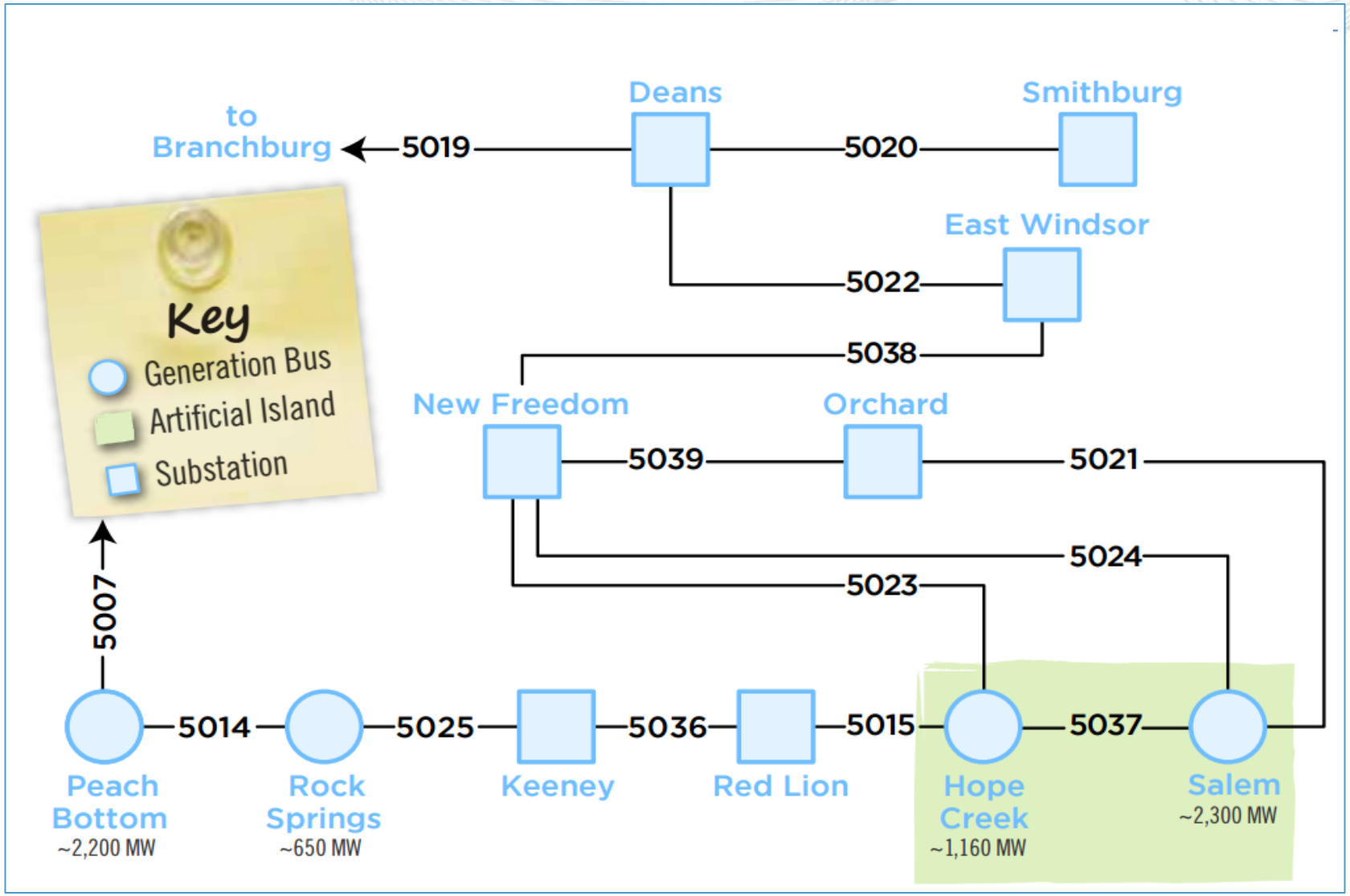
Reliability Analysis Update
Artificial Island Update

