Artificial Island Open Window Concerns re: Dominion Proposal 1A

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Dominion Proposal No. 1A

- The Dominion proposal incorporates Thyristor Controlled Series Compensator (TCSC) and Static Var Compensator (SVC) devices near New Freedom Switching Station and doubling up breakers at Hope Creek, New Freedom, and East Windsor.

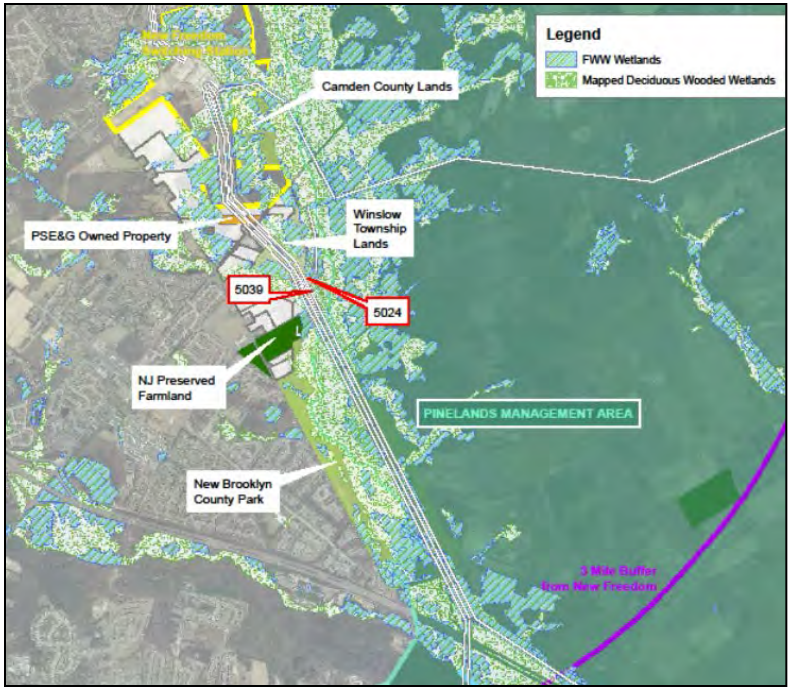
- The Dominion proposal relies completely on the unproven combination of active devices and does not provide additional transmission capacity for future use.

- This proposal was not considered sufficiently technically robust to be included with other finalists at first. Parties were not afforded the opportunity for comments as provided for other proposals.

- PSE&G is taking this opportunity to express serious concerns regarding this proposal. These concerns are grouped into :
  - Constructability
  - Technical

Constructability Concerns – Siting Issues

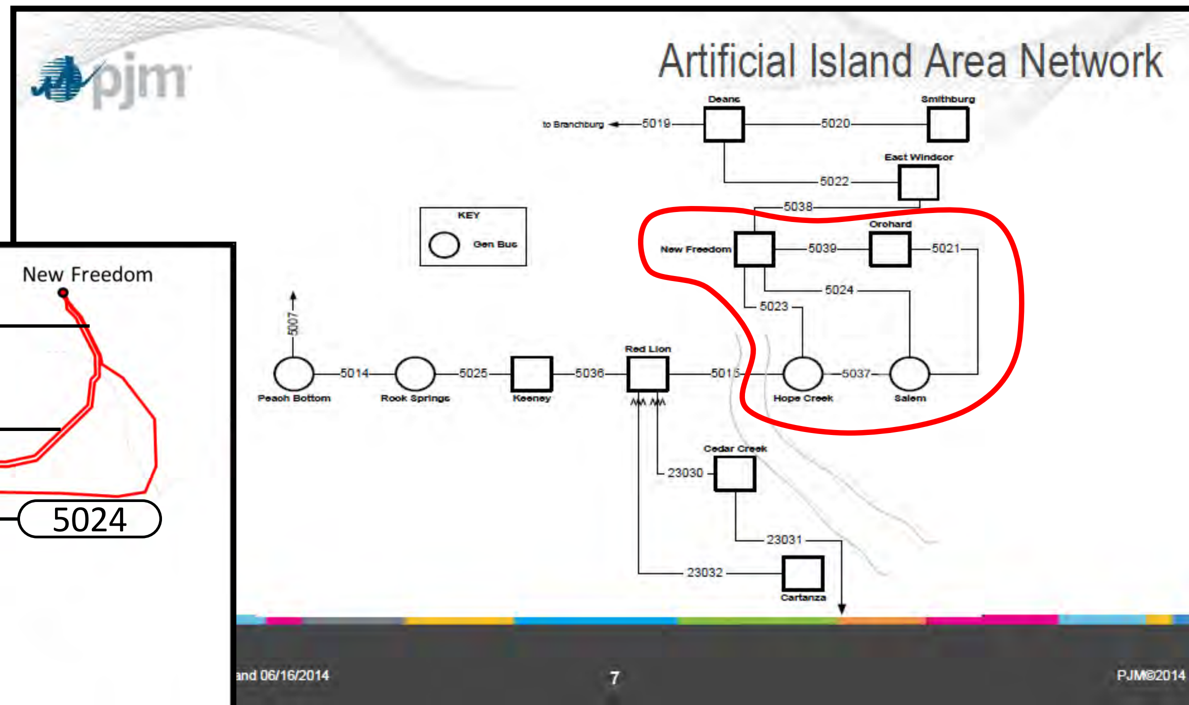
- **Dominion has not offered a cost cap or price assurance to PJM**
  - Dominion baseline SVC projects in the RTEP have seen cost escalation that have ranged as high as 57% of initial baseline estimate that should question developers' and suppliers' confidence in delivering this technology on budget.
- **30 – 40 acres property requirements**
  - A four bay breaker-and-a-half station is required to reliably route existing lines.
  - The SVC and two series capacitors/TCSCs providing up to 90% compensation were estimated at up to 40 acres by PSE&G whereas Dominion estimates 10 acres.
  - Additional right-of-way to bisect the 5023, 5024 & 5039 could include 6 parallel 500kV lines.
- **This proposal has no permitting advantage**
  - There are no suitable parcels within 3 miles.
  - The surrounding areas are either wetlands or protected NJ Pinelands National Reserve.
  - Options below the Atlantic City Expressway would encounter Federal permitting requirements.
  - Ultimately, no large parcels exist to accommodate the facilities required or permitting is extensive.

