SSR/SSCI Investigation/Study Approaches: A Discussion On Application Criteria

PWR Solutions
A GL GROUP COMPANY

ERCOT SSR Workshop

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October 14, 2013

Agenda

A **SSR/SSCI Phenomenon – Background**

B Study Approach – Traditional SSR Investigations

C Study Approach – Sub-Synchronous Control Interaction

D Key Ingredients for Success – Previous Experience

E Development of "SSR/SSCI Criteria" – Key Challenges

F A Holistic Approach – Maybe the Solution?

SSR/SSCI Phenomenon - Background

- Traditional SSR Definition
  - *Interaction phenomenon between power system series capacitors & turbine-generator units at a frequency below nominal frequency*
- Three (3) categories of SSR based on interaction principles
  - Induction Generator Effect (IGE)
  - Torsional Interaction (TI)
  - Torsional Amplification (TA)
- Torsional Interaction (TI)
  - Electrical resonance frequency (f_{en}) of system caused by series capacitors close to compliment of natural torsional resonance frequency of mechanical system (turbine-generator unit)
  - Result in shaft fatigue & undesirable stress

SSR/SSCI Phenomenon - Background

- Induction Generator Effect (IGE)
  - Purely electrical phenomenon
  - Self-excitation of SS oscillations
  - Negative SS resistance of generator rotor circuit exceeds the sum of:
    - Generator Armature/Stator circuit
    - System/Network resistances
- Transient Torsional Torque
  - Oscillations in the shaft torque immediately after a large disturbance
  - Could be sustained over long periods of time (and may even grow) in series compensated networks
  - Grid side reactance scans can provide good insight into transient torque issues
  - Reactance minimum with significant dip in vicinity of (60-TMF)

SSR/SSCI Phenomenon - Background

- SSTI also includes:
  - Impact/interaction of power electronic (typically classic HVDC) controls on closely coupled turbine-generator units
  - “Static” frequency scan techniques may not be adequate for screening such phenomenon
- Sub-Synchronous Control Interaction (SSCI)
  - Interaction of the controls of power electronic devices with series compensated lines in the vicinity
  - In case of WGRs, turbines may offer “negative apparent resistance” at SS frequencies thereby providing negative damping at SS frequencies
  - Presence of network resonant frequency at such SS frequencies can trigger SSCI oscillations (depending on network damping)

SSR/SSCI Phenomenon - Background

- Sub-Synchronous Control Interaction (SSCI)
  - First instance of SSCI observed in ERCOT system – October 2009
  - Tripping of 345kV line on AEP-TCC system resulted in WGR being radial to series caps
  - Significant R&D/investigation has been performed since to study potential for such phenomenon

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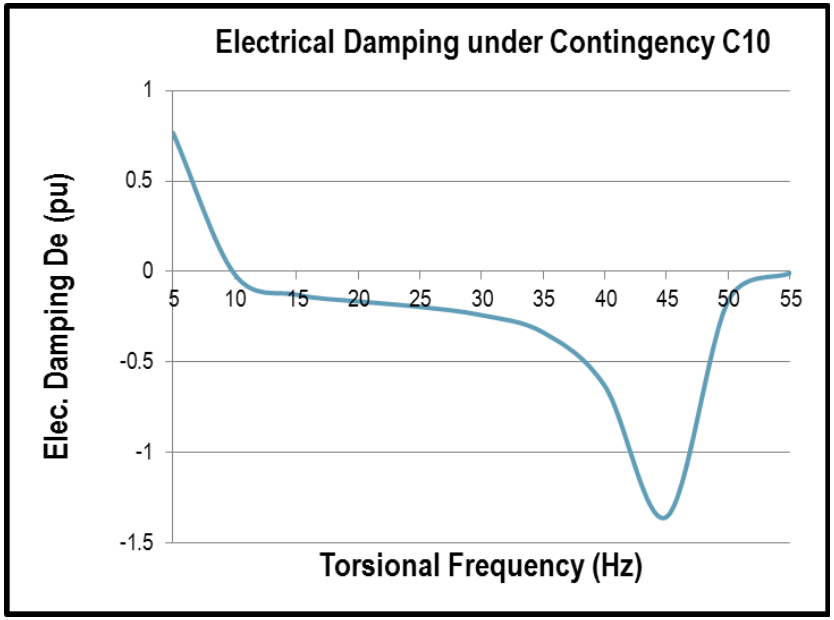
Study Approach – Traditional SSR Investigations

- Traditional SSR Investigation can be classified into three (3) key tasks
  - Task #1 – Torsional Mode & Modal Damping Assessment
    - Shaft mass models can range from rather simple ones to fairly complex ones per PWR experience
    - Perform Eigen value analysis to obtain key information related to the mechanical system
  - Task #2 – System Frequency Scans & Electrical Damping Assessment (Screening Tool)
    - Identify credible & critical system conditions to be evaluated for grid side frequency scans
    - Perform system side frequency scans for all conditions and identify “conditions of interest”
    - Short list conditions of interest for electrical damping analysis
    - Perform electrical damping analysis and compare with modal damping

Study Approach – Traditional SSR Investigations

Contingency Condition	Category	Network Resonant Condition (Y/N)	Fr	(60-fr)	Condition of Interest?
C#1	NERC C	No			
C#2	NERC C	No			
C#3	NERC C	No*	18-19 Hz	41-42 Hz	
C#4	N-4	Yes	20-21 Hz	39-40 Hz	
C#5	N-5	Yes	26-27 Hz	33-34 Hz	
C#6	N-6	Yes	15-16 Hz	44-45Hz	
C#7	N-7	Yes	18-19 Hz	41-42Hz	
C#8	N-7	Yes	16-17 Hz	43-44Hz	
C#9	N-9	Yes	20-21 Hz	39-40Hz	
C#10	N-9	Yes	22-23 Hz	37-38 Hz	

