N-1-1 Reactive Upgrades

Previous Analysis – Discussed at November 2011 TEAC

- Voltage collapse for multiple 500 kV N-1-1 contingency pairs

- A number of reactive upgrade locations evaluated to determine a optimal locations of a recommended solution

- Analysis included a review of several previously approved reactive upgrades

Status of N-1-1 Reactive Upgrades

Location	Reinforcement Recommended to PJM Board – December 2011	PJM Board Status – December 2011
Altoona 230 kV	250 MVAR SVC	Approved for inclusion in the RTEP
Doubs 500 kV	300 MVAR switched shunt and an increase (~50 MVAR) in size of existing switched shunt	
Loudoun 500 kV	450 MVAR SVC and 300 MVAR switched shunt	
Pleasant View 500 kV	150 MVAR switched shunt	
Mansfield 345 kV	100 MVAR FSS and two 100 MVAR switched shunt	
Hunterstown 500 kV	500 MVAR SVC	Decision Deferred Until Next PJM Board Meeting in February 2012
Meadow Brook 500 kV	600 MVAR SVC	
Petersburg 500 kV (a.k.a. Mt. Storm – Valley)	250 MVAR SVC	

Mt. Storm &
Mt. Storm – Valley (a.k.a. Petersburg)

Mt. Storm - Valley Reactive Upgrade Status

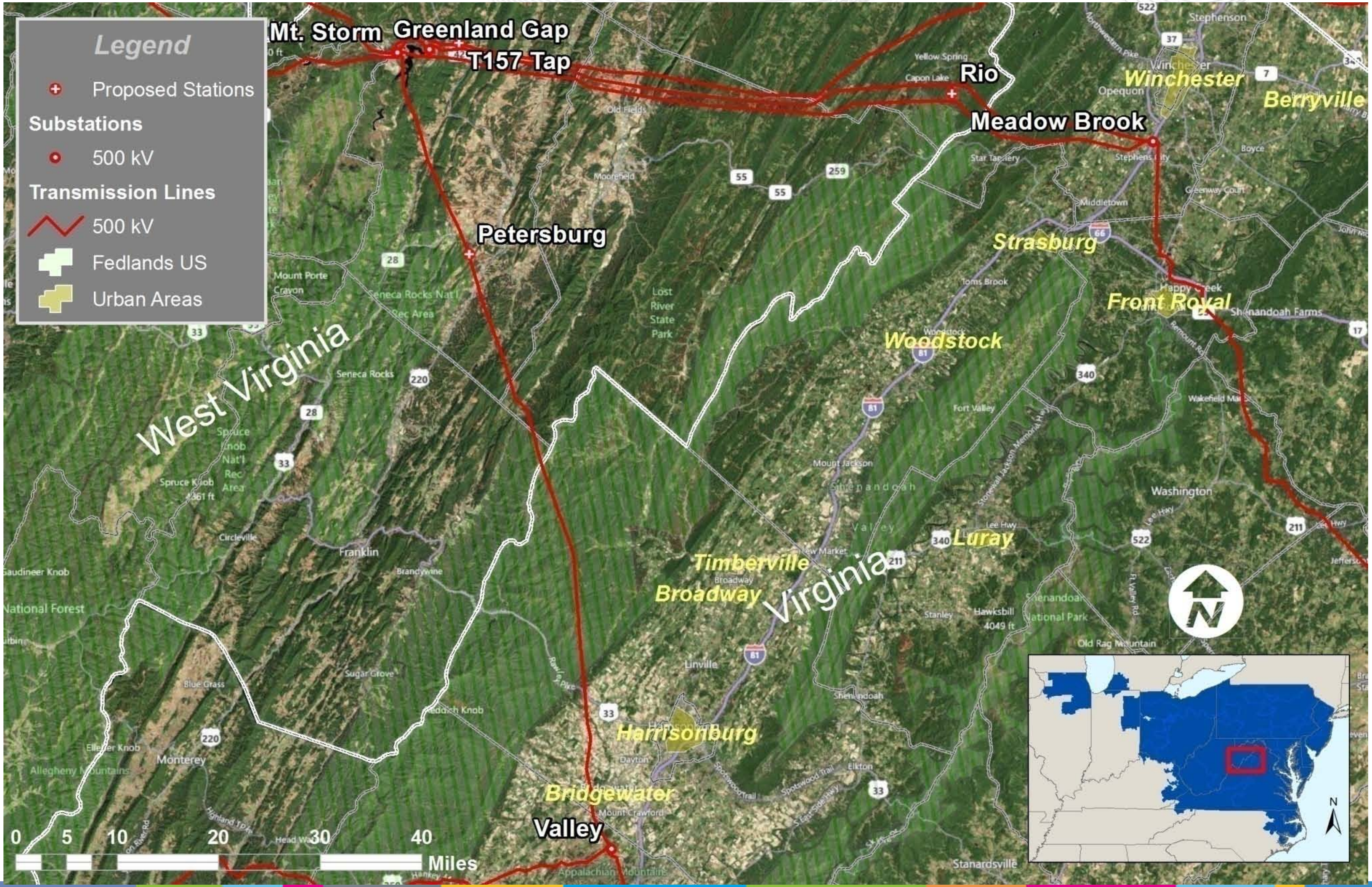
- Previous Recommendation to PJM Board for a 250 MVAR SVC at a new station called Petersburg in the Mt. Storm - Valley
- Stakeholder suggestion to locate the SVC at Mt. Storm
- Board decision deferred pending additional review of alternatives