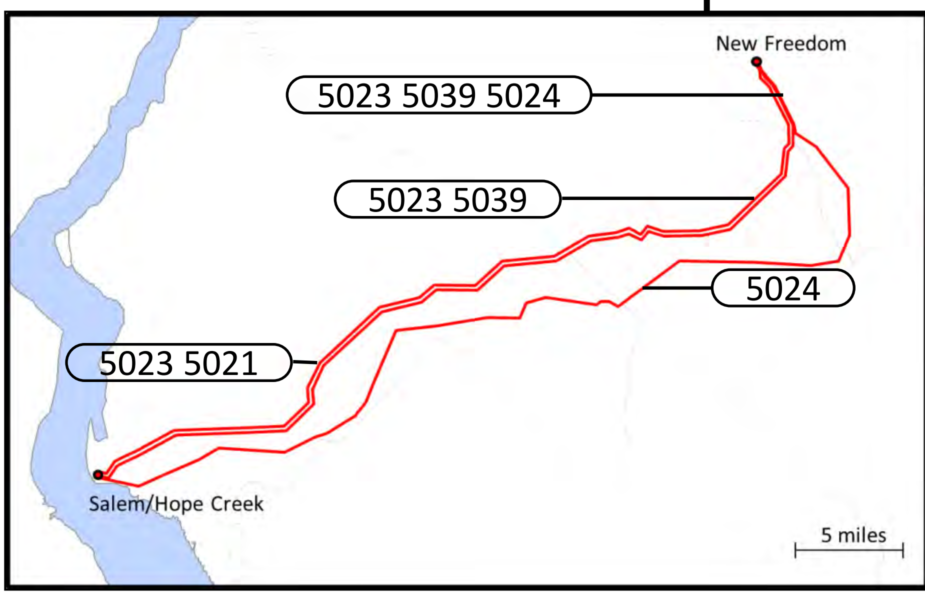


New Freedom Station & Pineland Proximity
500kV circuits left to right: 5023, 5039, 5024 & 5038

Constructability Concerns – Line Configuration

- Constructability and design appear not to reflect physical layout
  - 5023 & 5024 are not parallel as shown in the associated one-line but rather are separated by 5039.
  - Alternatives include a highly undesirable 500kV line crossing, two full stations opposite of 5039, or significantly greater facility size to resolve this separation.
  - Outage impacts of alternatives would be deterring.





PSE&G Technical Concerns

1. **First proposed application of a combination of TCSC and SVC devices used in US and in the World**

2. **Insufficient field operational history for TCSC/SVC operational reliability**

3. **Subsynchronous Oscillations (SSO) issues**
   - **Sensitivity on percent series compensation**
   - **Initial frequency scan results**

4. **Other technical concerns**

PSE&G Technical Concerns

1. **First proposed application of a combination of TCSC and SVC devices in the United States and in the World**

   - The effects and interactions of these devices have not been experienced/tested and the impacts and phenomena they may create are not known.

     The following are concerns for these devices in close proximity of each other of which the industry has no practical experience record:

     - Turbine shaft torsional response
     - Generator voltage and reactive power control
     - Effect of harmonics, varying frequency, and varying transmission system voltage on the timing and consistency of electronic gating

   - Proper tuning of controls becomes more difficult and challenging as the number of strongly interacting elements increases. When considering excitations systems, prime movers, PSS, AVR, SVC, and TCSC, it could lead to potentially destabilizing control mode oscillations.

   - The ability to study such control interactions by simulation is limited, even with present simulation technology.