Typical Results, Frequency Scan Assessment



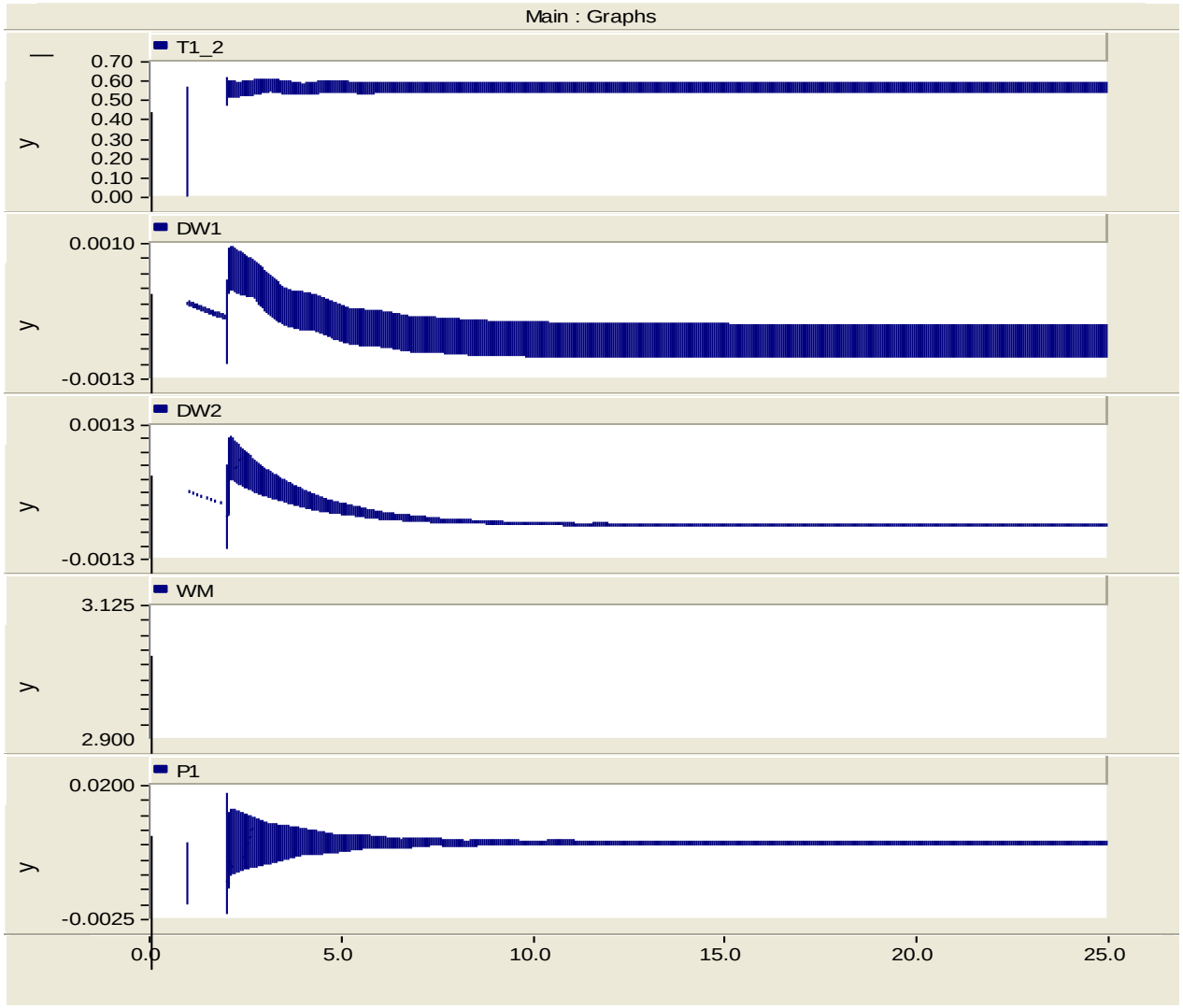
Compare Electrical Damping with modal damping MD#1 & MD#2 to assess over-all damping at two torsional modes

Typical Data from Eigen Value Analysis – Torsional

Study Approach – Traditional SSR Investigations

- Task #3 – Detailed EMT (time domain) simulations
  - Develop detailed EMT models for the machine/unit under study
  - Run faultless and fault based outages to simulate shortlisted contingencies from screening assessment
  - Utilize the results of the EMT simulation to comment on adequacy (or otherwise) of damping and/or presence of any SSR/TT concerns
    - Always advisable to have the vendor review/comment on results