- Previous analysis and subsequent recommendation for Petersburg SVC location was based on the assumption of a 1.04 p.u. scheduled voltage at Mt. Storm generation
- Updated analysis with Mt. Storm generation regulating to 1.05 p.u. improves performance of the Mt. Storm SVC location

- Existing Mt. Storm bus regulation (520 kV / 1.04 p.u.):
  - Nominal Voltage Magnitude Limit – 520 kV
  - Emergency Voltage Magnitude Limit – 525 kV
  - Units currently often operate in the lead (absorb MVAR) to maintain voltage
    - Operated in the lead 75% of the hours in 2011
    - Not ideal for stability

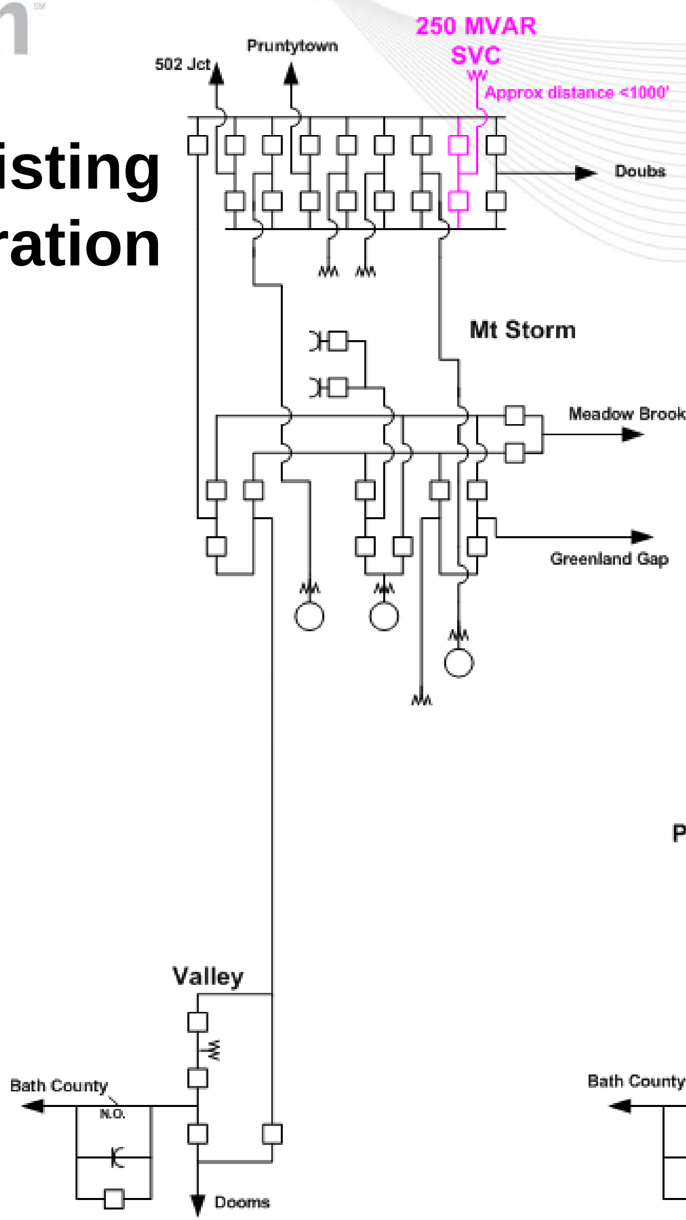
- Proposed regulation (525 kV / 1.05 p.u.):
  - Nominal Voltage Magnitude Limit - 525 kV
  - Emergency Voltage Magnitude Limit - 538 kV (1.075 p.u.)
  - Units will operate in the lag (produce MVAR) more often
    - More stable

