Subsynchronous Resonance Workshop on

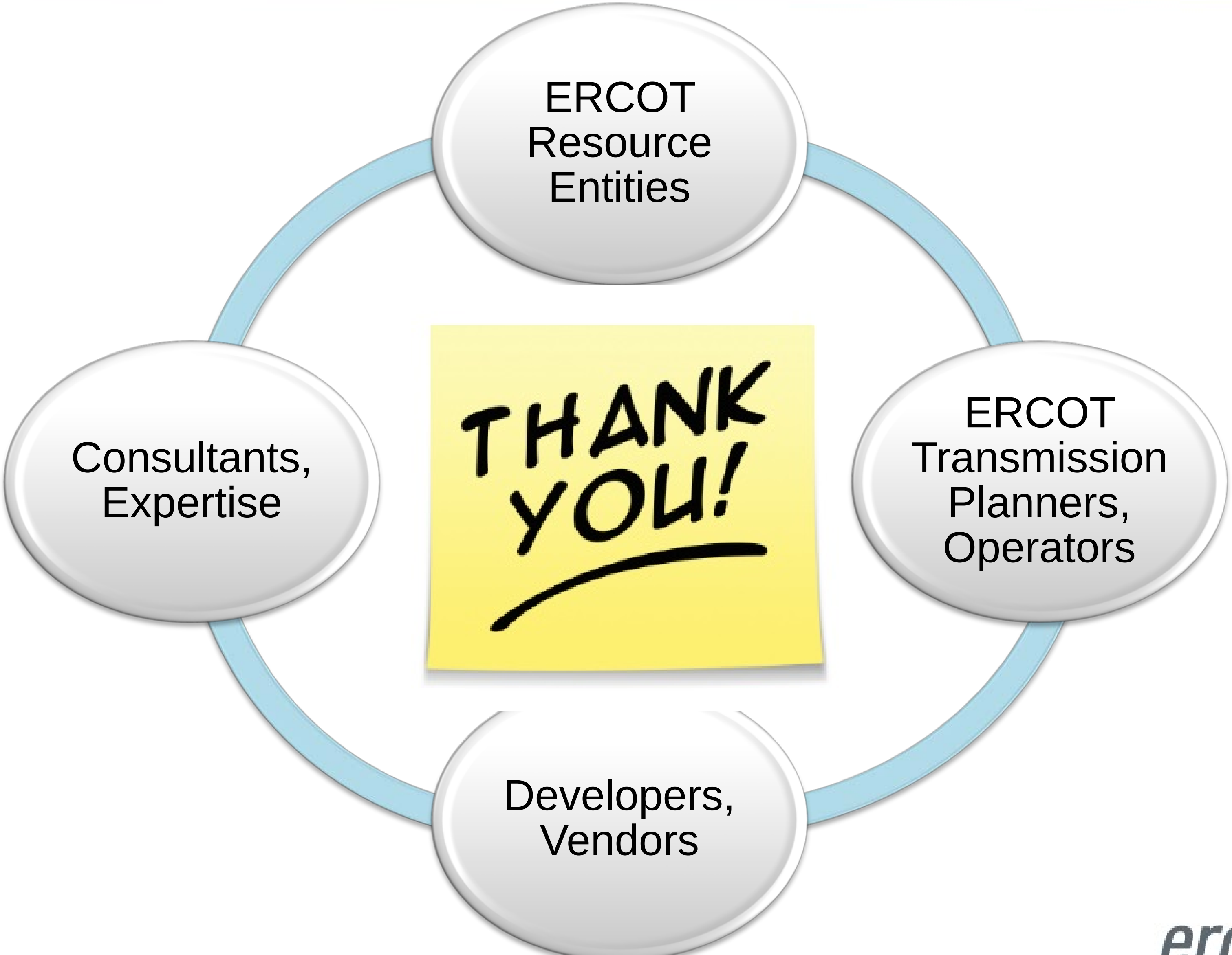
NPRR 562

January 31, 2017

Agenda

- Introduction
- NPRR 562 Comments
- SSR Assessment
- NPRR562 Revision

Acknowledgement



SSR History and SSR in ERCOT

Series Caps: Pros: Increase Transfer

1970: Mohave Event

Series Caps: SSR

~2000: Series Caps in Valley

2008: CREZ Series Caps were Proposed

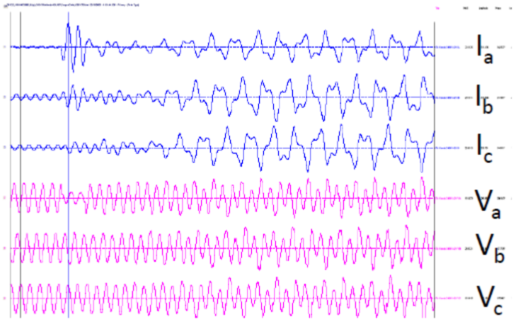
2009: South Texas SSCI Event

2013: Series Caps were Constructed

8/12/2013: NPRR562
Key comments:
- Cost Allocation
- Technical Assessment

2015/2016
- Workshops/Stakeholders' Feedback
- Technical Assessment/Tool Development

2017: Revised SSR Language
- Study Scope and Criteria
- Process: Planning, Operation, Maintenance
- Responsibility (Who, What, How, When)



Recorded Data of the SSR(SSCI) Event in 2009

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NPRR 562 Revision

- Scope:

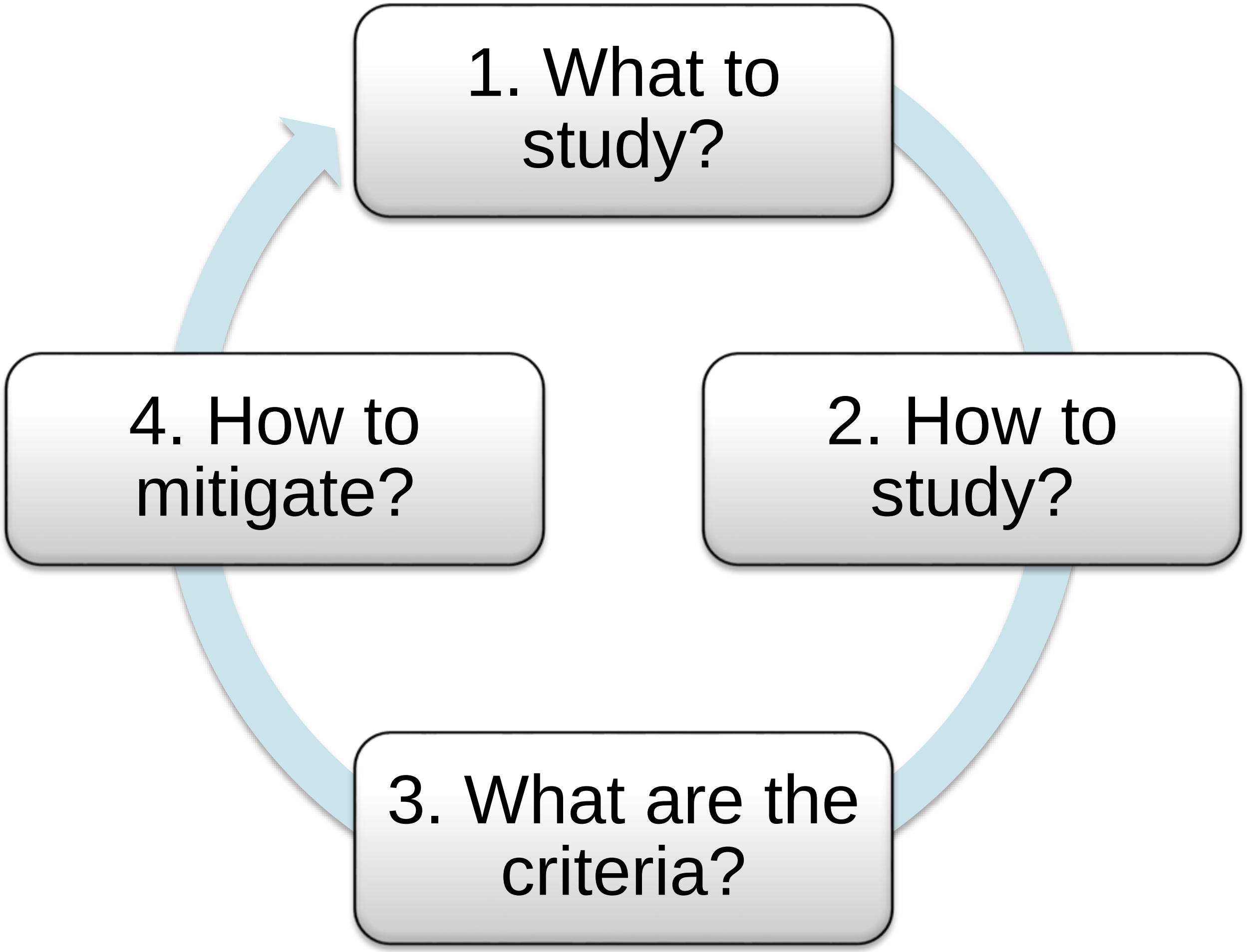
Focus on SSR between Generation Resources and a series capacitors compensated transmission system

- Goal:

Have series capacitors in service without causing SSR vulnerability

SSR Assessment

SSR Technical Assessment



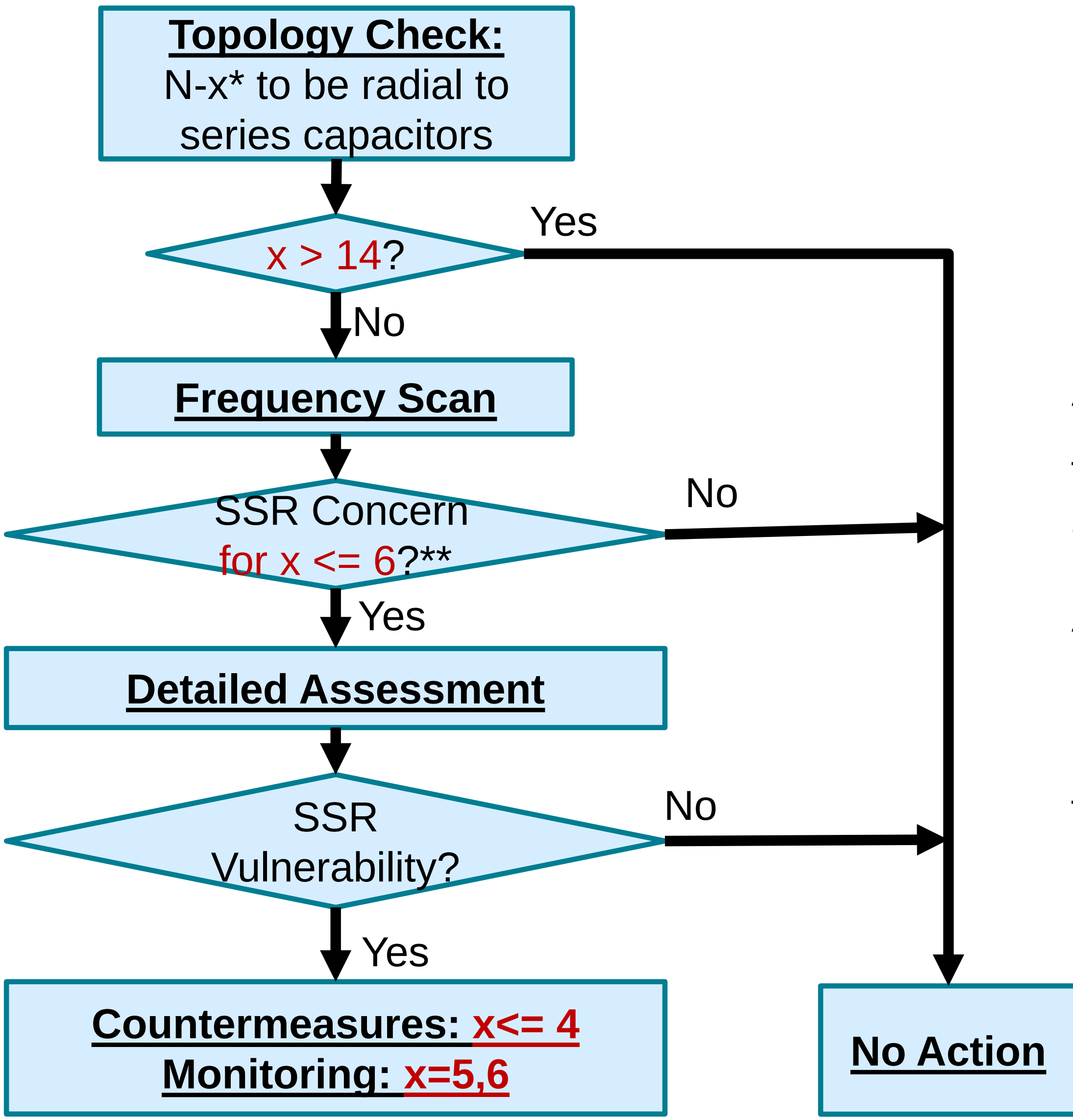
1. What to Study?