Study Approach – Traditional SSR Investigations



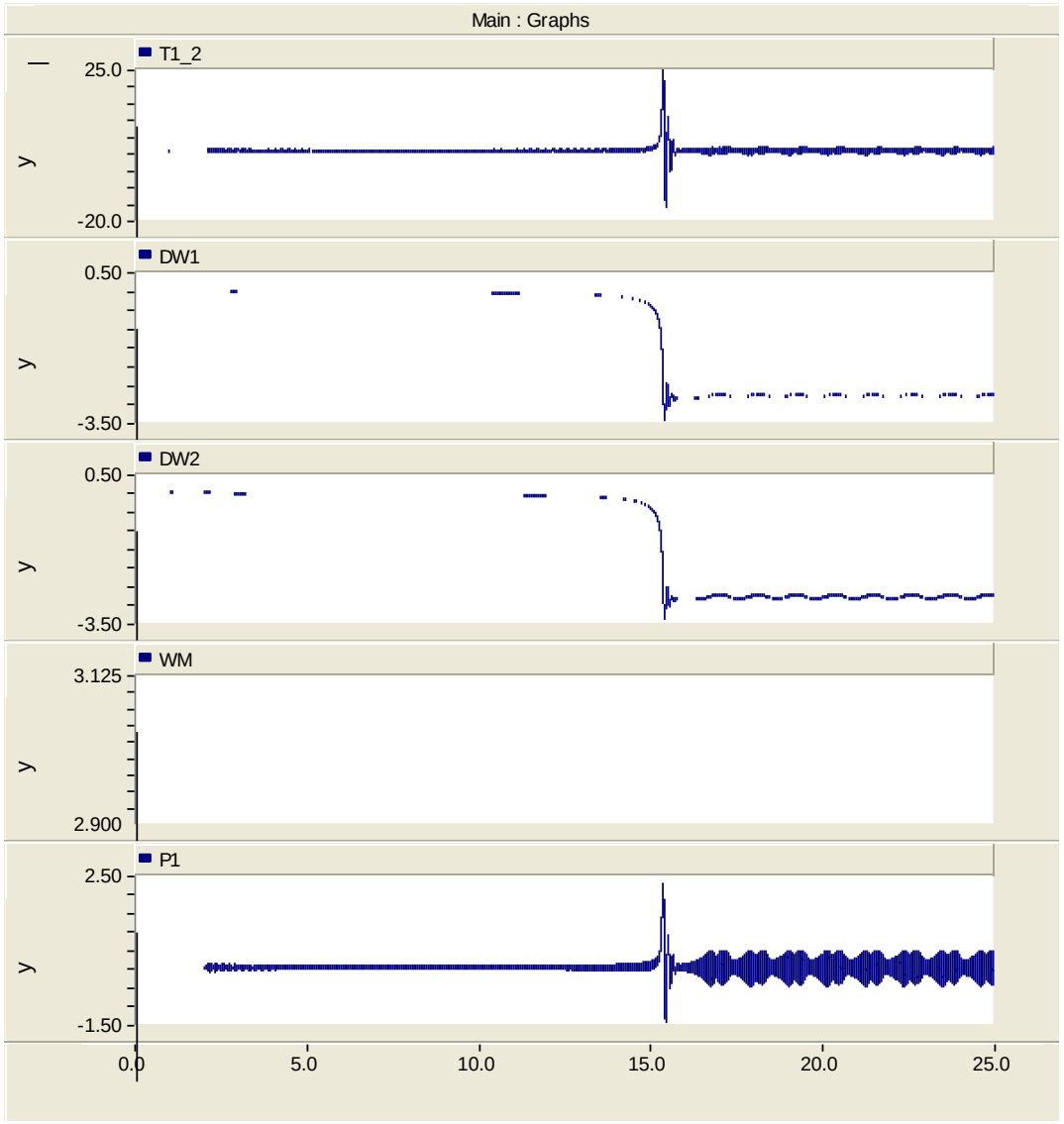
T1_2: Torque on shaft from Mass1-2. Almost settles down

DW1/DW2: Delta of mech speed of mass1/2 w.r.t rated speed. Returns to constant value after disturbance

P1: Mech. Position of mass 1 w.r.t generator. Settles down to constant value i.e. constant twist i.e. no shaft fatigue

Typical Time Domain Simulations – No SSR Issues

Study Approach – Traditional SSR Investigations



T1_2: Torque on shaft from Mass1-2. Keeps oscillating after event cleared

DW1/DW2: Delta of mech speed of mass1/2 w.r.t rated speed. Drastic change at 15.0 secs and keep oscillating after

P1: Mech. Position of mass 1 w.r.t generator. Keeps oscillating i.e. twist not constant i.e. shaft subjected to fatigue