Mt Storm – Petersburg – Valley a.k.a. Mt. Storm - Valley

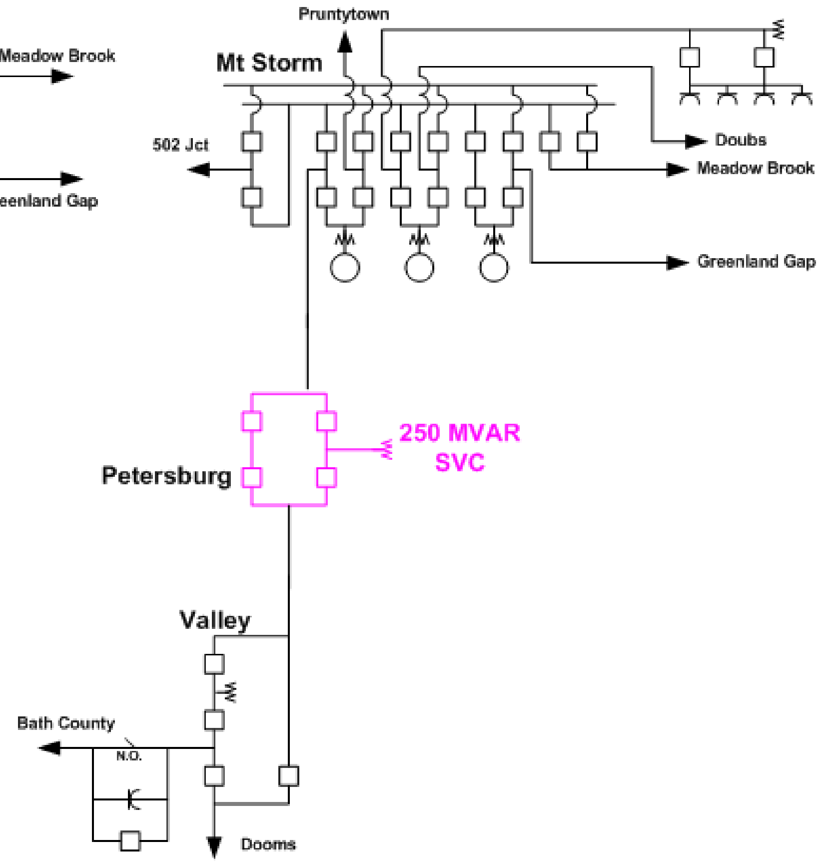


Mt. Storm - Valley

Existing Configuration

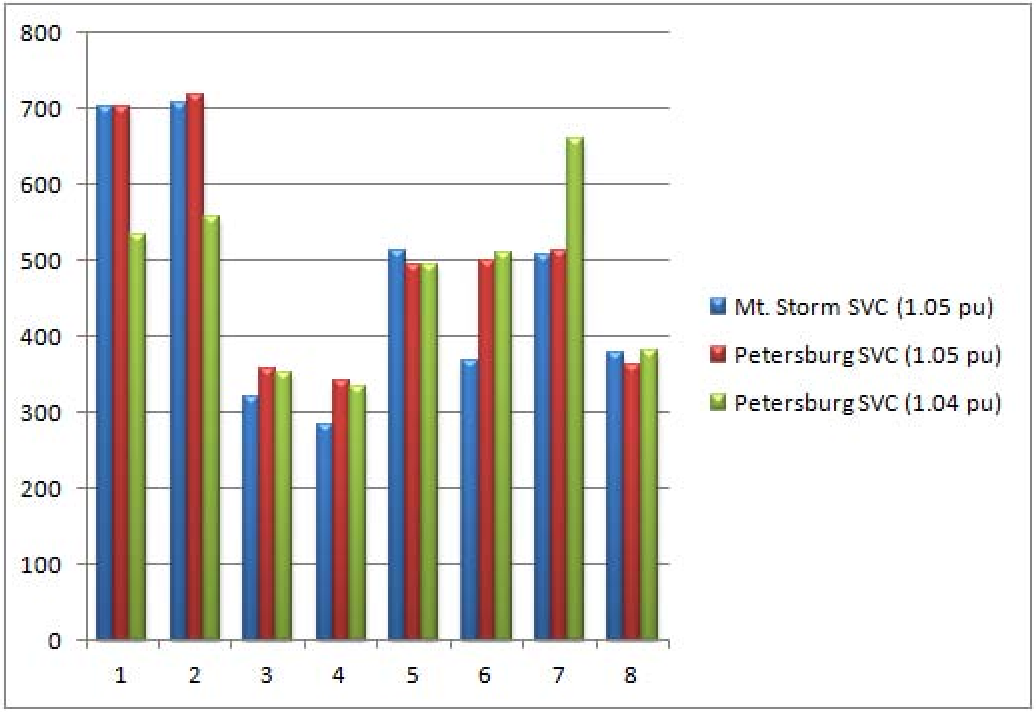


Proposed Configuration



Comparison of N-1-1 Transfer Capability

N-1-1 Outage Pair	Mt. Storm SVC (1.05 pu)	Petersburg SVC (1.05 pu)
N-1-1 Outage # 1	703	703
N-1-1 Outage # 2	707	719
N-1-1 Outage # 3	320	358
N-1-1 Outage # 4	284	340
N-1-1 Outage # 5	512	495
N-1-1 Outage # 6	368	500
N-1-1 Outage # 7	506	512
N-1-1 Outage # 8	377	363
Average Increase in MW transfer into MAAC	472	499



Configuration

- Mt. Storm Location
  - SVC remains integrated with the remaining transmission system following any single contingency (other than the SVC)
- Petersburg Location
  - SVC becomes radial following the loss of either Mt Storm to Petersburg 500 kV or following the loss of Petersburg to Valley 500 kV

Mt. Storm & Petersburg Considerations

	Petersburg 500 kV	Mt. Storm 500 kV
Criteria Violation Performance	Equivalent – both locations resolve N-1-1 criteria violations	
N-1 Performance	Equivalent – Both locations resolve N-1 reactive limits	
N-1-1 Performance	Petersburg average transfer capability slightly higher	
Configuration	2 Outlets SVC becomes radial post contingency	8 Outlets - SVC remains integrated with the system post contingency
Operations	Coordinate across multiple sites	Coordinate single site
Land & ROW	New	Existing
CPCN	Required	Not Required
Construction Schedule	Mt. Storm construction schedule is shorter	
Cost	$45	$36