SSR has several manifestations. All must be considered…

<table>
<tr><th></th><th>Synchronous Generator</th><th>Inverter Based (Wind/Solar)</th></tr>
<tr><td rowspan="3">Subsynchronous Resonance (SSR)</td><td>Induction Generation Effect (IGE)</td><td rowspan="3">(IGE) / Subsynchronous Control Interaction (SSCI)</td></tr>
<tr><td>Torsional Interaction</td></tr>
<tr><td>Torque Amplification*</td></tr>
</table>

*New added in the NPRR562 comments

2. How to study?



*A double circuit transmission line is considered as N-2.

**Detailed assessment may still be required for renewable projects if frequency scan shows no SSR concern for x<=6.

Topology Check Criteria

- More than 100 units can be radial to series capacitor(s) within N-14 outages,

- No SSR vulnerability is identified for N-12~N-14

N-14 is adequate for topology scan criteria

SSR Countermeasure and Monitoring Criteria

SSR	# of Outages	Comments
Countermeasure*	N-0~N-4	
Monitoring/Outage Coordination	N-5, N-6	The occurrence is once in more than 2000 years**
No action required	N-7 and beyond	

*Countermeasure

Protection: includes disconnecting the affected Generation Resource

Mitigation: without disconnecting the affected Generation Resources

** Calculated based on ERCOT historical outage data

SSR Technical Assessment Lessons Learned

- Proposed SSR study approaches and criteria are adequate
- Found no reported/documented Torque Amplification events
- Units with SSR vulnerability are connected to 345 kV.
- Collaboration: Resource Entities, TSPs, Vendors, Consultants, …

NPRR 562 Revision

NPRR 562 will address SSR for **<u>all generators</u>** and the related **<u>series capacitors</u>**.

Process to Cover

- Existing Gen
- New Gen
- New Transmission
- Annual Review
- Operation
- Outage Coordination