Transmission Expansion Advisory Committee

December 15, 2016

Artificial Island Topology



Approved Artificial Island Solution – August 2015

Upgrade Id	Description
b2633	Artificial Island Solution
b2633.1	Build a new 230 kV transmission line between Salem and Silver Run
b2633.2	Construct a new Silver Run 230 kV substation
b2633.3	Install an SVC at New Freedom 500 kV substation
b2633.4	Add a new 500 kV bay at Salem (Expansion of Salem substation)
b2633.5	Add a new 500/230 kV autotransformer at Salem
b2633.6	Implement high speed relaying utilizing OPGW on Deans - East Windsor 500 kV at East Windsor Substation
b2633.6.1	Implement high speed relaying utilizing OPGW on East Windsor - New Freedom 500 kV line at East Windsor Substation
b2633.6.2	Install OPGW on the Deans - East Windsor 500 kV circuit
b2633.6.3	Install OPGW on the East Windsor - New Freedom 500 kV circuit
b2633.6.4	Implement high speed relaying utilizing OPGW on Deans - East Windsor 500 kV at Deans Substation
b2633.6.5	Implement high speed relaying utilizing OPGW on East Windsor - New Freedom 500 kV at New Freedom Substation
b2633.7	Implement high speed relaying utilizing OPGW on Red Lion - Hope Creek 500 kV line at Red Lion Substation
b2633.7.1	Install OPGW on the Red Lion - Hope Creek 500 kV line (Delaware Portion)
b2633.7.2	Install OPGW on the Red Lion - Hope Creek 500 kV line (New Jersey Portion)
b2633.7.3	Implement high speed relaying utilizing OPGW on Red Lion - Hope Creek 500 kV line at Hope Creek Substation
b2633.8	Implement high speed relaying utilizing OPGW on Salem-Orchard, Hope Creek-New Freedom, New Freedom-Salem, Hope Creek-Salem, and New Freedom-Orchard 500 kV lines at Salem, Hope Creek and New Freedom
b2633.8.1	Implement high speed relaying utilizing OPGW on Salem - Orchard 500 kV and New Freedom - Orchard 500 kV at Orchard substation
b2633.8.2	Install OPGW on the Salem - Orchard 500 kV, Hope Creek - New Freedom 500 kV, New Freedom - Salem 500 kV, Hope Creek - Salem 500 kV, and New Freedom - Orchard 500 kV circuits
b2633.91	Implement changes to the tap settings for the two Salem units' step up transformers
b2633.92	Implement changes to the tap settings for the Hope Creek unit's step up transformers
b2633.10	Interconnect the new Silver Run 230 kV substation with existing Red Lion - Cartanza and Red Lion - Cedar Creek 230 kV lines

Artificial Island Project Temporary Suspension

- PSE&G provided cost estimate updates in February, 2016

- Analysis parameter updates
  - Updated critical relay clearing times
  - Generator Step-up transformer impedances
  - Generating unit excitation systems model updates
  - Artificial Island project 500/230 kV transformer anticipated impedance

At their August 2016 meetings, the PJM Board of Managers directed PJM staff to suspend the project and perform a comprehensive analysis to support a future course of action

Artificial Island Comprehensive Analysis
Path to February 2017

Protection & Control Team – Technical whitepaper

Cost & Estimate Team – working to understand basis of estimates

Data and Operational Analysis Team – analyzing historical AI plant data and relevant data (e.g. maintenance outages)

Solution Space Team – identifying and analyzing solution alternatives

Conduct detailed analytical review of individual AI solution elements

Analyze combinations and permutations of existing elements and any new "solution space" alternatives

Document expected cost estimates of resulting alternates/options

Select viable Project paths forward

Prepare draft report and team recommendations to PJM Executive Team

Present PJM Board with final PJM Executive **Recommendation**(s)