Recommendation

- Change the voltage regulation set point at Mt Storm to 1.05 pu

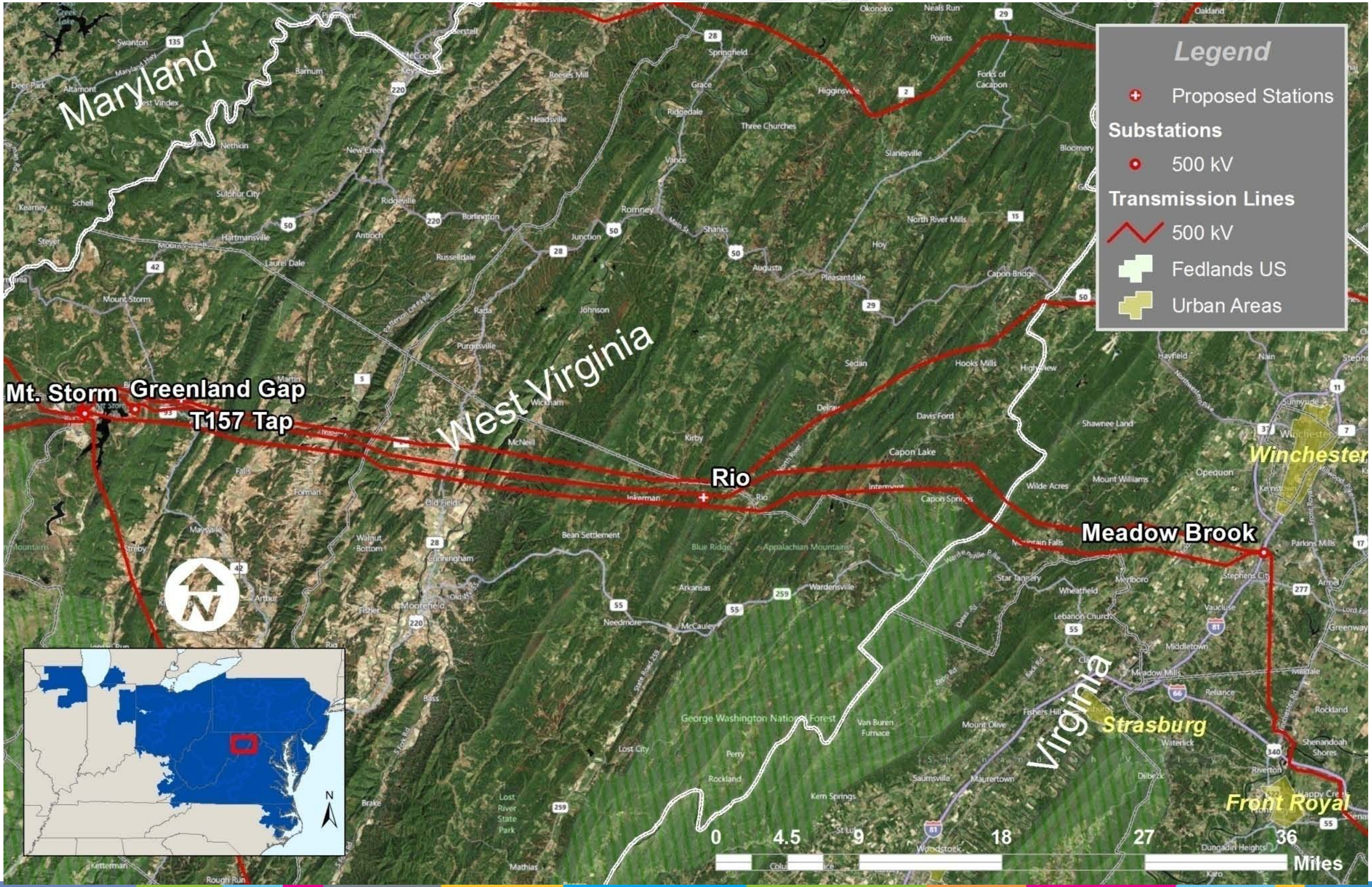
- Install 250 MVAR SVC at Mt Storm 500 kV
  - Assign construction responsibility to Dominion

Hunterstown and Rio

- Previous recommendation to PJM Board to install an SVC at Hunterstown and a new station Rio located west of Meadow Brook

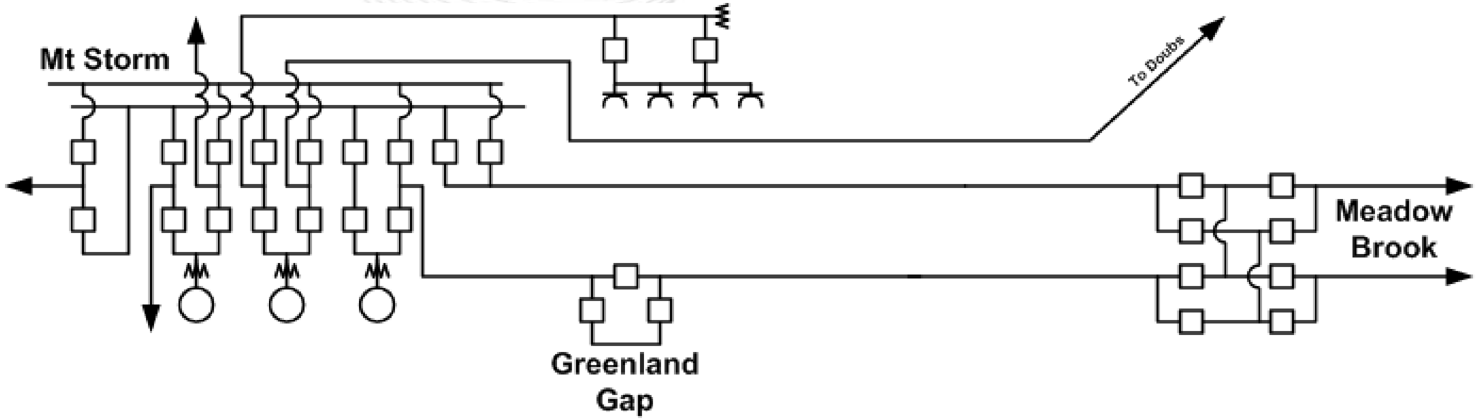
- Stakeholder suggestion a combination of Fast Switched Shunts and static capacitors would be more appropriate