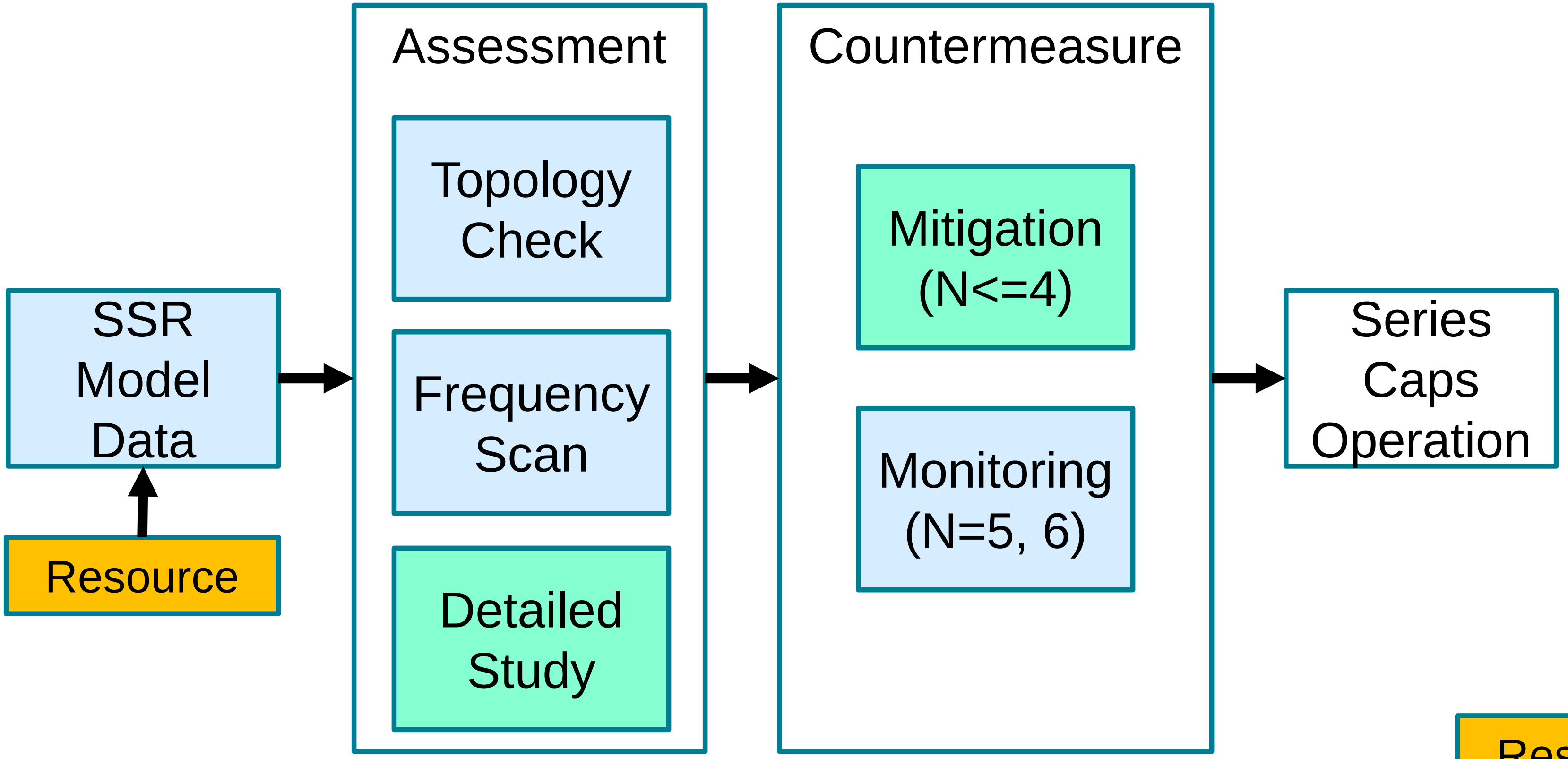
Assessment

- Topology Check
- Frequency Scan
- Detailed Study
- Countermeasures

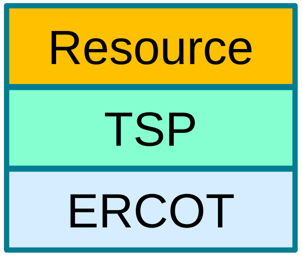
Implementation

- Interconnected TSP
- TSPs own series caps
- Resource Entity
- ERCOT

One-Time Existing Generation Resource Assessment



N: number of transmission element outages under the base case condition



Existing Generation Resources Consideration in the One-Time Only Assessment

All units were assessed for SSR vulnerability and only the ones with SSR vulnerability were notified and countermeasures will be implemented by the responsible entity.

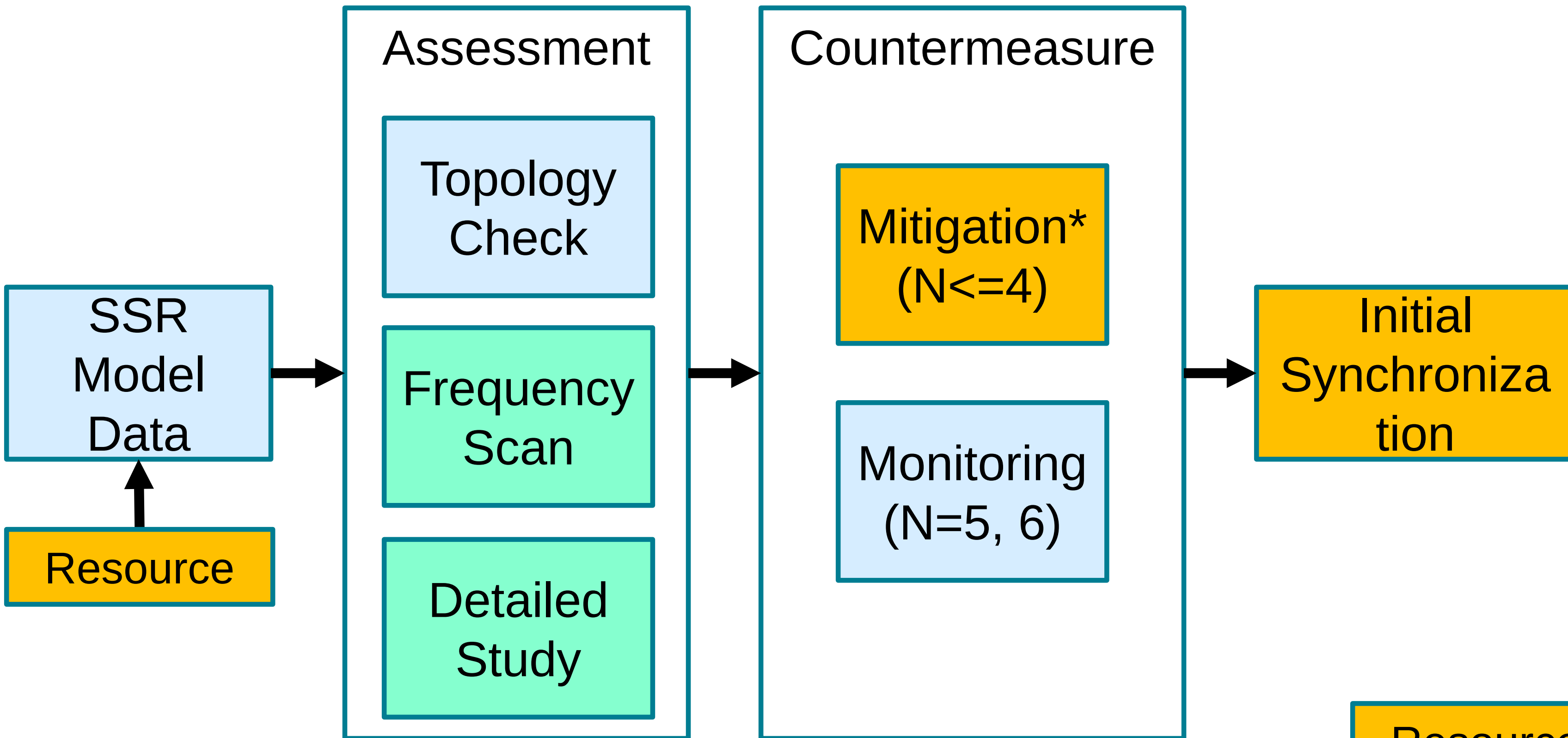
Existing Generation Resources

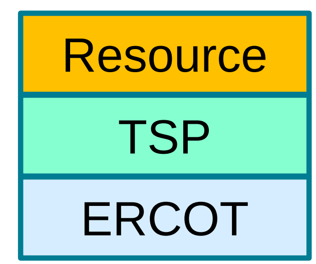
TSP/ERCOT are responsible for SSR Countermeasures