PSE&G Technical Concerns

2. Insufficient field history for TCSC/SVC operational reliability

Examples of TCSC Applications*

Year	Country	KV	Appliction: SSR mitigation	Appliction: Post-contingency stability	Appliction: Dynamic flow control	Location	Source
1992	USA	230			✓	Kayenta substation, AZ	1, 2
1993	USA	500	✓		✓	C.J.Slatt substation, OR	1
1998	Sweden	400	✓			Stöde	1, 3
1999	Brazil	500	✓	✓		Imperatriz and Sarra de Mesa	1, 4
2002	China	500	✓	✓		Pinguo substation, Guangzhou	1
2004	India	400	✓	✓		Raipur substation	1, 5
2004	China	220	✓	✓		North-West China	1
2014	United Kingdom	400	✓	✓	✓	Hutton substation	6

SVC Application History in PJM

Project	Type	Size	In-Service Date	Purpose
Loudoun 500kV	SVC	2 +250/-150MVAR	7/31/2014	voltage control
New Castle	SVC	150MVAR	6/1/2015	voltage control
Cedar 230kV	SVC	+150/-100MVAR	6/1/2016	voltage control
West Wharton 230kV	SVC	+40/-260MVAR	4/1/2015	voltage control
Squab Hollow	SVC	250MVAR	6/1/2015	voltage control
Waldo Run 138kV	SVC	70MVAR	12/1/2014	voltage control
Erie South 230kV	SVC	+250/-150MVAR	6/1/2016	voltage control
Black Oak 500kV	SVC	+575/-145MVAR	2012	voltage control
Larrabee 230kV	SVC		1990's	voltage control

- 1992: Kayenta, US (WAPA). This application did not work; converted to fixed series capacitor
- It has been over twenty years since the last US installation of a TCSC.
- PJM has limited history with SVCs with the exception of Larrabee, which was not considered a positive experience.
- TCSC and SVCs have been used for voltage and flow control, not for transient stability.

*Examples of TCSC Applications as cited in the Dominion proposal

PSE&G Technical Concerns

3. Subsynchronous Oscillations (SSO) issues

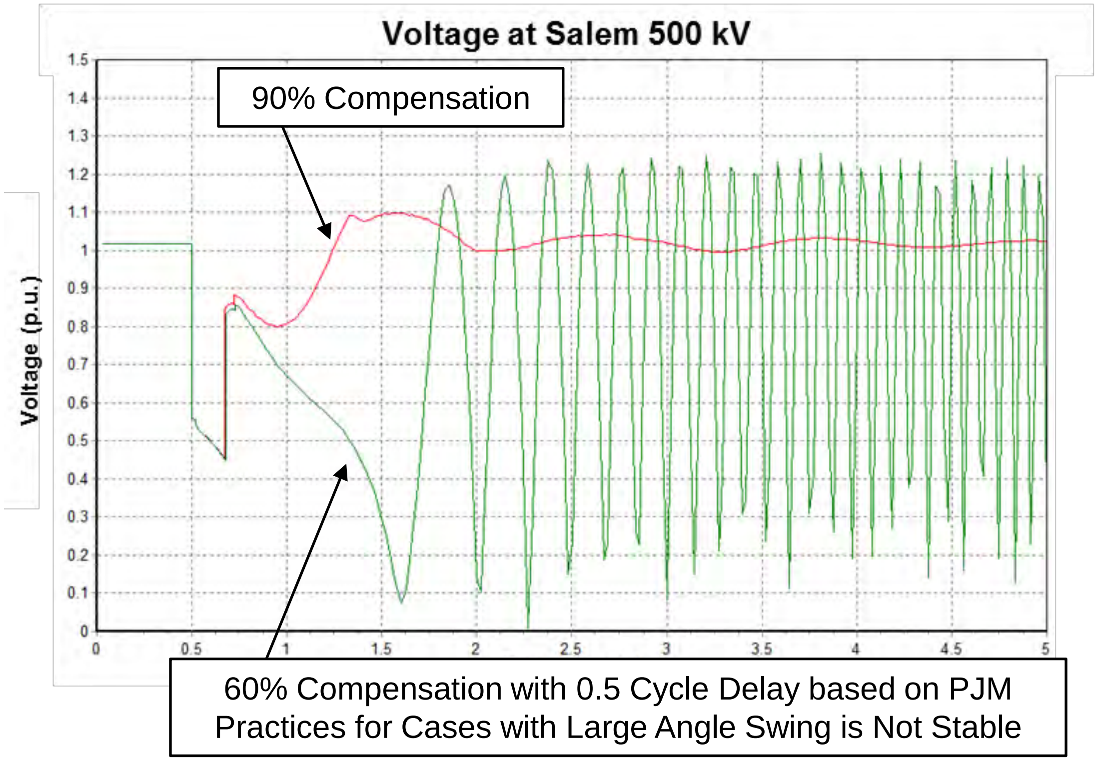
- TCSCs introduce subsynchronous oscillations that could have devastating impact on the three nuclear plants at Artificial Island and may as well impact Peach Bottom, Red Lion, Rock Springs, and other generating stations in the area.
- SSO has not been a concern on the PJM system before. If accepted, the Dominion project would introduce this new phenomenon to the PJM system and at the second largest nuclear complex in the United States.
- In 1990, the PJM transmission owners rejected a proposal to install series compensation on key 500kV facilities for fear of SSR impact on the Keystone and Conemaugh units.
- The following table shows historical incidents in the United States where SSO has caused severe damage to generation units. For more details, see Appendix (slides 20-22).