Mt Storm – Rio – Meadow Brook

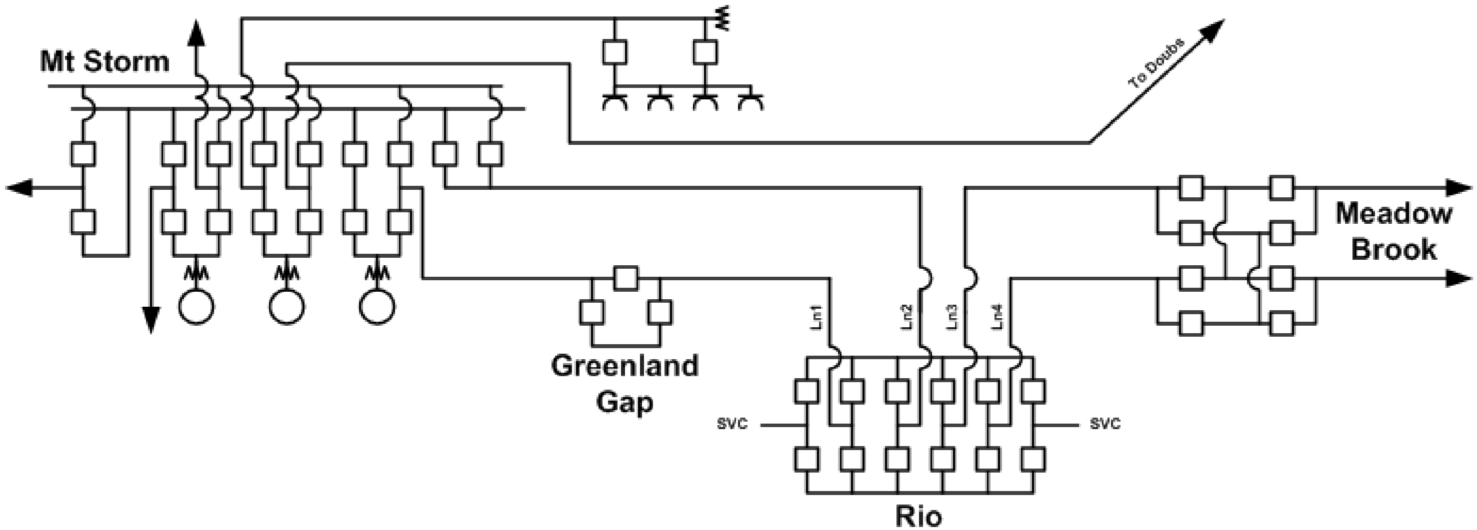


Mt. Storm – Rio – Meadow Brook

- Existing Configuration



- Proposed Configuration to tap existing Mt. Storm – Meadowbrook 500 kV and Greenland Gap – Meadowbrook 500 kV



Reactive Reinforcement Technology

	SVC	Fast Switched Shunt	Static Capacitor
Voltage Support	Dynamic	Static	
Control	Linear	Discrete (On/Off)	
Reactive Envelope	Absorb and Produce MVAR	Produce MVAR	
Reaction Time	Cycles	3 Seconds	Operator Control
Operations	Linear support of pre and post contingency voltage	Discrete voltage support, automatically switched post contingency	Discrete voltage support, manually switched
Ancillary Benefits	system dynamic stability, coordination, control, operations	Can be automatically switched	

Output (MVAR) of reactive devices under N-1-1 conditions

N-1-1 500 kV Contingency*	Meadow Brook SVC N-0 Base Case	Meadow Brook SVC N-1 Collapse Point	Meadow Brook SVC N-1-1 Collapse Point	Loudoun SVC N-0 Base Case	Loudoun SVC N-1 Collapse Point	Loudoun SVC N-1-1 Collapse Point	Hunterstown SVC N-0 Base Case	Hunterstown SVC N-1 Collapse Point	Hunterstown SVC N-1-1 Collapse Point
Contingency Pair #1	53	379	500	0	312	450	18	77	370
Contingency Pair #2	53	410	500	0	360	450	18	83	327
Contingency Pair #3	53	N/A	N/A	0	N/A	N/A	18	N/A	N/A
Contingency Pair #4	53	127	500	0	49	450	18	97	500
Contingency Pair #5	53	167	500	0	166	450	18	72	500
Contingency Pair #6	53	190	500	0	245	450	18	84	0
Contingency Pair #7	53	156	500	0	139	450	18	12	161
Contingency Pair #8	53	132	500	0	63	450	18	59	500
Contingency Pair #9	53	132	500	0	63	450	18	59	500
Contingency Pair #10	53	459	500	0	299	450	18	43	435
Contingency Pair #11	53	468	500	0	264	450	18	45	401

N-1-1 500 kV Contingency*	Altoona SVC N-0 Base Case	Altoona SVC N-1 Collapse Point	Altoona SVC N-1-1 Collapse Point	Mansfield FSS N-0 Base Case	Mansfield FSS N-1 Collapse Point	Mansfield FSS N-1-1 Collapse Point	Mt. Storm - Valley SVC N-0 Base Case	Mt. Storm - Valley SVC N-1 Collapse Point	Mt. Storm - Valley SVC N-1-1 Collapse Point
Contingency Pair #1	7	60	122	0	0	0	7	0	217
Contingency Pair #2	7	64	120	0	0	0	7	0	185
Contingency Pair #3	7	N/A	N/A	0	N/A	N/A	7	N/A	N/A
Contingency Pair #4	7	57	250	0	0	0	7	0	243
Contingency Pair #5	7	81	250	0	0	100	7	0	226
Contingency Pair #6	7	89	187	0	0	100	7	0	235
Contingency Pair #7	7	41	217	0	0	100	7	0	250
Contingency Pair #8	7	55	250	0	0	100	7	0	243
Contingency Pair #9	7	55	250	0	0	100	7	0	243
Contingency Pair #10	7	36	118	0	0	0	7	0	250
Contingency Pair #11	7	40	118	0	0	0	7	0	250