October **November** **December** **January** **February**

Protection & Control Team Update

- Clearing time assumption update
  - Recent update from PSE&G
  - Bus fault with delayed clearing longer than line fault with stuck breaker with the existing protection systems
  - Evaluation of the AIOG
  - Impact of optical ground wire (OPGW)

- Line fault with stuck breaker vs. bus fault with stuck breaker

Clearing Time Assumption Update

- PSE&G provided PJM information about clearing time associated with bus faults with delayed clearing that was not explicitly addressed in the existing operating guide
- PJM has evaluated the impact of these new fault clearing times on the Artificial Island Operating Guide (AIOG) and the future configuration
- Evaluation of the AIOG:
  - Eighteen different system conditions for three units operation case were evaluated
  - With the existing/present configuration, PJM found the bus faults with delayed clearing were all stable for the studied system conditions
  - The bus faults with delayed clearing were less severe than the most critical fault defined in the AIOG in terms of margin to critical clearing time in most cases
- Impact on the future configuration:
  - The critical outage condition changes
  - The critical contingency changes

Clearing Time Assumption Update

- Optical ground wire (OPGW) application
  - Typical benefits
    - Improved (faster) total fault clearing times that result in improved stability margin
    - May limit potential relay mis-operation resulting in an over-trip of un-faulted circuits
  - High speed relaying utilizing OPGW on a number of 500kV lines is part of the existing approved solution
    - Due to the recent protection timing update, the most critical fault location has changed from a line fault to a bus fault
    - The proposed OPGW and line relay changes provide no benefit at this location to the timing of the clearing of the most critical bus fault
    - Since the timing is not improved by the OPGW and line relay changes, they will not improve the stability margin
    - OPGW and line relay changes may have other ancillary benefits however they do not directly impact the AIOG

Clearing Time Assumption Update

- Preliminary recommendation to remove OPGW/Relay upgrades from the project scope

- Continue to evaluate OPGW /Relay upgrades with respect to other relay system benefits
  - If a future need is identified for a OPGW/Relay upgrade, a solution would be pursued separately and would not be associated with the Artificial Island solution

Existing Artificial Island Operating Guide (AIOG) Overview

- Implemented in 1987
- Addresses a wide variety of operating scenarios, including key outages, AI unit status (i.e. the number of online units), Power System Stabilizer (PSS) status
- Currently 550 pages
- Updated periodically
- Requires detailed operator interaction to determine the current system configuration and interpret the correct controlling action

Current AIOG Assumptions

- The existing operating protocol follows unit specific MVAR outputs to maintain system stability
- Establishes operating limits for both system normal and also maintenance conditions
- The local Artificial Island voltage in the AIOG study case results from the power flow solution and is influenced by the surrounding system topology, reactive devices, load and generation.
- Critical faults are identified and evaluated
- Equipment status
  - Considers the status of the power system stabilizers (PSS) on the generating units
  - Considers the number of units at Artificial Island that are currently online