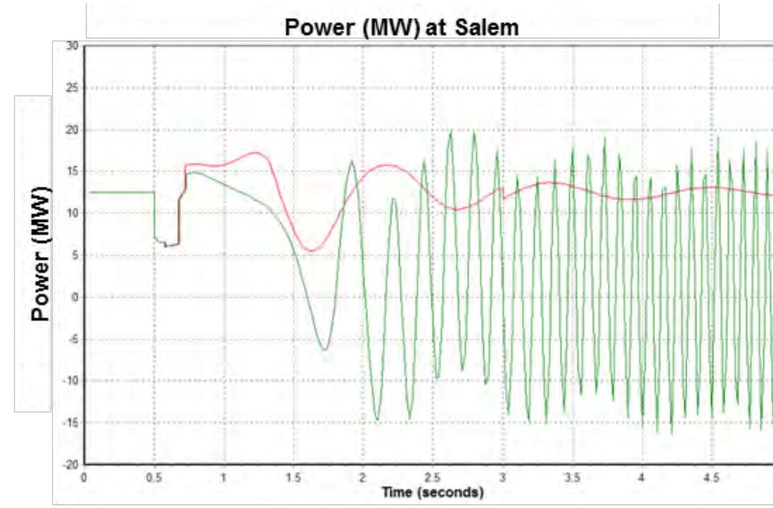
Location	Description	Year
Mohave Mohave	1580MW coal-fired 1580MW coal-fired	1970 1971
South Texas - Ajo	wind farms – 1000MW	2009

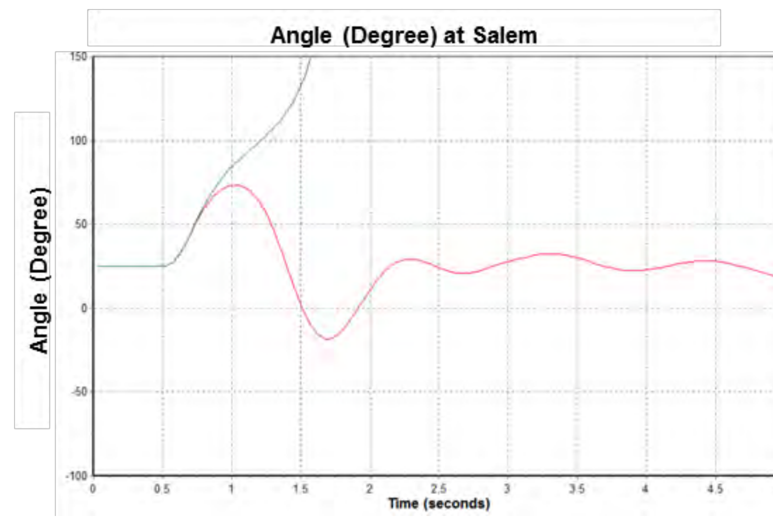
- Preliminary results from a screening frequency scans show subsynchronous resonance (SSR) concerns for N-1 outages. N-2 outages and beyond are expected to show more severe concerns
- PJM Staff dynamic simulations tested the proposed TCSC devices at 90% compensation only. If the capacitor is to be modulated, it will be necessary to ensure that all potential modulation (10% to 80%) are also stable.

Sensitivity on Percent Series Compensation

MEPPI examined Series Compensation of 60%, 70%, 80%, and 90%







Stability simulations modeled TCSC at a fixed 90% compensation without modulation. Lower compensation/modulation may lead to system instability.

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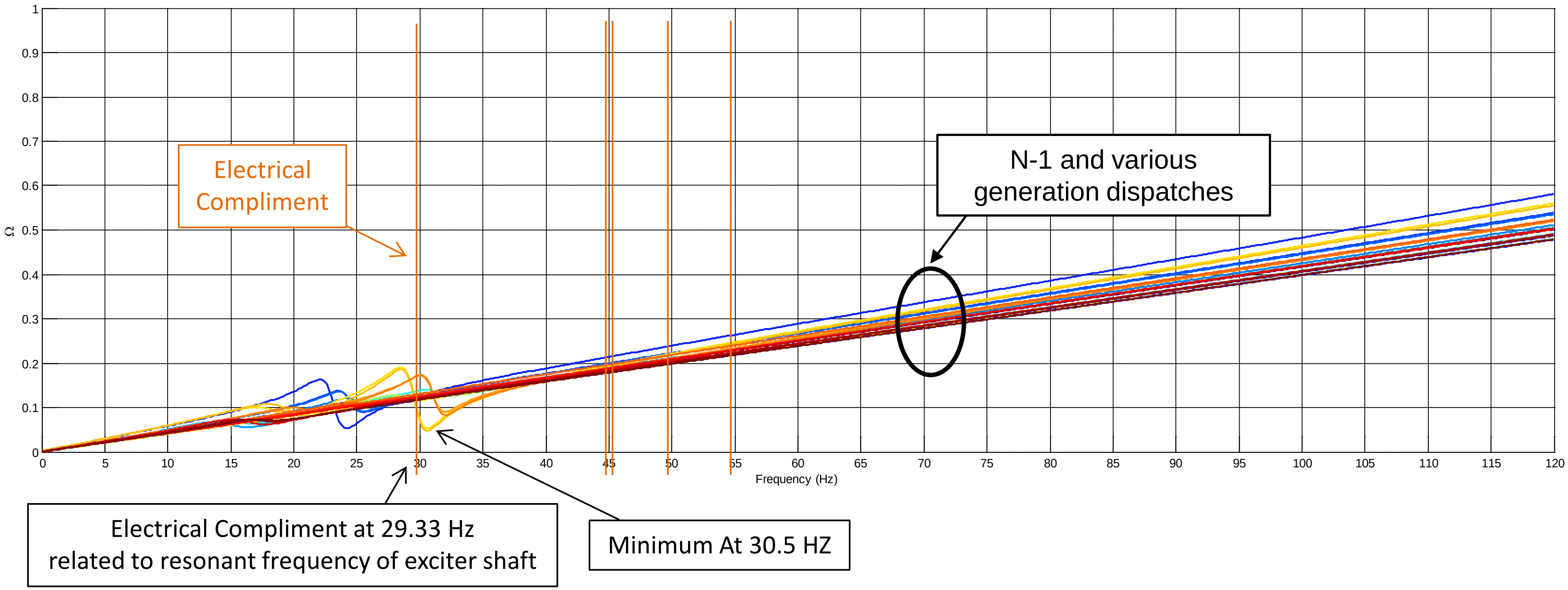
Preliminary Results-Subsynchronous Frequency Scans