Typical Time Domain Simulations – Presence of SSR concern and shaft fatigue

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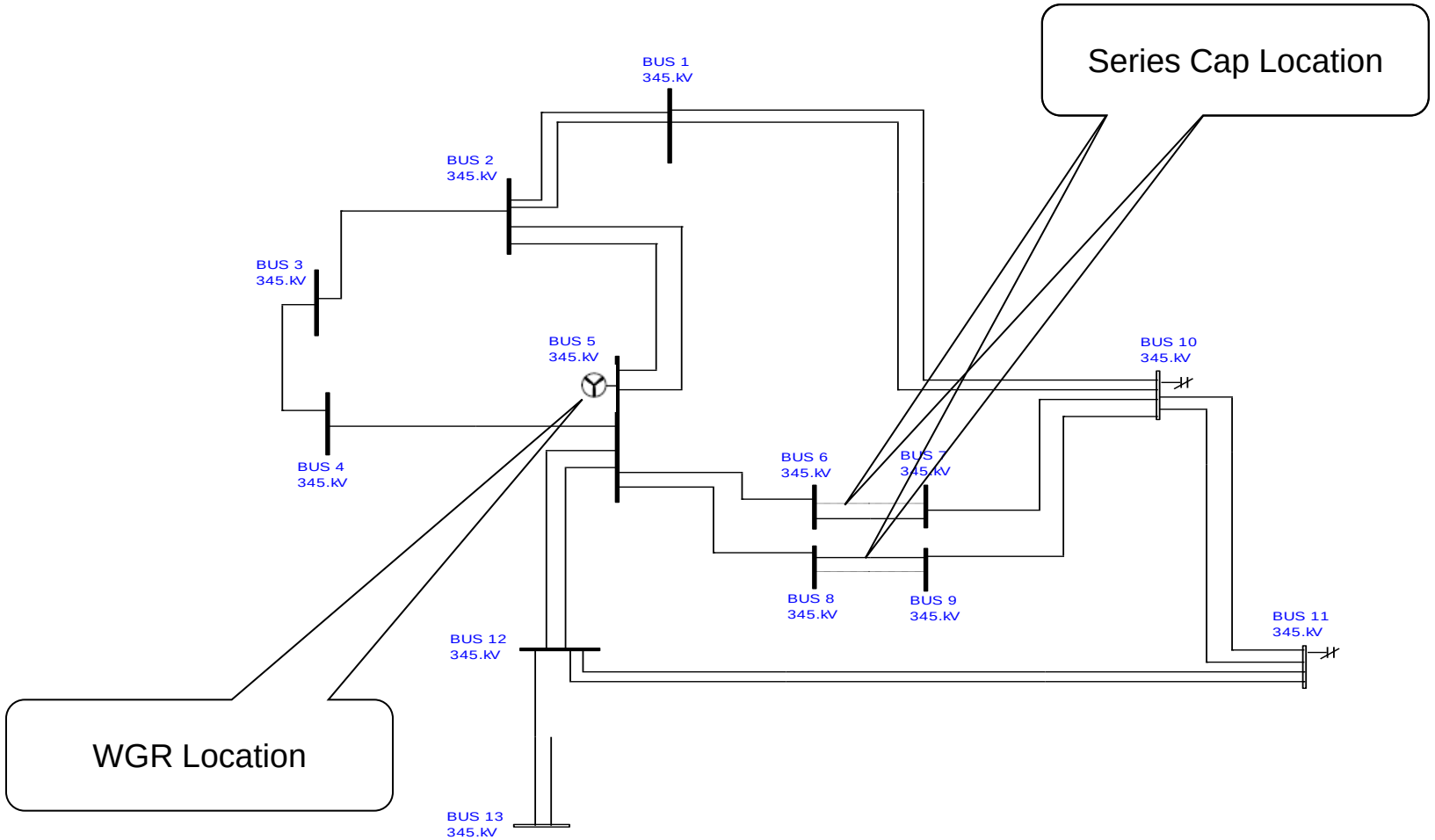
Study Approach – SSCI Investigations

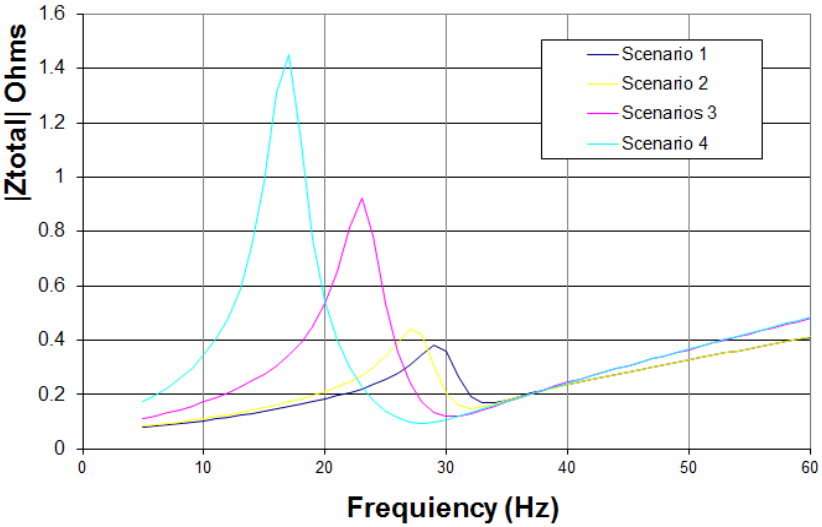


One-line Schematic, Excerpt from ERCOT CREZ System

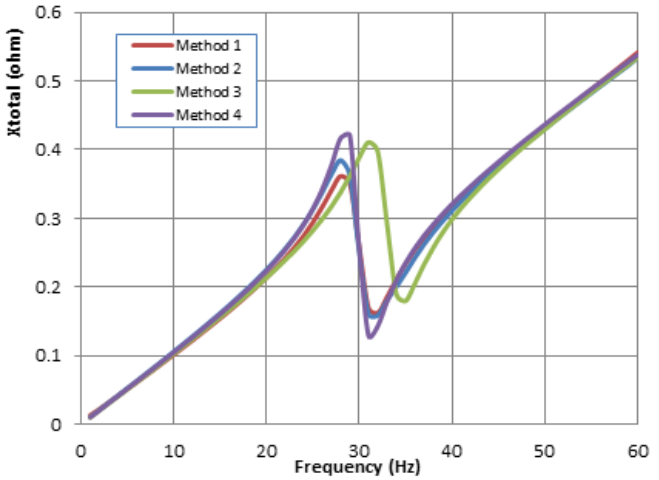
Study Approach – SSCI Investigations

Scenario #	System Conditions
1	All lines in-service
2	Bus 5 - Bus 2 Double Circuit Out
3	Bus 5 - Bus 12 Double Circuit Out
4	Bus 5 - Bus 2 Double Circuit & Bus 5 - Bus 12 Double Circuit Out

Scenario Definitions



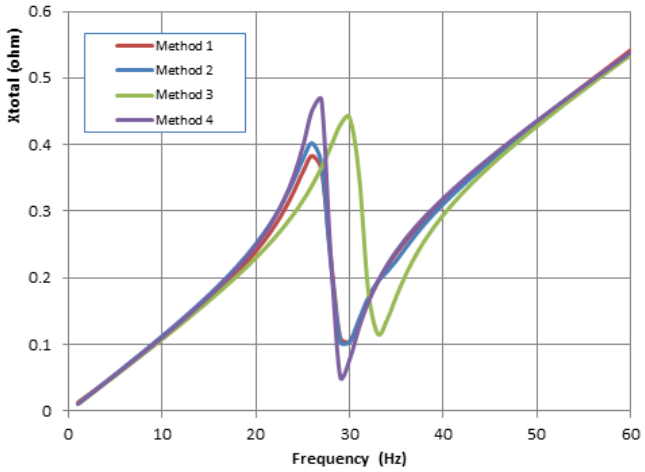
Impedance Scans, Sc 1-4[1]