Real Time Transient Stability Analysis (TSA) Program

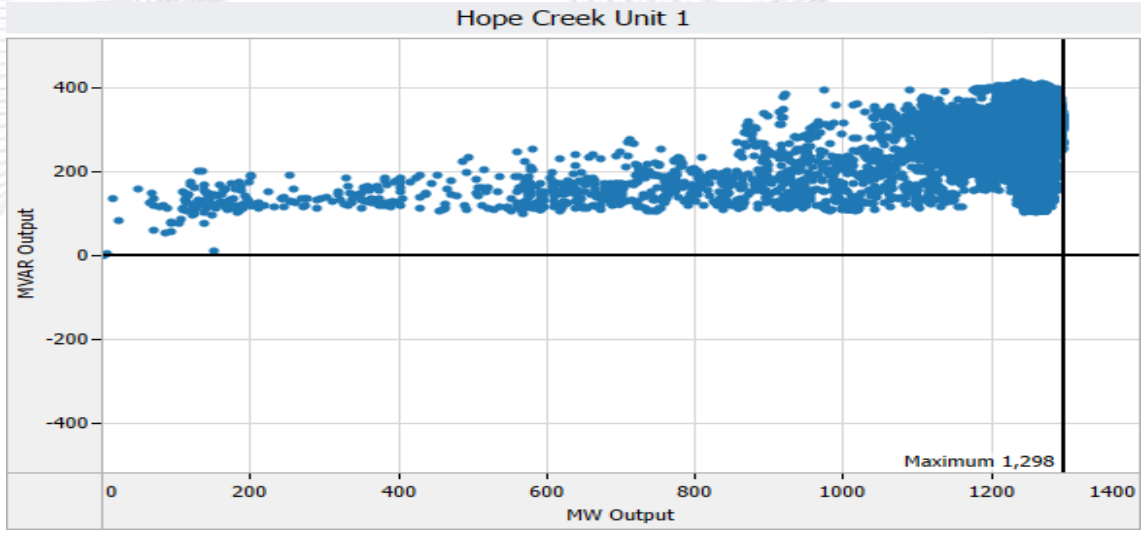
- PJM Operations TSA program
  - Provides real time and contingency scenario stability feedback to PJM operators
  - Reliability & Redundancy
    - TSA is a dual primary system (both PJM Valley Forge and PJM Milford)
  - Implemented at intervals by PJM zones over a several year period
  - Considers a range of real time telemetry in the calculation
    - Current operating parameters are automatically updated
    - Contingency events are pre-defined and automatically simulated

