analysis to calculate the impedance at subsynchronous frequency spectrum.

System Side Scan (PSS/e)

- Scale transmission network reactance & Run short-circuit analysis to obtain the system impedance
  - Scaling by the study frequency
    - Transmission Line/Transformer: $X_L(f) = X_{LN} \times \frac{f}{60}$
    - Series/Shunt Capacitors: $X_C(f) = X_{CN} \times \frac{60}{f}$
  - Pros
    - Whole ERCOT system is modeled
    - Easy to handle multiple outages
    - Nearby generation can be modeled by the impedance gained from their generator side scan
  - Cons
    - Some nonlinear characteristics cannot be modeled

ERCOT’s Tool and An Example

- ERCOT has developed a SSR study tool (topology screening & frequency scan) and run it for hundreds of generation resources.
- An example of a DFIG based wind farm (WF1, 290MW) connected to a series compensated transmission network.
  - Compensation level is set at 25%.
  - An N-4 outage is studied:
    - Loss of double circuit line of Bus 1 – Bus 7.
    - Radial connection between WF1 and SC under this outage.

ERCOT’s Tool and An Example

Wind Farm Impedance

System Side Impedance Scan

Total Impedance

SSCI Vulnerability Identified at 8-9Hz
ERCOT’s Tool and An Example

Active power (MW)

Current (kA)

FFT indicates 9Hz oscillation

Active power and Current on the series capacitor
(PSCAD Simulation Results)
Summary

• SSCI could occur with:
  – low series compensation level
  – non-radial connection between generation resources and series capacitors

• Multiple generation resources could change SSCI performance. It is possible to have:
  – Undamped SSCI with one wind farm & Damped SSCI with multiple wind farms
  – Damped SSCI with one wind farm & Undamped SSCI with multiple wind farms

• Challenges:
  – More efficiently filter out unnecessary SSCI studies with many meshed series capacitors and hundreds of generation interconnection requests.
  – Accurately capture SSCI risk in the study/simulation (study scenarios & modeling)
  – Extremely high series compensation for generation resources directly connect to series capacitors