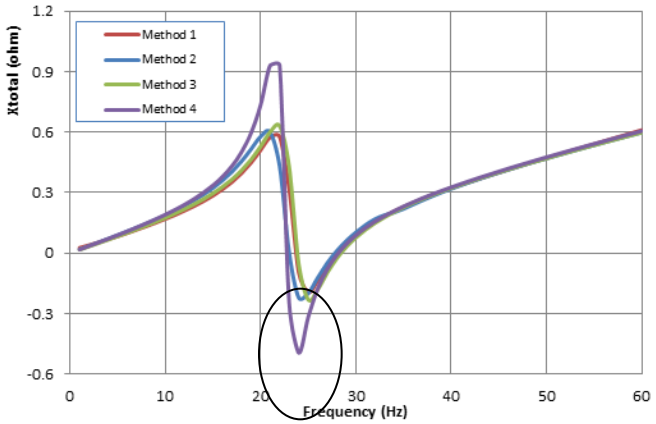
System Reactance Scans, Scenario #1[1]

1: Reactance Scan Cross-Over Based Approach for Investigating SSCI Concerns under Non-radial Conditions, Y. Cheng , M. Sahni, D. Muthumuni , B. Badrzadeh , IEEE Transactions on Power Delivery, Volume 28, Issue 2

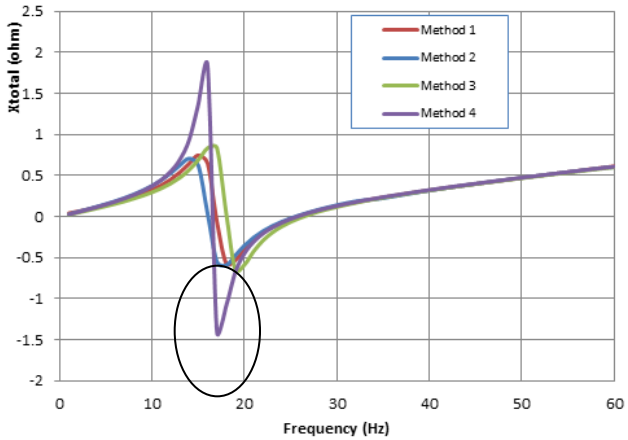
Study Approach – SSCI Investigations



System Reactance Scans, Scenario #2[1]



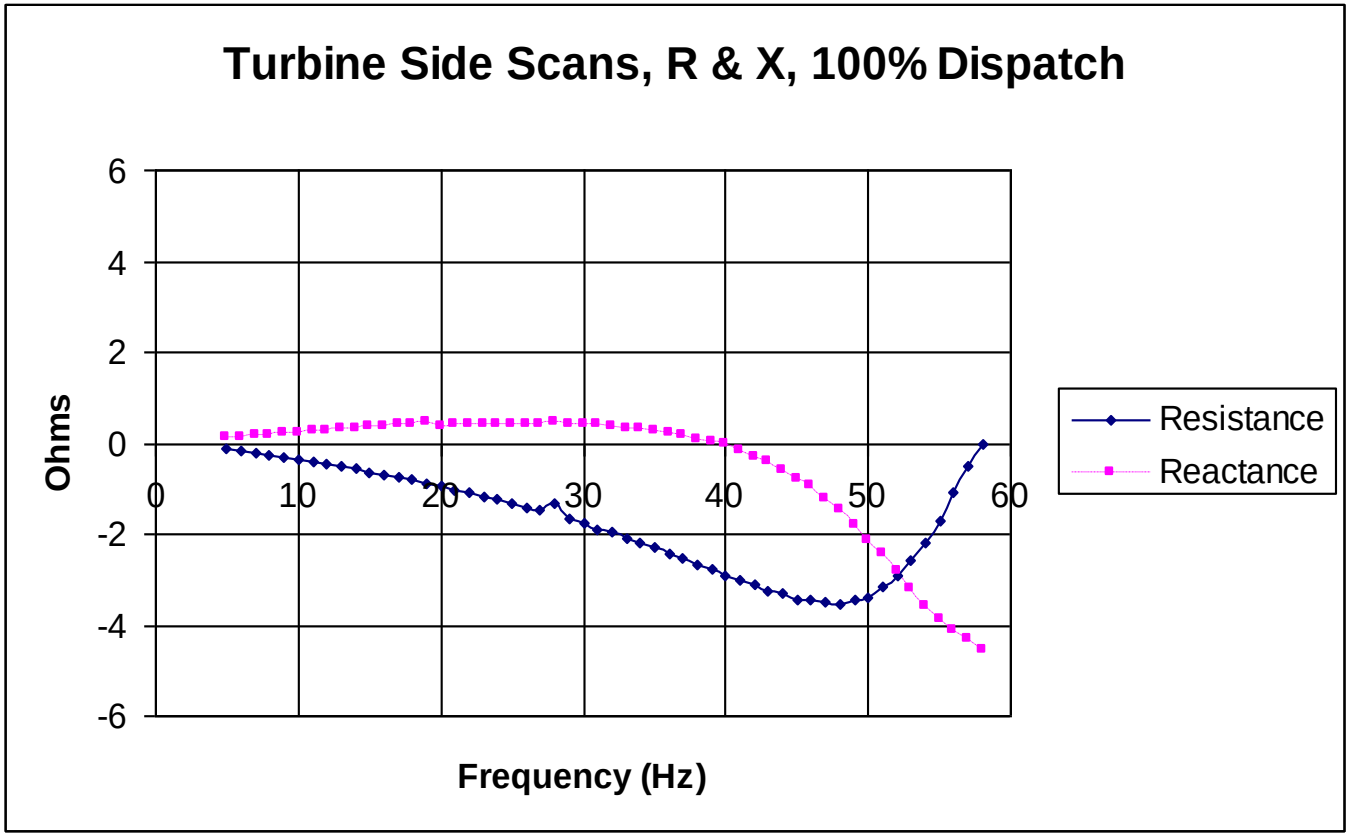
System Reactance Scans, Scenario #3[1]