* The specific contingency pairs are considered CEII

PJM Voltage Recovery Criteria

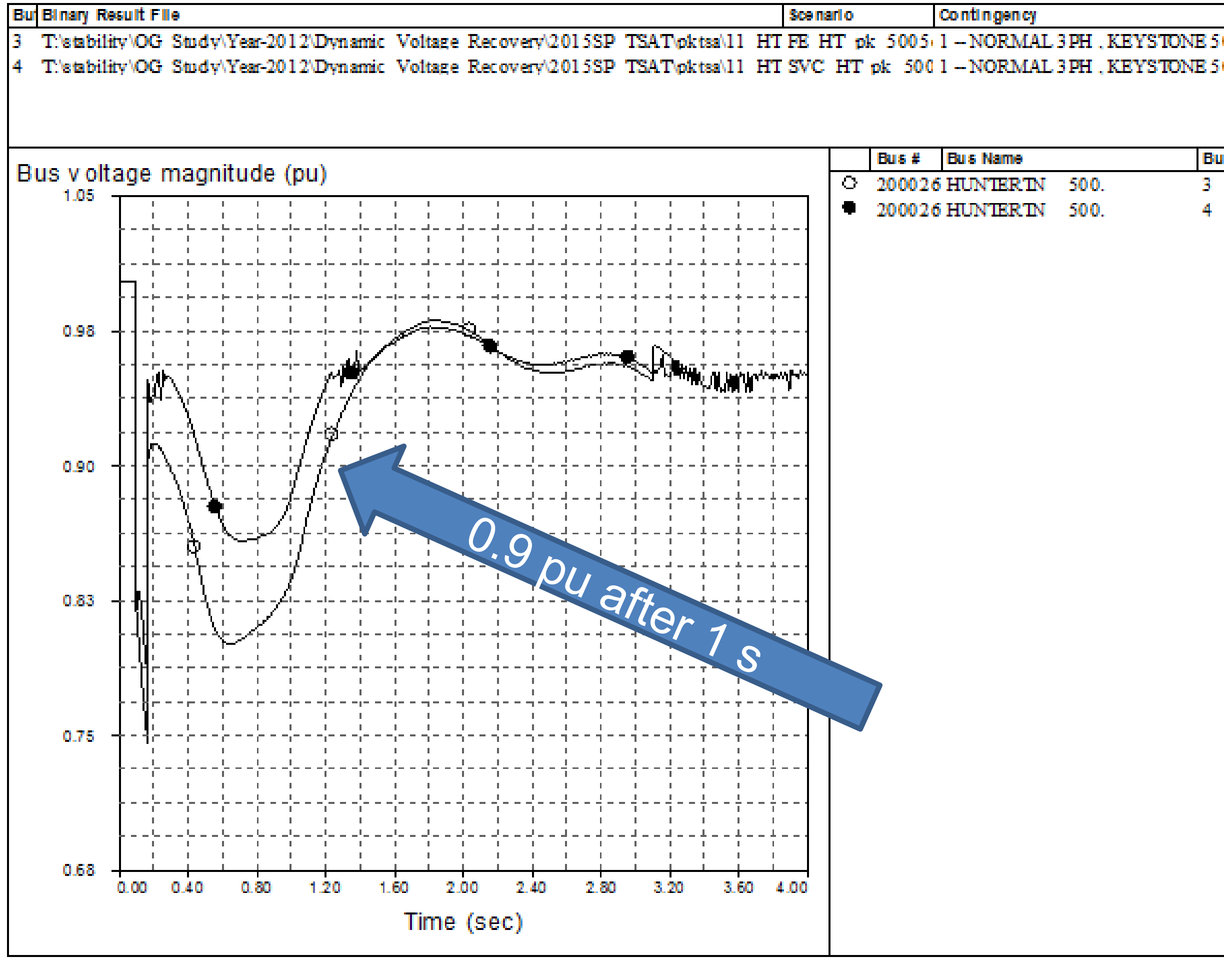
– Voltage must recover to 0.7 p.u. within 20 cycles (1/3 of a second) after the fault is cleared

– Voltage must recover to 0.9 p.u. within 60 cycles (1 second) after the fault is cleared

- Approximately 46 scenarios
  - Varied outage condition, fault, and load modeling
- Subsequent slides demonstrate the performance difference between an SVC and Fast Switched Shunt