Generators are responsible for SSR Countermeasures

Satisfied PG 6.9 on or before 8/12/2013

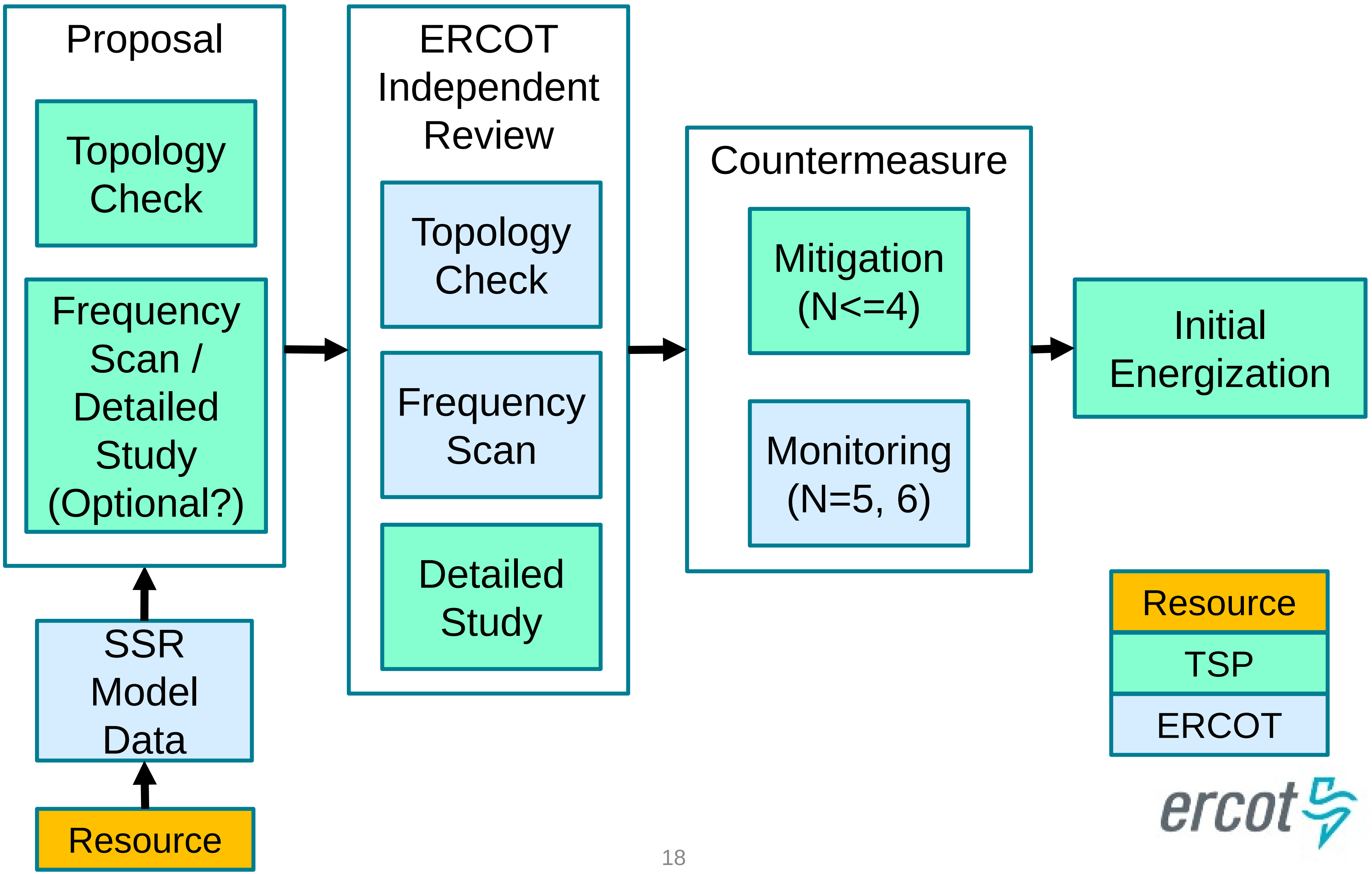
Resource
TSP
ERCOT



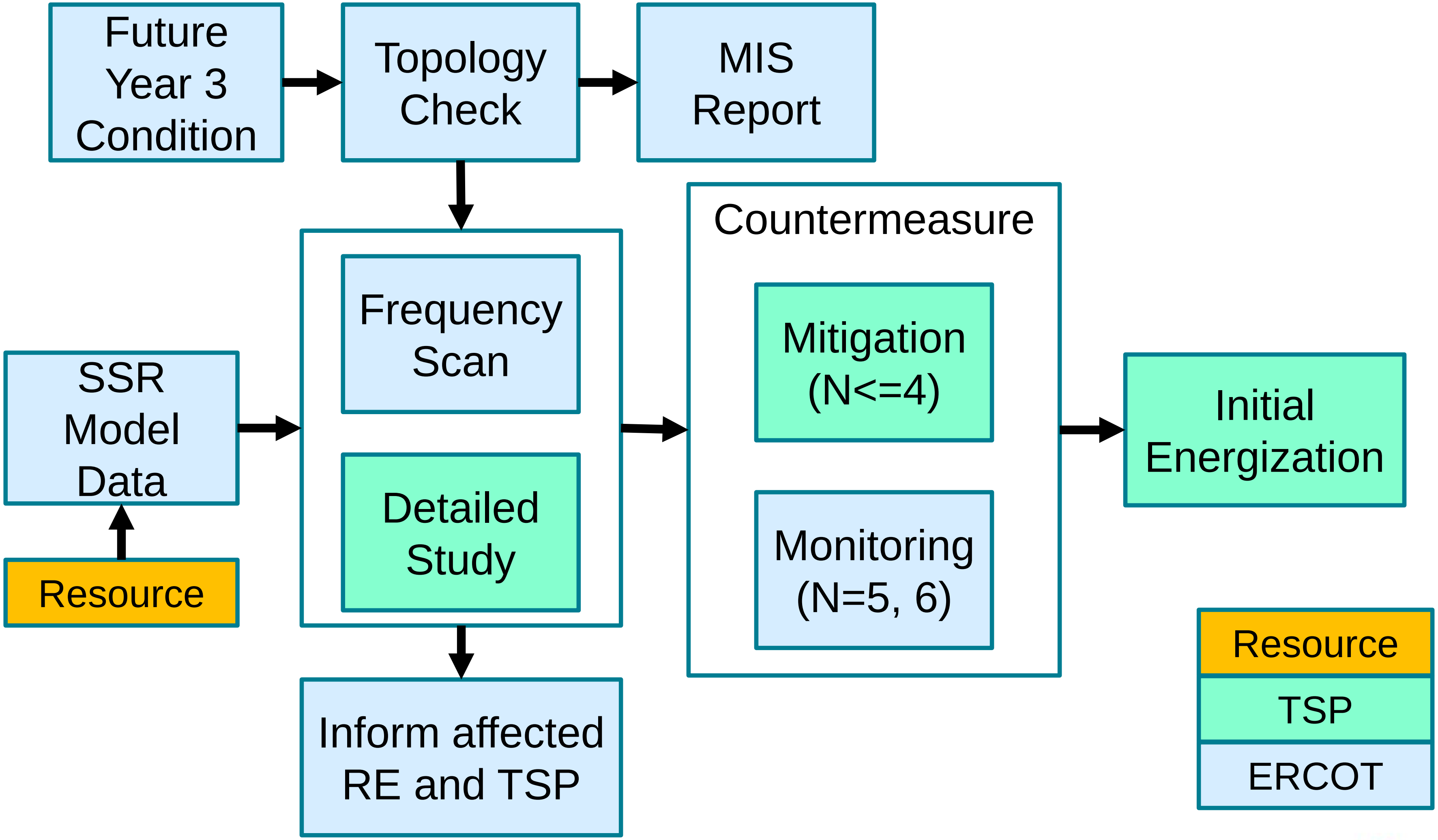


* Resources that satisfied PG 6.9 between 8/12/2013 and 3/20/2015 may implement SSR Protection if approved by ERCOT

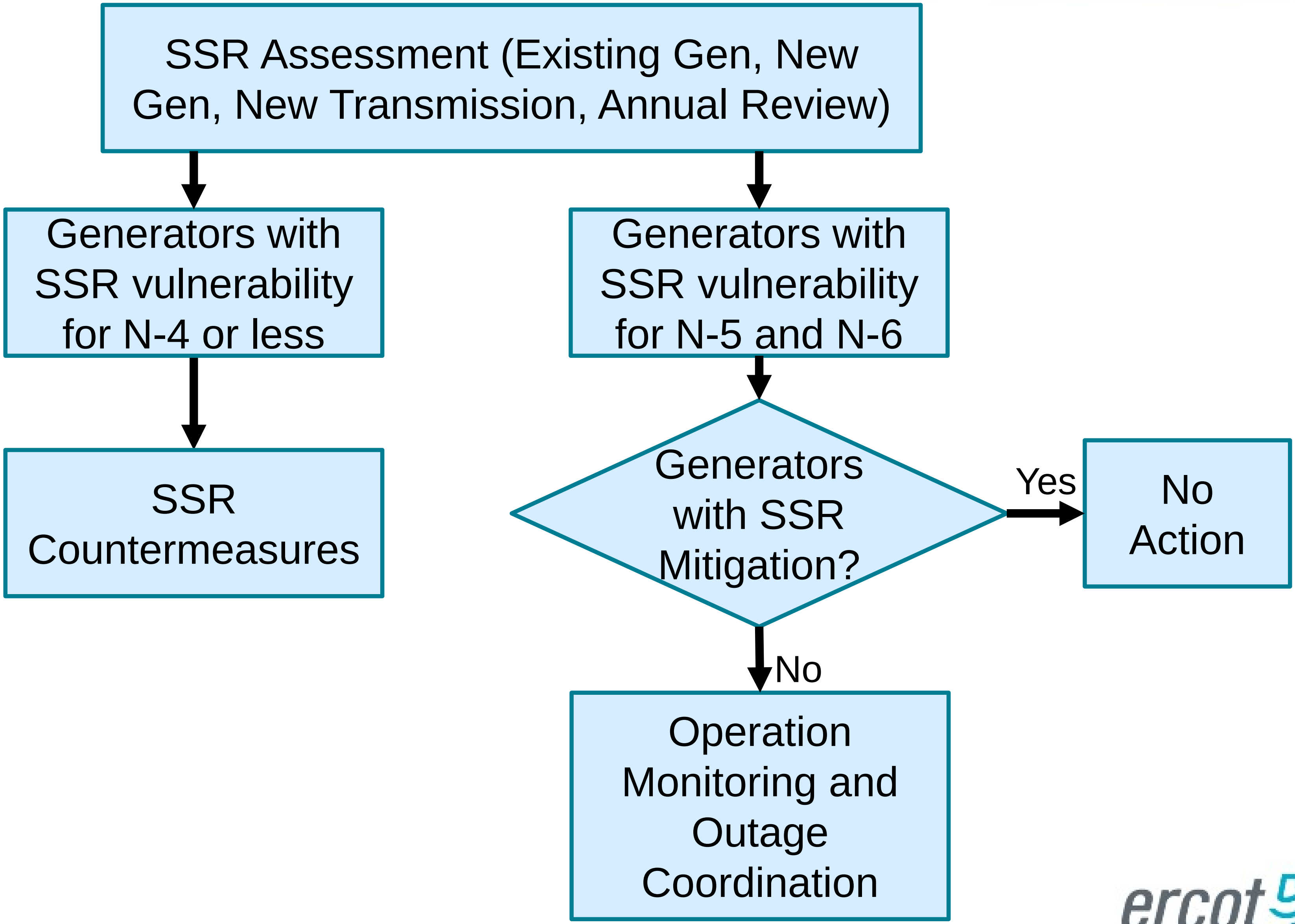
Transmission Project Assessment: 345 kV related



Annual SSR Review



Operations Monitoring, and Outage Coordination



Operation Monitoring and Outage Coordination

Three Contingencies* away from SSR vulnerability

Normal Operation

Two Contingencies away from SSR vulnerability

Develop Mitigation Plan

One Contingency away from SSR vulnerability

Implement Mitigation Plan

*according to Credible Single Contingency definition in ERCOT Protocol

Mitigation Plan Options

1. • No action (if Gen is equipped with SSR Protection)

2. • Withdraw outages

3. • Bypass the affected series caps

4. • Decommit the affected Generation Resource(s)

Consider the actions in the order listed above unless reliability considerations would dictate a different order. May also consider other actions specific to the situation.