MEPPI performed preliminary screening subsynchronous frequency scans for Salem Unit 2 using modal data received by PSE&G. Data for S#1 and HC units are not available.

40% COMPENSATION



The results show:

- There are interaction and SSR problems associated with 40% compensation that may cause serious damage to AI units.
- N-2, N-3 … circuit outage results are expected to show more/severe concerns.
- It is recommended that up to N-5 outages be studied, since these analyses could not be readily done in time.

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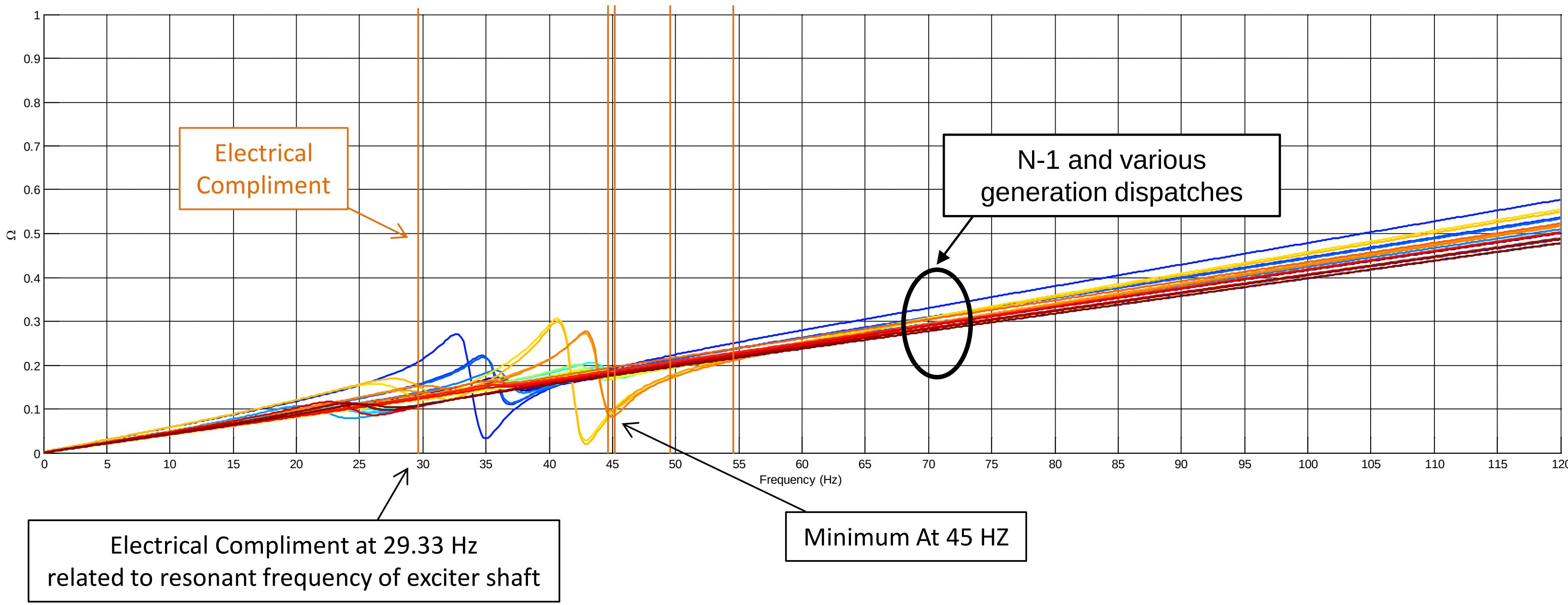
90% COMPENSATION



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PSE&G Technical Concerns

4. Other Technical Concerns - Torsional Impacts Caused by Switching Events:

- Resonant coupling can occur [1] with dangerous effect when the frequency of an electrical resonance in the transmission system coincides with a mechanical resonant frequency of a turbine shaft.
- Transmission system events that cause sudden changes in turbine-generator torque are a significant concern [2]. A single sudden change in electric power flow on transmission near a power plant can cause a change in torque large enough to adversely impact a shaft. Rapid sequences of electric power flow changes can cause amplification of torsional responses of turbine shafts, [3],[4]. For References 1-4, see Appendix (slide 19)

The proposed use of series compensation in the AI-to-NF lines raises the possibility of occurrence of sequences of power flow changes that could have adverse impacts on the shafts of the Artificial Island generating units.