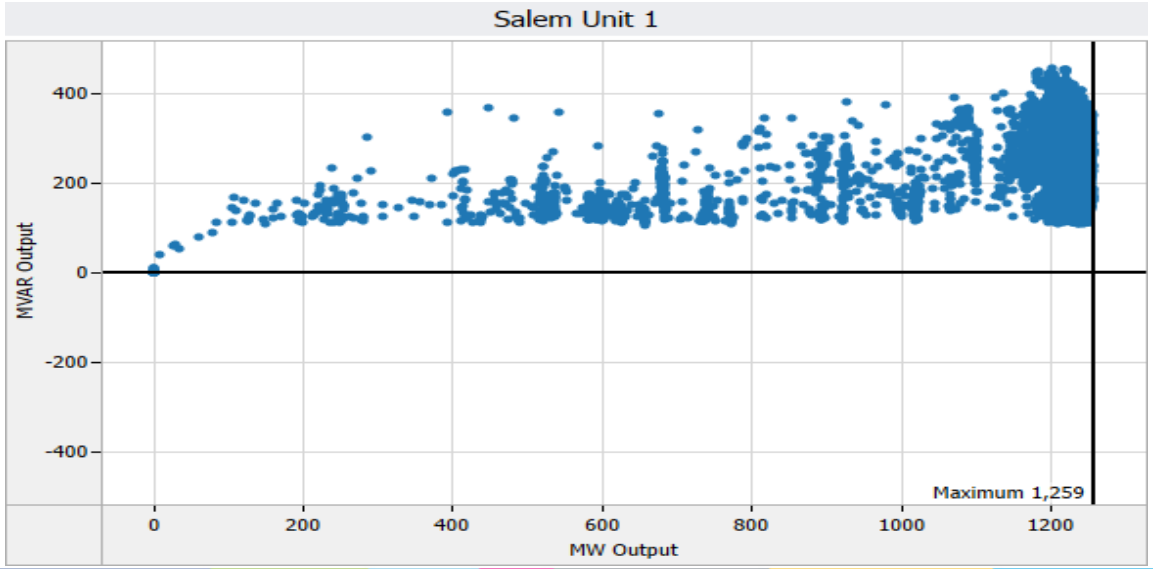
AIOG and TSA Summary

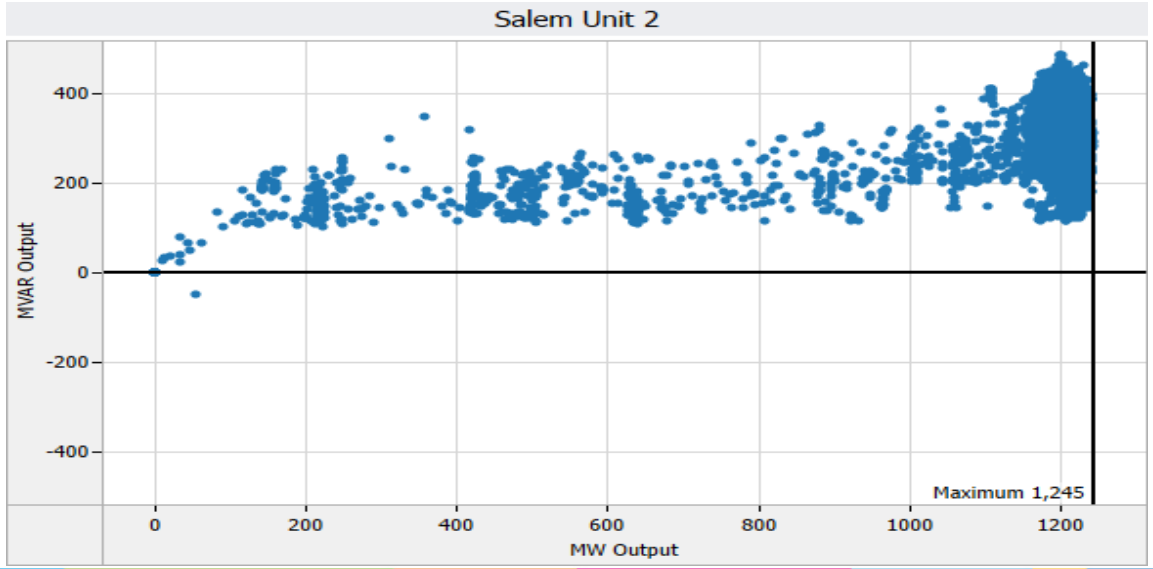
- AIOG is based upon pre-determined critical system conditions assumptions and outage scenarios and fault conditions that are updated periodically
- TSA dynamically incorporates real-time system conditions and parameters
- June 1, 2013 the TSA was implemented for the Artificial Island system area
- This has led to a review of operational data at Artificial Island

Historical Unit MVAR Output

- All units produced MVARs in all operational conditions over a 4.5 year period
- 41,000 measurements recorded.