Guide/RARF/Procedure Update

- PGRR-56
  - Align with revised NPRR562
  - Add SSR model data requirements
- Operating Procedure
- RARF(SSR model data)

Next

- Stakeholders provide comments by February 10, 2017

- For questions, contact Shun-Hsien (Fred) Huang, shuang@ercot.com

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THANK
YOU

Appendix

Historical ERCOT Outage Statistical overview

Probability of Occurrence at Least once in 50 yrs

Doubles \ Singles	0	1	2	3	4	5	6
0	100.000%	100.000%	100.000%	90.439%	4.804%	0.101%	0.002%
1	100.000%	99.999%	21.956%	0.519%	0.011%	0.000%	
2	71.657%	2.584%	0.055%	0.001%	0.000%		
3	0.302%	0.006%	0.000%	0.000%			
4	0.001%	0.000%	0.000%				
5	0.000%						

SSR Mode Data Needs

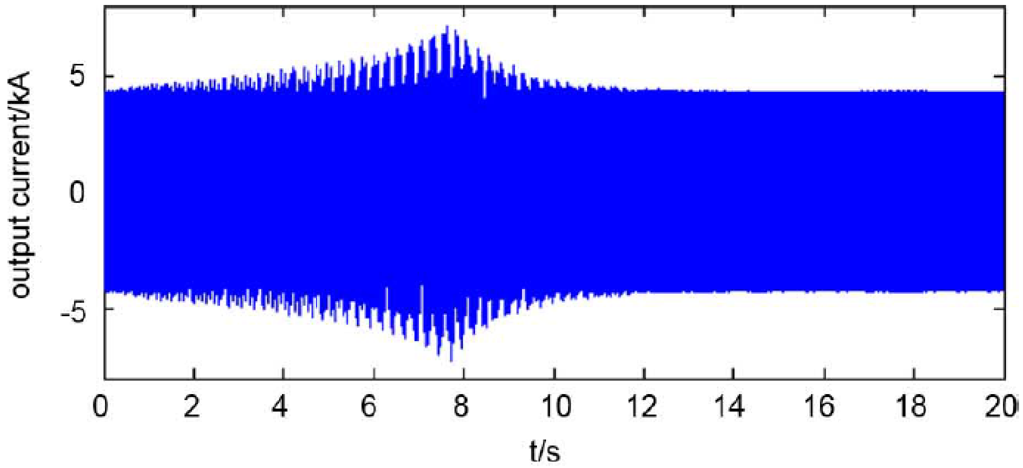
Data Requirements and Availability		Topology Check	Frequency Scan	Detail Study
System Topology		√	√	√
Synchronous Gen	Generator Dynamic Model		√	√
	Generator Mechanical Model		√	√
	Fatigue Life Expenditure Curve			√**
Wind/Solar	Generator Dynamic Model		√	
	Generator Frequency Dependent Impedance Table		√	
	Generator PSCAD Model		√*	√

* Required if frequency dependent impedance table is not available

** Alternative criteria may be applied if data is not available

SSR Phenomenon

- IGE (Induction Generator Effect)
  - IGE is a self excitation and purely electrical phenomenon
  - A synchronous generator behaves like an induction generator and may demonstrate negative resistance at subsynchronous frequencies
  - IGE would be expected to result in excessive voltages and currents.



Xiaorong Xie, etc, “Applying Improved Blocking Filters to the SSR Problem of the Tuoketuo Power System”, TRANSACTIONS ON POWER SYSTEMS, VOL. 28, NO. 1, FEBRUARY 2013

IGE / SSCI

- Trigger:
  - Disturbance (w/wo fault),
  - Reactive crossover at subsynchronous frequency, and
  - Negative resistance that can be caused by
    - Rotor slip: synchronous or renewable generation
    - Inverter control: renewable generation

SSR Phenomenon (continue)

- Torsional Interaction
  - Turbine-generator shaft system responds to disturbances with oscillations at the torsional natural frequencies (fn).
  - Turbine-generator shaft system has an inherent positive mechanical damping (Dm) under the torsional natural frequencies (fn).
  - Electrical system (including generator and transmission system) has an electrical damping (De) which could be negative with the series capacitors in the transmission system.
  - With even a small disturbance, TI would be expected to result in growing torque oscillation and the shaft torque may reach to the damaging level within a minute or minutes, as occurred at Mohave generation station.

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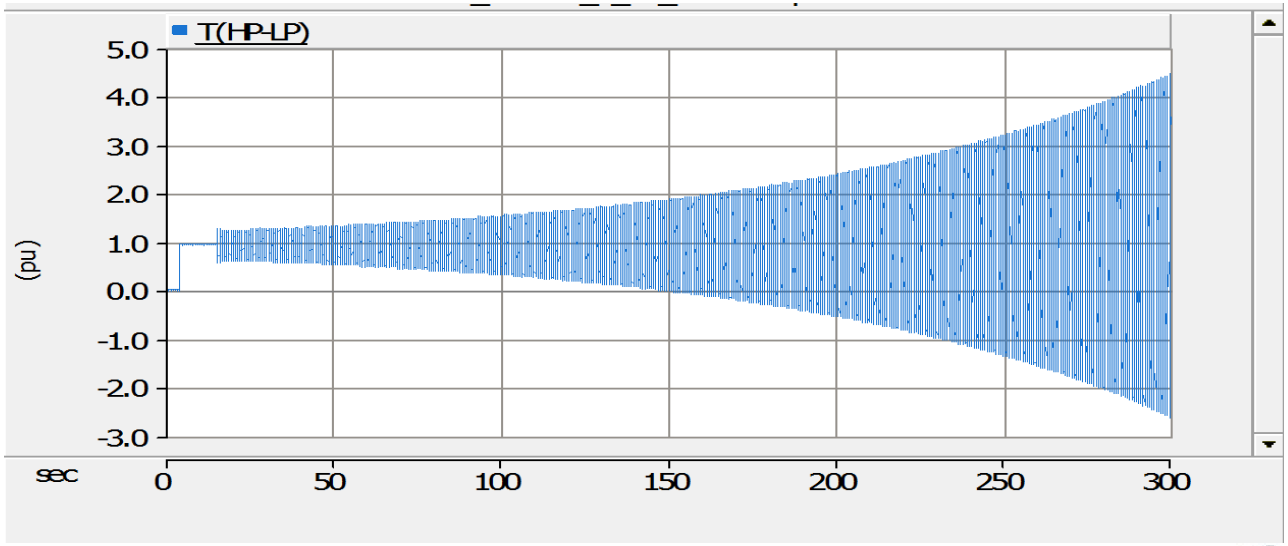
- Trigger:
  - Disturbance (w/wo fault),
  - A precise frequency mode alignment (generator mechanical mode, system mode), and
  - Negative damping (mechanical + electrical)



Growing Torque Oscillation in PSCAD Simulation

SSR Phenomenon (continue)

- Torsional Amplification
  - A significant system disturbance (eg. 3 phase fault), electrically close to both the study generators and the series capacitors, occurs in a series compensated system.
  - When the series capacitors gain a large amount of energy from the charging during fault period and the majority of the charged energy discharges to the generator after the fault is cleared, it may result very high shaft torque (damaging level) within a short duration (0.1 second).