Evidence from preliminary frequency scans necessitates detailed transient torque simulations. This will determine the extent of the series compensation impacts on shaft torques and corresponding shaft fatigue.

PSE&G Technical Concerns

4. Other Technical Concerns - Resonant Interaction of Electric Transmission and Turbine Shafts:

- If resonant coupling occurs and is unchecked by either natural or synthetic damping, the likely consequence of such interaction is a failure of the turbine generator shaft. In practice, either or both of electrical and mechanical protection schemes would be set up to detect evidence of resonant interaction and trip the affected turbine(s) before structural damage is incurred.

If the protection means operates properly, up to 3 units (3800MW) of generation could be tripped, which could lead to system wide blackout.

If the designed protection fails to operate properly, the three AI unit shafts are potentially exposed to serious damage followed by unit tripping and the potential for system wide blackout.

PSE&G Technical Concerns

4. Other Technical Concerns - Combined Effect of Subsynchronous Current and Switching:

- The switching of a series compensated line can initiate or amplify the torsional response of nearby turbine generators by two mechanisms:
  - The change in fundamental frequency current caused by the switching creates a sudden change in generator torque
  - The switching initiates a component of subsynchronous current in the series compensated line that, in turn, creates an oscillatory torque response in nearby generators
- Events associated with the cases under consideration here involving fault application, breaker operations, and series capacitor insertion can initiate the phenomena described above.

This demonstrates the concern of the torsional response of the turbine shafts and torsional interactions.

While these effects are not necessarily additive, they can be additive, depending on the timing with which events occur. It is practically impossible to control the sequencing of events with sufficient precision to ensure that individually small effects are not amplified to have potentially significant adverse effects on turbine shafts.

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Risks Presented by Dominion TCSC Proposal

The Dominion project introduces the following the risks:

- The proposed devices do not have sufficient field operating history to judge their reliability and response time. A critical area such as Artificial Island should not be used as a test bed for a first of a kind TCSC/SVC application.
- Early results from a frequency scan study showed serious SSR concerns for N-1 outages that may cause damage to AI units and serious consequences to the power system.
- N-2 and beyond outages are expected to show more/severe SSO concerns.
- Safeguarding the AI units by installing relays to detect resonant interaction and trip units, is not a viable solution. If relays fail, turbine/generator shafts may be damaged, unit would trip and could potentially lead to a system wide blackout. If the relays operates properly and disconnects the units, tripping 3800MW of generation at EMAAC would also cause system wide blackout.
- The cost for this project is not capped. PSE&G feels that the cost of the project is understated and the project will meet serious environmental and constructability obstacles.

This proposal is dependent on active devices without a proven history of operation. It introduces new application of devices with risks that could lead to consequences that can severely impact the reliability of the PJM grid.

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Potential Consequences

The risks associated with the Dominion project could lead to the following consequences:

1. Introduction of a harmful and potentially devastating phenomena to the PJM system that does not exist today
2. Serious damage to the nuclear units
3. Uncontrolled shutdown of nuclear units
4. System blackout from loss of 3800MW at Artificial Island
5. Uncontrolled shutdown of other nuclear units without offsite power

The U.S.-Canada Power System Outage Task Force estimated the 2003 Blackout to cost between $4 and $10 billion.

This sequence of events could result in one or more nuclear units being out of service for a lengthy period of time. The cost of the higher LMPs resulting to the ultimate customer would be incalculable.

Conclusion

PSE&G submits that the risks of any of these consequences would greatly outweigh any potential savings associated with the Dominion TCSC proposal.

Appendix

Definitions of Sub-Synchronous Oscillations (SSO)

Sub-Synchronous Oscillations is a phenomena where growing quantities of power are exchange between the electric network and a turbine generator at frequencies lower than 60Hz. It can occur between two or more transmission elements or generation resources at a natural harmonic frequency lower than 60Hz including, but not limited to, following types of interactions:

Sub-Synchronous Resonance (SSR)

Resonance is the tendency of a system under excitation to oscillate at certain frequencies.

SSR is the torsional interaction between series capacitors and long-shaft multi-mass generator. SSR has the potential to break generator shafts, damage generator protection and series capacitor banks. Adding series compensation to a power system introduces SSR concerns.

Sub-Synchronous Torsional Interaction (SSTI)

The Torsional interaction between active transmission elements and turbine-generators

Sub-Synchronous Control Interaction (SSCI)

Detrimental interaction between firing level controls of closely located power electronic devices.