System Reactance Scans, Scenario #4[1]

1: Reactance Scan Cross-Over Based Approach for Investigating SSCI Concerns under Non-radial Conditions, Y. Cheng , M. Sahni, D. Muthumuni , B. Badrzadeh , IEEE Transactions on Power Delivery, Volume 28, Issue 2

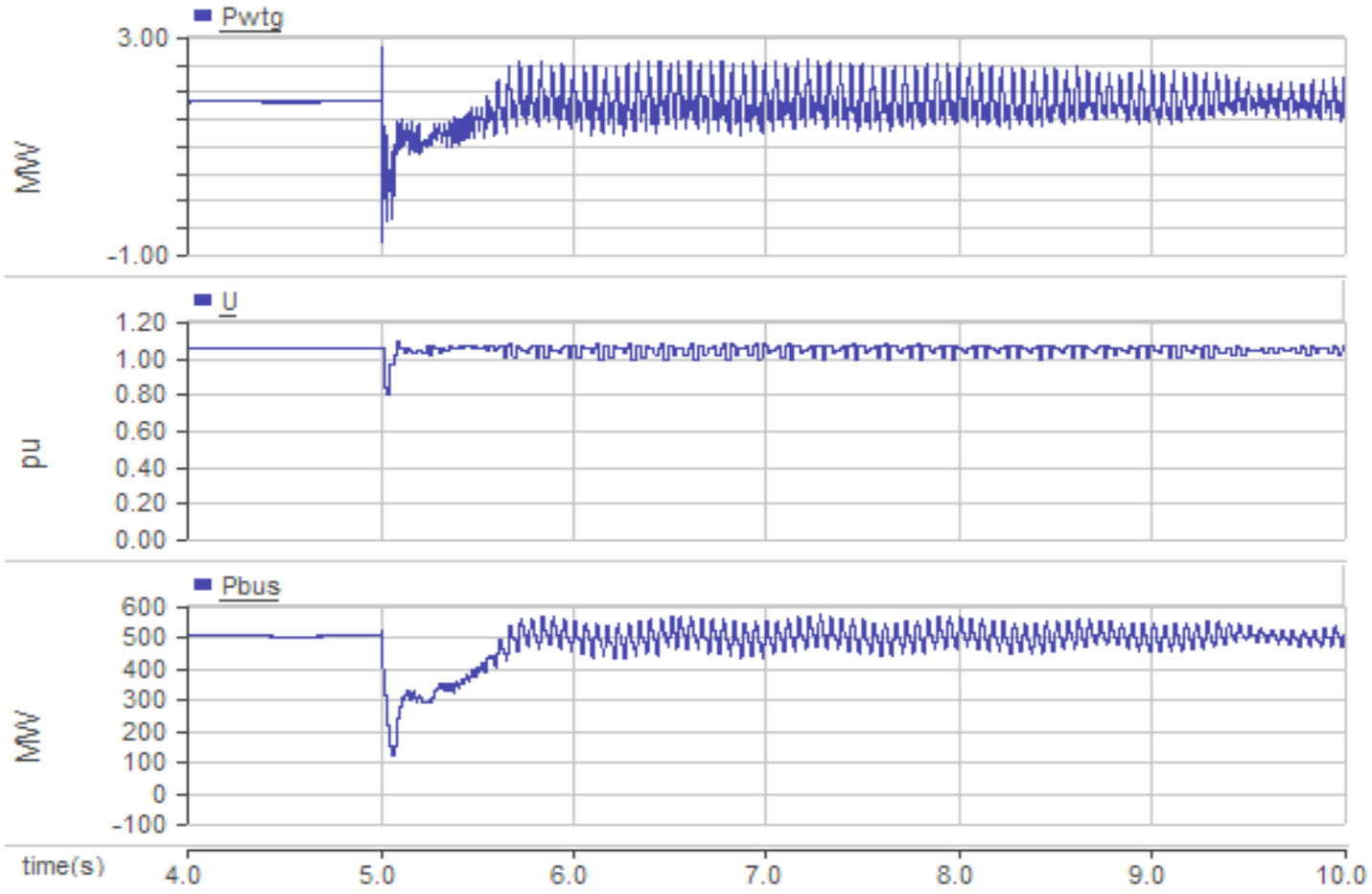
Study Approach – SSCI Investigations



Turbine Side Scans, Sub-Synchronous Frequency Range [2]