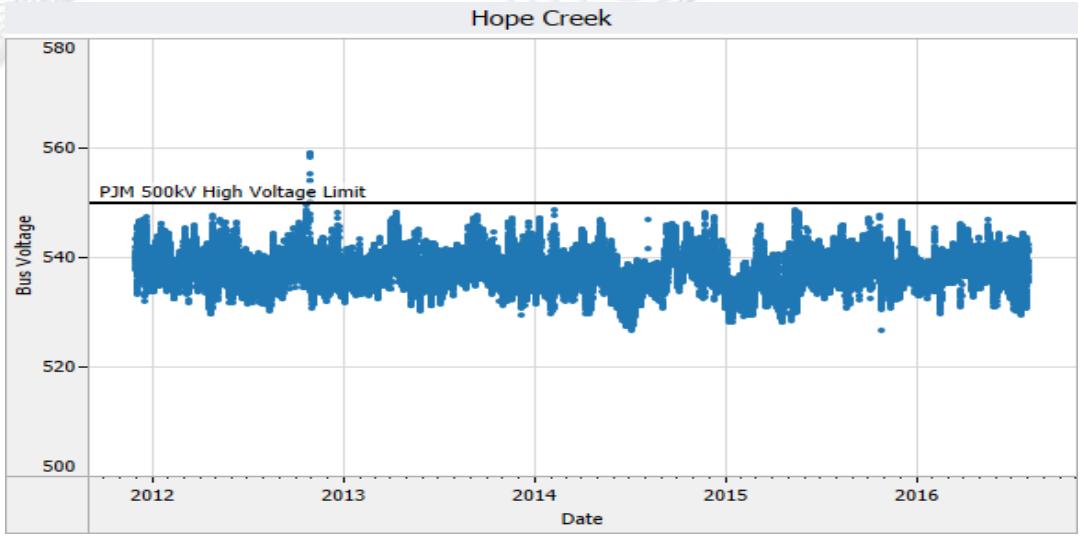


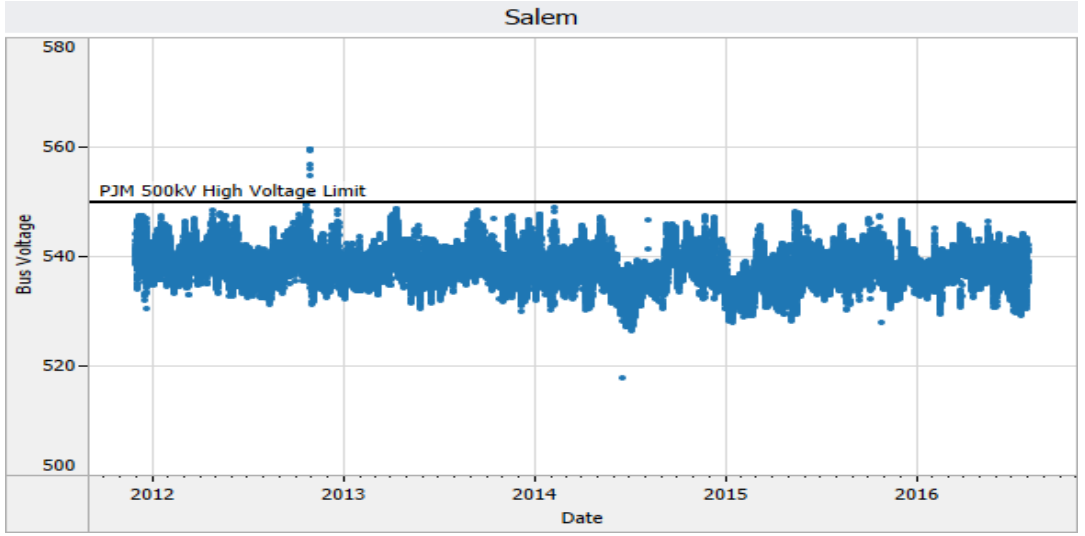


Hope Creek and Salem Bus Voltages

- One event when Hope Creek and Salem bus voltages exceeded 550 kV in 4.5 years (October 30, 2012 12am-8am)
  - Hurricane Sandy
  - Salem Unit 2 was offline prior to this period and Salem Unit 1 went offline in this window.