References

1. READER'S GUIDE TO SUBSYNCHRONOUS RESONANCE IEEE Committee Report, IEEE Transactions on Power Systems. Vol. 7, No. 1, February 1992

2. IEEE SCREENING GUIDE FOR PLANNED STEADY-STATE SWITCHING OPERATIONS TO MINIMIZE HARMFUL EFFECTS ON STEAM TURBINE-GENERATORS, IEEE Working Group Report, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99, No. 4 July/Aug 1980

3. TURBINE-GENERATOR IMPACT TORQUES IN ROUTINE AND FAULT OPERATIONS, J. M. Undrill, L. N. Hannett, IEEE Transactions on Power Apparatus and Systems, Vol.PAS-98, No.2 March/April 1979

4. STATUS OF EVALUATING THE FATIGUE OF LARGE STEAM TURBINE-GENERATORS CAUSED BY ELECTRICAL DISTURBANCES, J. Joyce, D. Lambrecht, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-99, No. 1 Jan./Feb. 1980

Mohave SSR Incident (1970)

An example of SSR Torsional Interaction

- Mohave generator: 1,580 MW coal-fired in NV.
- Gradually growing vibration that eventually fractured a shaft section.
- First investigations incorrectly determined cause. After 2nd failure in 1971 cause was identified as Subsynchronous Resonance.
- An electrical resonance at 30.5 Hz excited a mechanical resonance at 30.1 Hz.
- Problem was cured by reducing compensation percentage and installing a torsional relay.

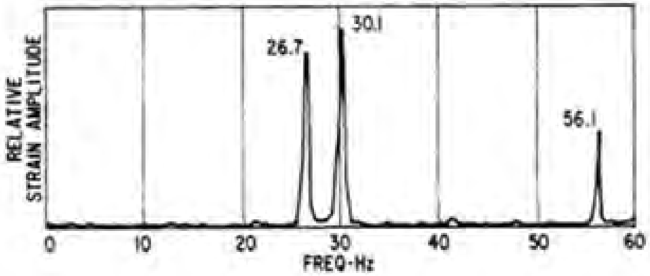
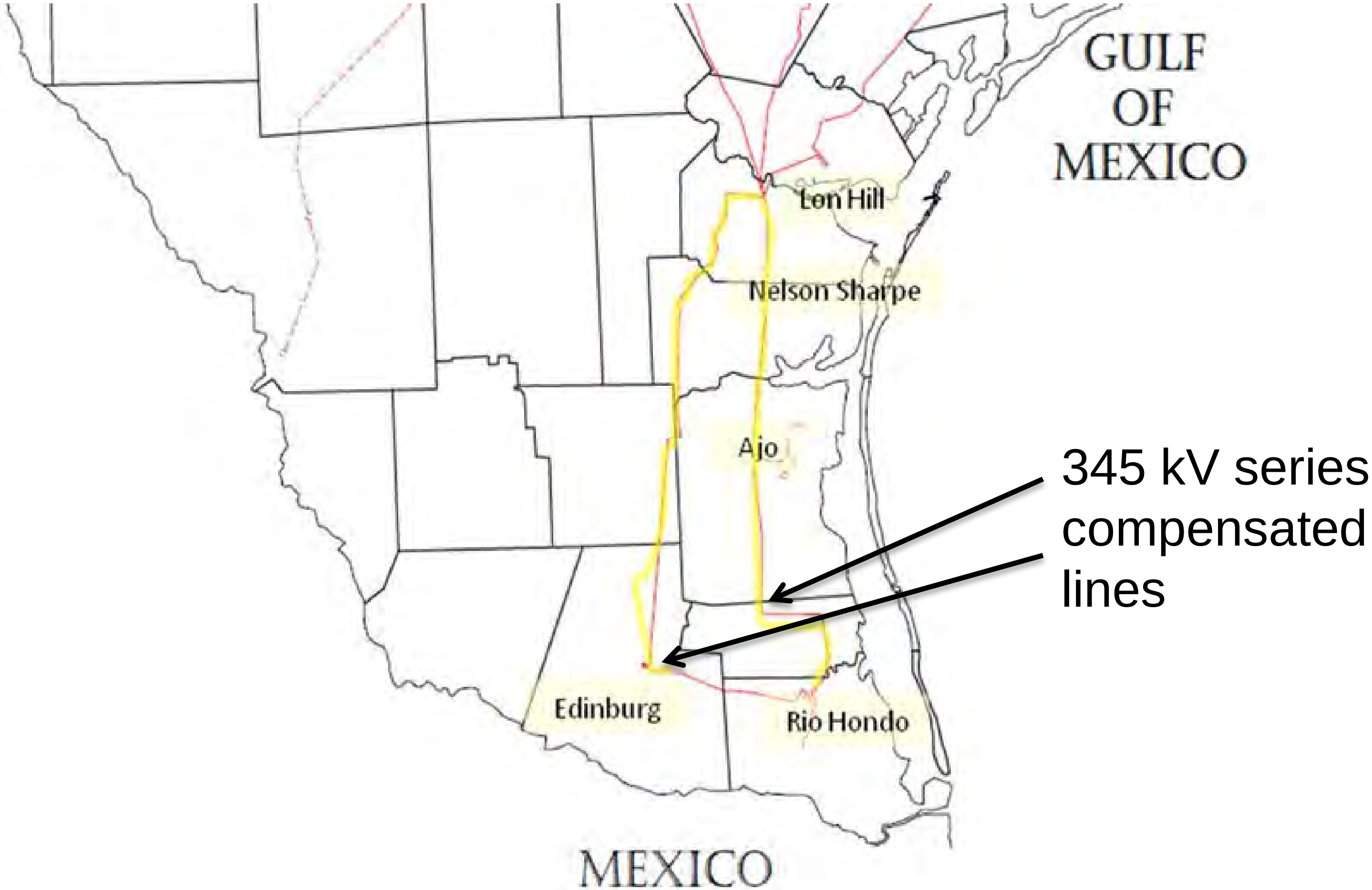