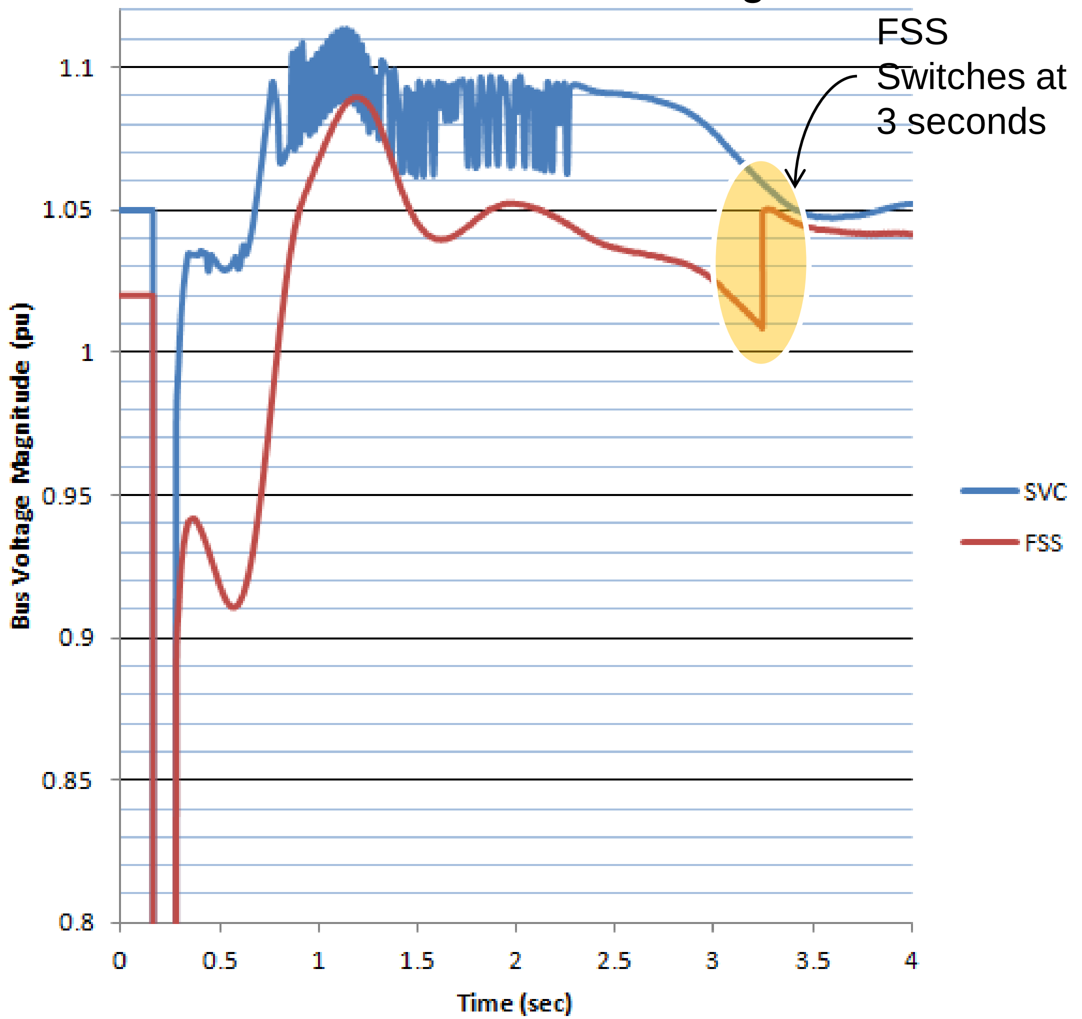
Voltage Recovery Analysis – Conservative Load Modeling

- 250MVAr FSS is turned off and HT 500kV bus voltage is above 1.0 pu. in pre-contingency condition.
- Conservative load model (PL: 65%,45%,0%; QL: 65%,0%,45%)
- Outage condition: Conemaugh – Juniata 500kV line.
- Contingency: three phase fault at Keystone 500kV in the line of Keystone-Juniata 500kV.



- Voltage Recovery Analysis
- 2015 MAAC peak load stability case
  - Conservative load model
- Performance
  - Fast Switched Shunt
  - SVC