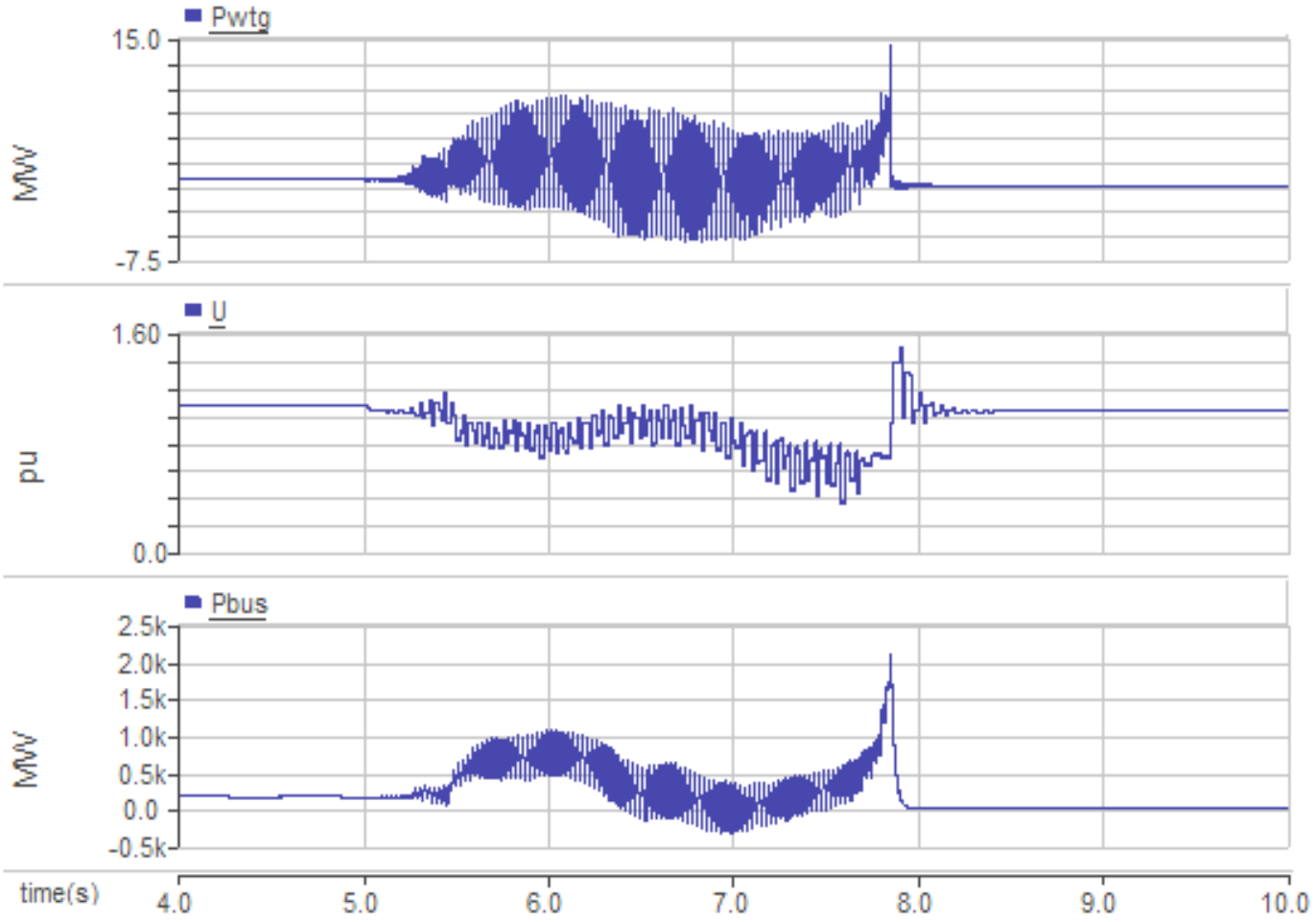
2: Sub-synchronous Interaction in Wind Power Plants- Part I: Study Tools and Techniques, B. Badrzadeh, M. Sahni, D. Muthumuni, Y. Zhou, A. Gole, IEEE Power & Energy Society General Meeting

Study Approach – SSCI Investigations



EMT Simulation Results, Fault-based Outage, Scenario #3 [1]

Study Approach – SSCI Investigations



EMT Simulation Results, Faultless Outage, Scenario #4 [1]

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Key Ingredients for Success – Previous Experience

- Numerous lessons learnt from significant experience in running varied SSR/SSCI studies
  - Numerous SSR/SSCI studies performed spanning all parts of the ERCOT grid including CREZ and LRGV
  - Traditional SSR studies performed for various generation technologies including coal fired units, NG CC facilities and even reciprocating engines
  - SSCI studies performed for numerous turbine vendors including Type III and Type IV turbines
  - Working with turbine vendors in performing such studies on the ERCOT grid
  - SSTI screening studies performed for Railroad DC Tie expansion
  - Trained ERCOT on SSCI screening techniques for both SSR/SSCI studies
  - **Numerous lessons learnt from each of these efforts**

Key Ingredients for Success – Previous Experience

- Numerous lessons learnt from significant experience in running varied SSR/SSCI studies
  - Transmission grid or the generation technology evaluation alone cannot provide complete picture
  - Presence of reactance cross over on grid side scans **does not guarantee** any SSR/SSCI issues
  - Presence of torsional modes at SS frequencies for conventional units does not guarantee SSR concerns
  - Presence of negative resistance for WGR turbine side scans is not s sure shot indicator of SSCI issues
  - A **combination of generation and transmission side evaluations** provides a complete picture on potential SSR/SSCI concerns
  - Makes SSR/SSCI investigations unique in that equal knowledge of both systems are required to perform a knowledgeable and complete study

Key Ingredients for Success – Previous Experience

- Key Performance Dictators
  - Developing accurate generator models are key to this effort and may require tools and expertise beyond what is currently deployed
  - Development of mechanical shaft-mass models for Eigen value & modal damping analysis expected to be performed in Matlab
  - Standard frequency scanning tools will not work for performing turbine side scans – Specific tools required
    - Dynamic frequency scanning techniques need to be deployed
  - Slightly advanced mathematical calculations for performing electrical damping analysis
  - Results of the turbine side scans and EMT simulations significantly dependent on PSCAD/EMT models for turbines
  - Models yet to exhibit the fidelity/maturity levels observed for PSS/e turbine dynamic models
  - Need to be cognizant of such issues when working on a study of this nature – **GIGO!**