Fig. 7. Synchronization Frequency Analysis

South Texas SSCI Event (2009)

- Series capacitors installed on long 345 kV lines to allow full loading.
- 1,000 MW of wind farms connected to Ajo.



www.ercot.com/content/meetings/other/keydocs/2013/0909-SSR/Concepts_for_SSR_v6.ppt

South Texas SSCI Event (2009)

- A fault occurred on the Ajo to Nelson Sharpe line due to a downed static wire.
- Fault cleared in 2.5 cycles by opening this line.
- The wind farms were then radially connected to the Ajo to Rio Hondo series compensated transmission line.
- The system experienced overvoltages (up to about 195%)
- The Doubly-Fed Induction Generators (DFIG) controlled by a voltage source converter introduces negative damping.
- Undamped oscillations at 22 Hz.
- Voltages reacted approximately 2.0 pu in ~150 ms.
- The series capacitors bypassed approximately 1.5 seconds.
- The series capacitor controls indicated subsynchronous currents during the event.
- This event caused numerous failures of crow bar circuits at the two wind farms and to series capacitors.

www.ercot.com/content/meetings/other/keydocs/2013/0909-SSR/Concepts_for_SSR_v6.ppt

Texas PUC is now tasked with how to address SSR phenomena

– The Texas Public Utility Commission (PUC) and ERCOT have recognized the concerns and issues with SSR and SSO caused by a combination of series capacitors and induction wind generation.

– The PUC has identified it as a…

"harmful phenomena involving coincident oscillation between two or more transmission elements or generation resources at frequencies lower than normal operating frequencies (60Hz of the ERCOT system)".

– At this time, the Texas PUC is asking for proposals to resolve this issue. Many proposals entail relay schemes to disconnect either generation or transmission to protect against this phenomena. Separation of generation or transmission circuits is counterproductive and could not be a solution at Artificial Island.

Texas PUC Stakeholder Discussions Regarding SSO

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NPRR562

Summary | Action | Voting Record | Background | Key Documents

562NPRR-01 Subsynchronous Resonance 081213
(08/12/2013, doc, 70 KB)

562NPRR-02 Impact Analysis 081213
(08/12/2013, doc, 56 KB)

562NPRR-03 Oncor Electric Delivery Comments 090513
(09/03/2013, doc, 50.5 KB)

562NPRR-04 Oncor Electric Delivery Comments - Attachment A 09051
(09/03/2013, pdf, 4.3 MB)

562NPRR-05 Lone Star Transmission Comments 090613
(09/06/2013, doc, 75.5 KB)

562NPRR-06 Calpine Comments 091313
(09/13/2013, doc, 58 KB)

562NPRR-07 PRS Report 091913
(09/24/2013, doc, 79.5 KB)

562NPRR-08 Wind Energy Transmission Texas Comments 092613
(09/26/2013, doc, 47 KB)

562NPRR-09 AEPSC Comments 100813
(10/08/2013, doc, 47.5 KB)

562NPRR-10 GDF SUEZ Comments 040314
(04/03/2014, doc, 48.5 KB)

562NPRR-11 ERCOT Comments 040914
(04/10/2014, doc, 81 KB)

562NPRR-12 Calpine Comments 041714
(04/18/2014, doc, 81 KB)

562NPRR-13 Calpine Comments 050614
(05/06/2014, doc, 89.5 KB)

562NPRR-14 Luminant Comments 050914
(05/09/2014, doc, 91 KB)

562NPRR-15 EDF RE Comments 051314
(05/13/2014, doc, 83 KB)

562NPRR-16 NRG Texas Power Comments 051314
(05/13/2014, doc, 40.5 KB)

562NPRR-17 ERCOT Comments 051414
(05/14/2014, doc, 227 KB)

562NPRR-18 PRS Report 051514
(05/19/2014, doc, 93.5 KB)

562NPRR-19 Calpine Comments 052114
(05/21/2014, doc, 81 KB)

562NPRR-20 ERCOT Comments 060914
(06/09/2014, doc, 85 KB)

562NPRR-21 NRG Texas Power Comments 060914
(06/09/2014, doc, 92 KB)

562NPRR-22 PRS Report 061114
(06/16/2014, doc, 96.5 KB)

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Flow-Chart for Subsynchronous Interaction Studies