- All other measurements were between 525kV and 550kV



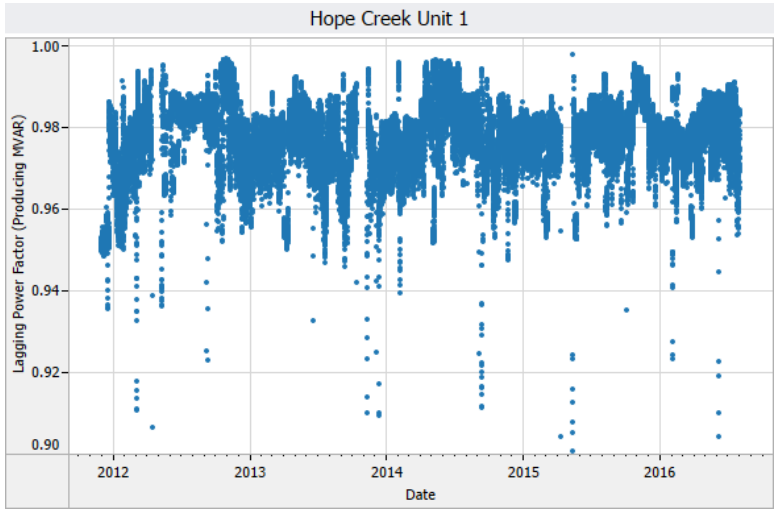


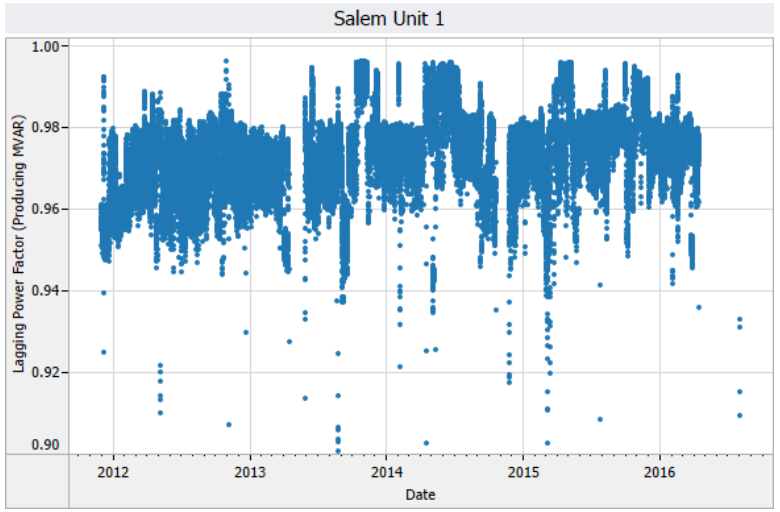
Critical Outages - Voltages

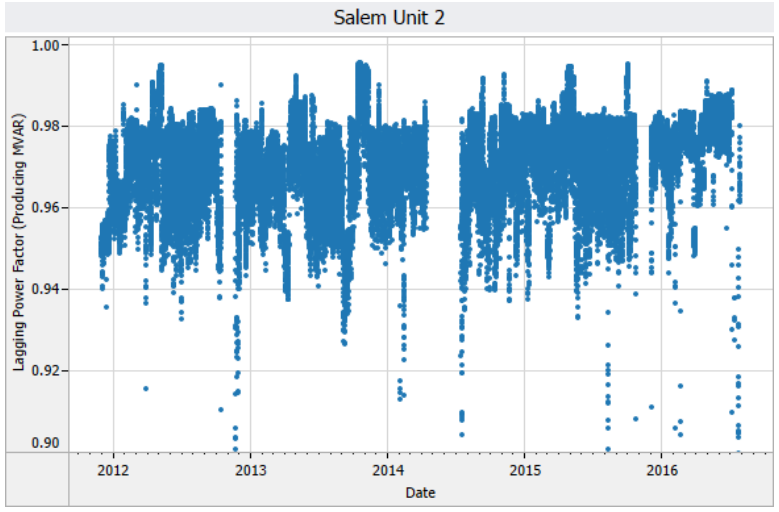
- Observed voltages under outage conditions in and around Artificial Island
  - Voltages remained above 1.055 p.u.
  - Lowest observed voltage during an outage was 528.10 kV or 1.0562 p.u. during an outage with the Hope Creek 3-4 circuit breaker open

Hope Creek and Salem Unit Power Factor

- PJM procedures evaluate generator stability with the unit at unity power factor
- No instances observed in real-time operation where power factor at unity or with a leading (absorbing MVAR) power factor
- Plots below of units with a lagging (producing MVAR) power factor







Artificial Island Power Factor

- Observed power factor under outage conditions in and around Artificial Island
  - Calculated power factor by measuring the real and reactive power at the high side of each generator GSU
  - All power factors observed are lagging (units all producing MVAR)