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Development of "SSR/SSCI Criteria" – Key Challenges

- Defining the "N-x" threshold is important albeit only part of the over-all picture
  - SSCI and/or SSR (TT) issues not limited to radial conditions
  - More probable N-2/N-3 events can result in such issues depending on system damping, generator technology and other factors
  - On the flip side, N-9/N-10 conditions, resulting in radial conditions may not result in SSR issues
    - Realistic example of this in ERCOT (study performed by PWR and presented to ERCOT)
  - Establishing the "N-x" condition helps "outline a boundary" of conditions
  - Establishing a "static" "N-x" criteria may be fraught with risk given the dynamic nature of the power system grid (and with all the developments in ERCOT)

Development of "SSR/SSCI Criteria" – Key Challenges

- Key questions to be asked and deliberated over in order to establish a practical and efficient criteria
  - Do we continue to treat SSR/SSCI as a "special study/condition"?
  - Why should (or should not) SSR/SSCI be treated as "any other" reliability concern to the system – **First Incremental Reliability Concern**
  - Is there a need to better integrate the SSR/SSCI investigation into the full interconnection study (for resource integration) in order to achieve optimal results from system planning perspective?
  - How do we treat SSR/SSCI issues arising from transmission expansions/additions in the long run?
    - This may require a "system level study" given the number of generators to be included in such an evaluation
  - What would that integration look like and individual entity responsibilities/liabilities?

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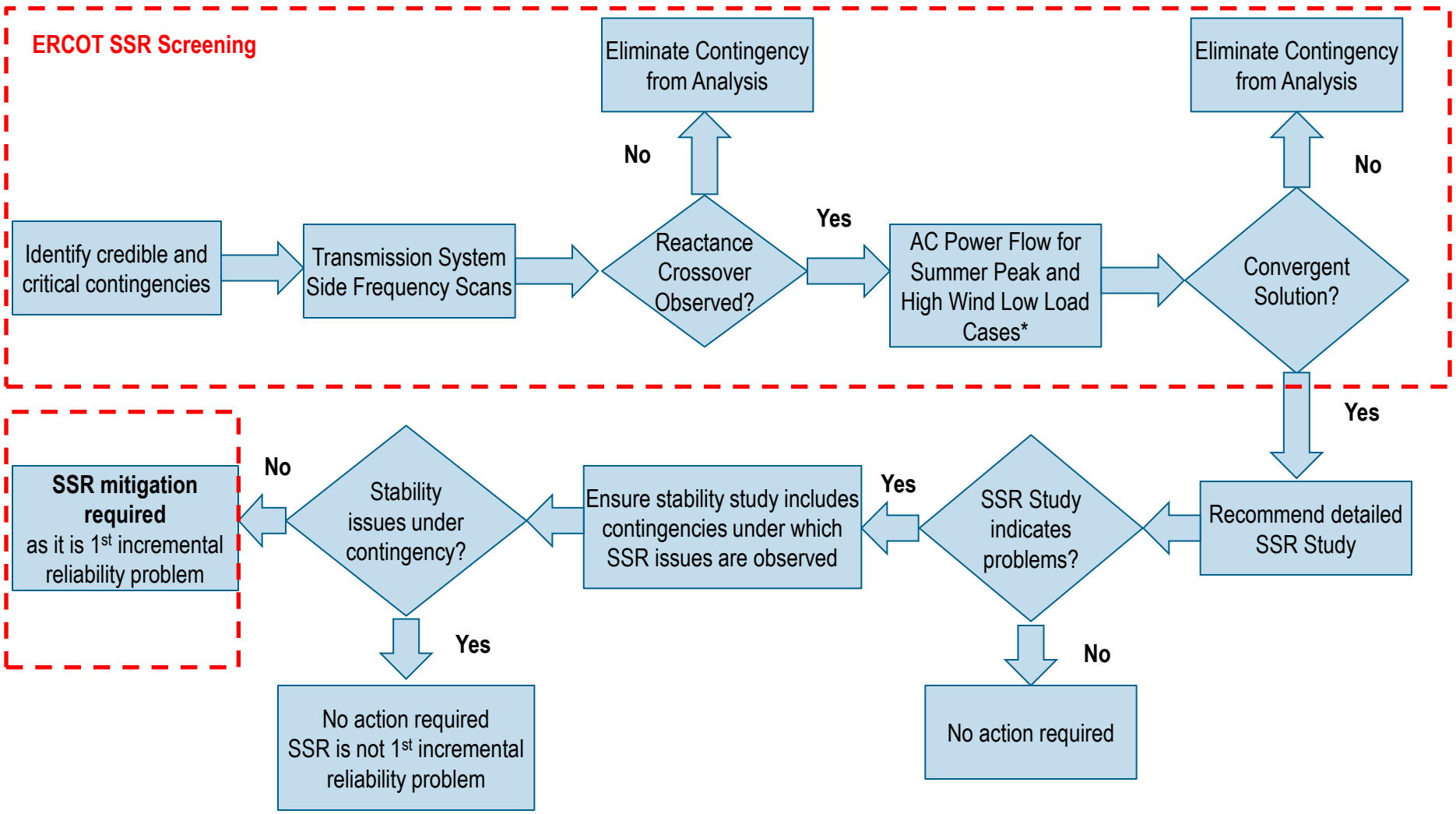
A Holistic Approach – Potential Solution?



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