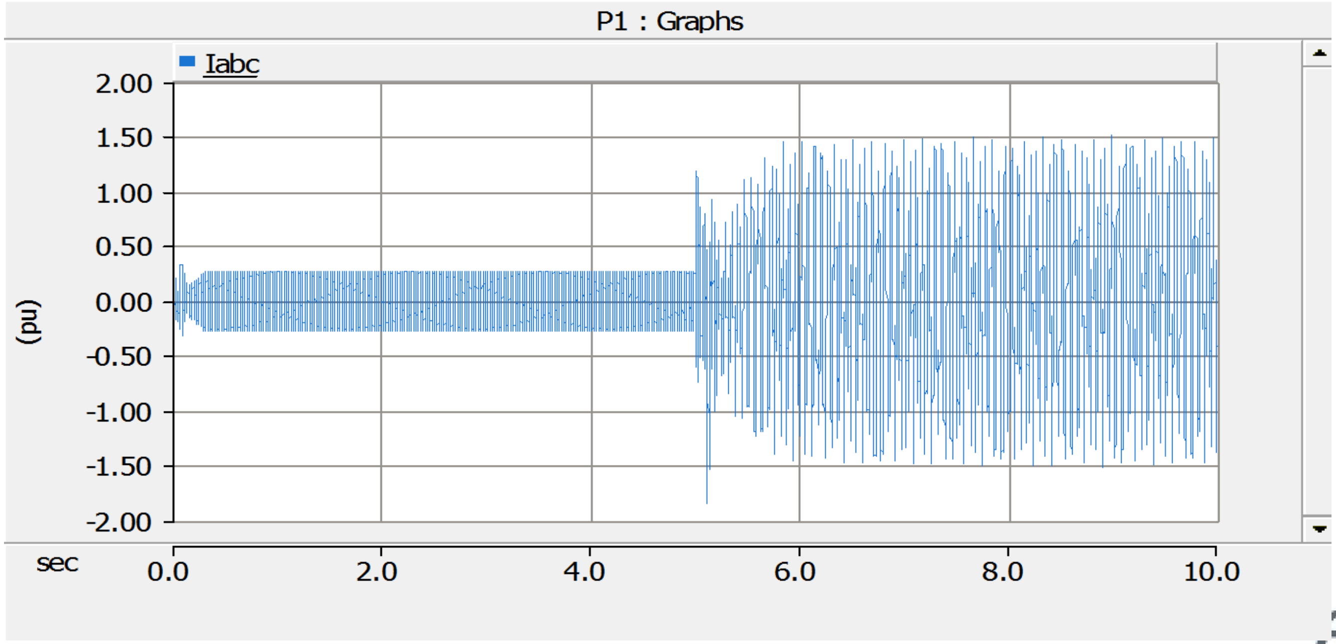
Torque Amplification – include in the SSR scope

- To trigger an TA event, it requires
  - A severe fault (3 phase fault),
  - A specific location (fault is electrically close to generator and series capacitors),
  - A specific configuration (radial or near radial condition),
  - A specific fault clearing time, and
  - A precise frequency mode alignment (generator mechanic mode, system mode)

All must coincide

SSR Phenomenon (continue)

- SSCI (Subsychronous Control Interaction)
  - Similar to IGE, SSCI is a purely electric phenomenon.
  - The self excitation of the induction machine could be exacerbated by the converter control, leading to fast growing un-damped electric oscillation.
  - SSCI would be expected to result in excessive voltages and currents.



Current Oscillation in PSCAD Simulation

SSR Assessment – Topology Check

- SSR Screening (Topology Check)
  - Identify the N-x contingency set leading to the radial connection between the study generation resource and series compensations
  - Purely based on transmission network topology
  - No electrical or mechanical data needed

N-14 is adequate for topology scan criteria

SSR Assessment – Frequency Scan Assessment

- Frequency Scan
  - Determine the resistance and reactance of the machine and system to provide at least an approximation of SSR vulnerability.
  - Identify SSR vulnerability under various contingencies
  - Model Required
    - System power flow case
    - Dynamic data for synchronous generators
    - Mechanic data (mass, shaft and damping) for synchronous generators
    - Frequency dependent impedance table or EMT (PSCAD) model for renewables.

Frequency Scan Assessment Criteria

Scope	Frequency Scan Criteria	Frequency Range
IGE/SSCI	Positive resistance at reactance crossover frequency (Generator + System)	5 ~ 55 Hz
TI	Positive Total Damping (Electrical De + Mechanical Dm) Dm at +/- 1 Hz of the modal frequency is utilized to compare to De.	5 ~ 55 Hz
TA	Less than 5% reactance dip within +/- 3Hz of the 60 Hz complement of a modal frequency. *	5 ~ 55 Hz

* M. El-Marsafawy, "Use of frequency-scan techniques for subsynchronous resonance analysis of a practical series capacitor compensated AC network", Proceedings of IEE Generation, Transmission and Distribution conference, vol. 130, no. 1, pp. 28-40, 1983.

SSR Assessment – Detailed SSR Analysis

- Detailed SSR Assessment
  - Precisely identify SSR vulnerability under various contingencies through a time-domain simulation that models the system in detail.
  - Model Required
    - System power flow case
    - Dynamic data for synchronous generators
    - Mechanic data (mass, shaft, damping and S-N curve) for synchronous generators
    - EMT model for renewables.

Detailed SSR Assessment

- Shall not result in more than 50% of fatigue life expenditure (FLE).
  - If the FLE is not available, the highest torsional torque caused by SSR shall be under 110% of the torque experienced during a transmission fault with the series capacitors bypassed.
- The oscillation shall be damped and not result in disconnection of any existing transmission and generation facilities.

P.M. Anderson, R. G. Farmer, “Series Compensation of Power Systems”, 1996