Operational Data Review and Analysis Findings

- Sensitivity testing was performed
- Reviewed unit's stability under critical maintenance outages and critical faults, assuming a voltage schedule of 1.055 p.u.
  - Sensitivity with and without New Freedom SVC
  - Finding: units were stable for all faults under all critical maintenance outages

- Preliminary recommendation is to remove the New Freedom SVC from the project scope and utilize a voltage schedule at Artificial Island
  - The real-time TSA would continue to run continuously and provide operator feedback and alarms
- Final voltage schedule to be determined in collaboration with PJM Operations
- Continue to evaluate voltage performance in the AI area and the need for possible reactive reinforcement
  - If a future need is identified for a reactive upgrade, a solution would be pursued separately and would not be associated with the Artificial Island solution

Cost Estimate and Alternative Artificial Island Attachment Analysis

Recommended Artificial Island Project Cost Estimate

- Artificial Island project current approved scope and cost estimate as developed by PJM as of July 2015

LS Power 5A 230k V Submarine	
Cost Containment	$146
Salem Expansion	$61 - $74
OPGW	$25
SVC Cost Estimate	$31 - $38
Project Total	$263 - $283

Cost Estimate from March 2016 TEAC

LS Power 5A 230k V Submarine		Costs as of March 2016[1]
Cost Containment	$146	$146
Salem Expansion	$61 - $74	$152
OPGW	$25	$39
SVC Cost Estimate	$31 - $38	$81
Project Total	**$263 - $283**	**$418**

[1]Incoporates cost estimates from PSE&G and excludes PSE&G risk and contingency

Cost and Constructability Analysis Conducted by Project Entities

- PJM, PSE&G and LS Power held multiple meetings
- More granular look at cost and the cost components
  - Additional marine and terrestrial surveying
  - Permit review
  - Property rights review
  - Schedule review
  - Additional site visits
  - Review of existing substation drawings
  - Preliminary engineering
  - Major equipment pricing
- Evaluation of alternatives
  - Investigated alternative Artificial Island attachments at both Salem and Hope Creek
  - Evaluated impacts to the 230kV line

Artificial Island Constructability Analysis

- Finalist Projects:
  - TCSC Project
    - Dominion 1A
  - 500kV Line Hope Creek to Red Lion
    - Dominion 1C
    - PSE&G 7K
  - Southern Crossing 230kV Lines
    - Transource 2B
    - LS Power 5A

Finalist Project Analysis Factors for 2015 Recommendation

Project Type	Strengths	Weaknesses
TCSC Project	– TCSC components are employed in the industry with high reliability – Limited work anticipated at Artificial Island facility	– Technical performance lower than line alternatives – Potential permitting challenges at identified sites – Proposed compensation higher than industry norm – Inconclusive SSR study results could drive lengthy restudy – NRC approval may be required
500kV Line Hope Creek to Red Lion	– Hope Creek expansion considered more constructible than Salem expansion	– Permitting through Supawna Meadows National Wildlife Refuge – Permitting through state wildlife management areas – River crossing permitting – Potential view-shed impacts – 5015 line outage requirements
Southern Crossing 230kV Lines	– Submarine cable installation technology removes potential view-shed issue and lowers risk for a NEPA EIS being required	– Salem is constrained with limited space for expansion – River crossing permitting – Permitting through state wildlife management areas

Refer to 04/28/2015 TEAC presentation for full detail of 2015 evaluation and recommendation.

Constructability Considerations

- No new information has emerged with respect to constructability challenges

- LS Power confirmed cost cap still valid with alternate attachment options studied
  - Cost escalation will be applied per cost containment provisions for the project suspension directed by PJM

- Hope Creek remains the preferred point of interconnection
  - Option 2B mitigates constructability concerns with Salem interconnection

Artificial Island Next Steps

- Complete technical review
- Work with PJM Operations to develop voltage schedules
- Evaluate cost and schedule impacts of temporary project suspension with the effects of escalation
- January 2017 – Staff recommendation at TEAC meeting
- February 2017 – Final recommendation to PJM Board