Hunterstown 500 kV Voltage*

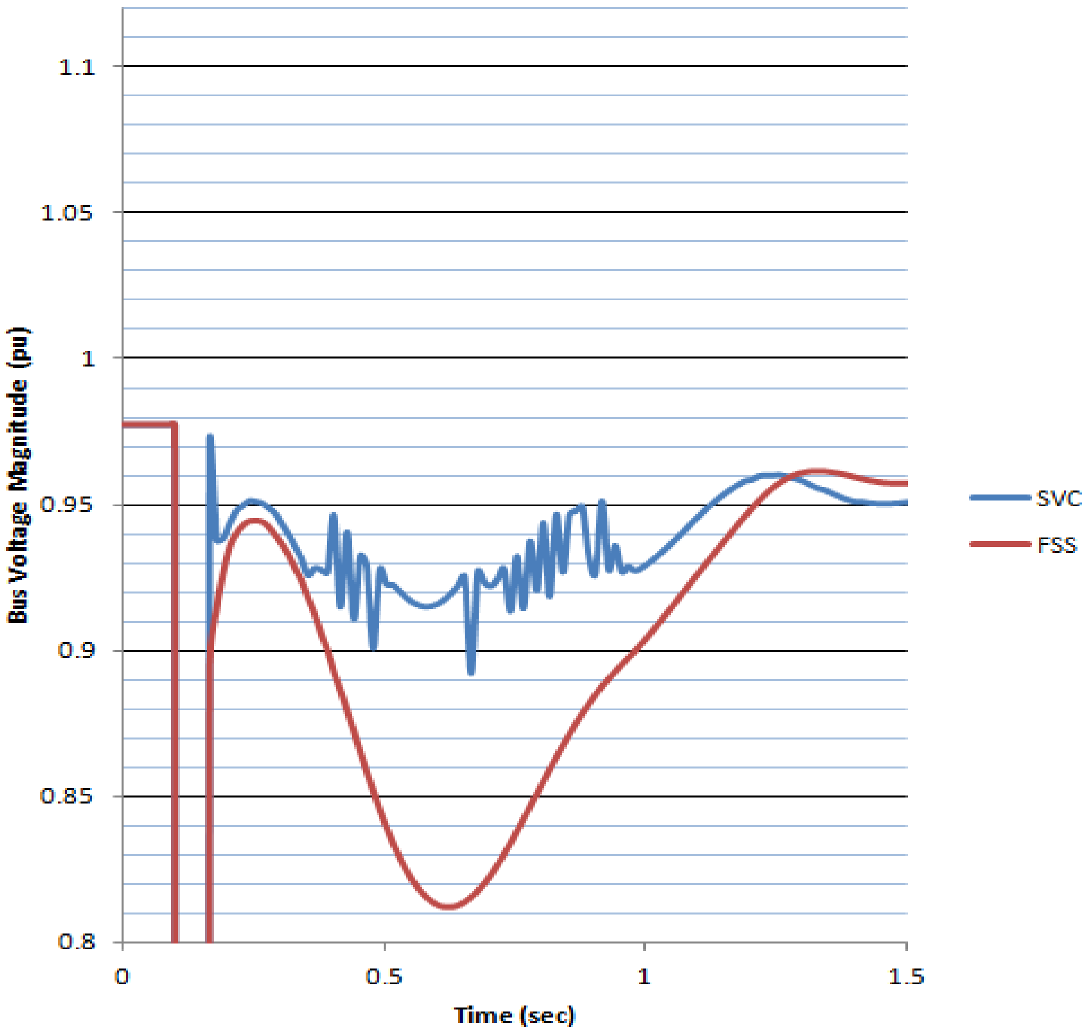


* Post contingency voltage for an N-1 initial condition with an additional N-1 fault (combination CEII)

Voltage Recovery Analysis – Stressed Import

- Voltage Recovery Analysis under a stressed import
- 2015 MAAC peak load stability case with stressed import
  - Conservative load model
- Performance
  - Fast Switched Shunt
  - SVC

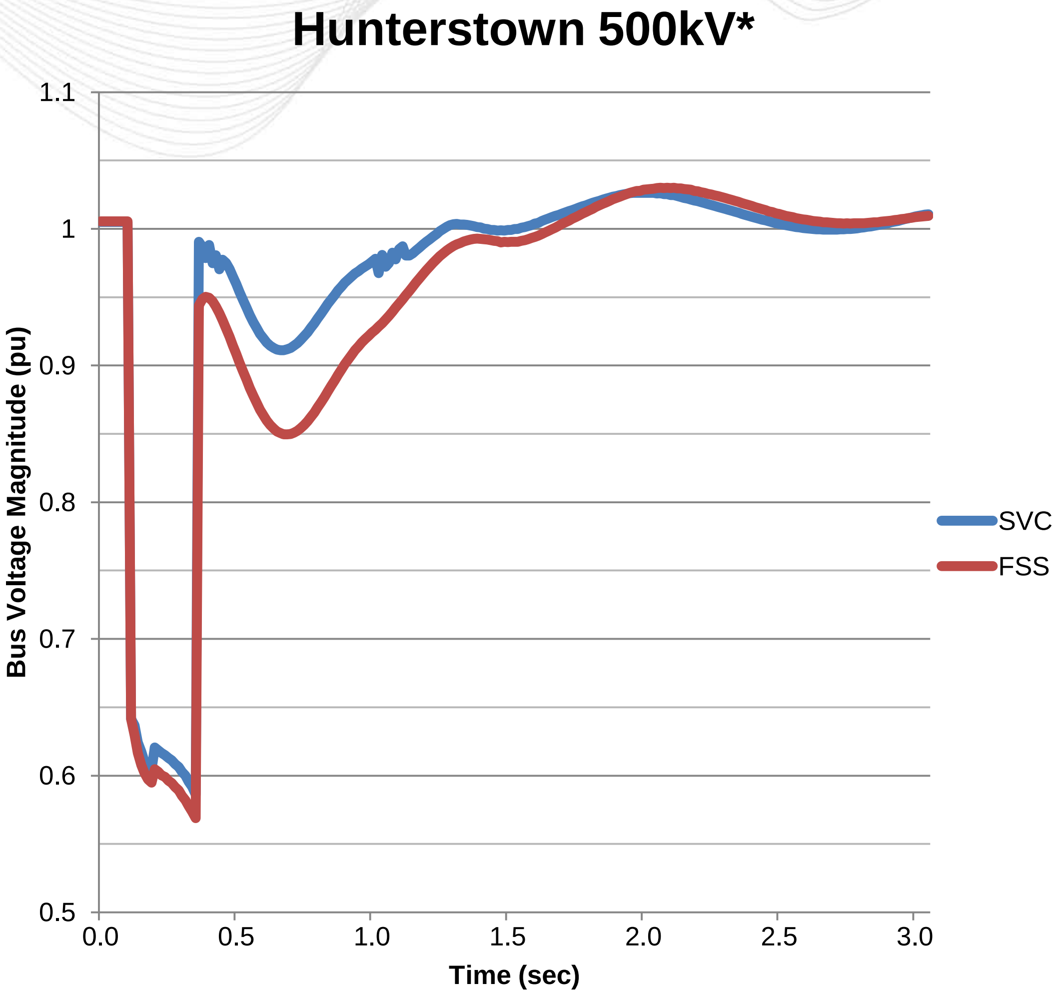
Hunterstown 500 kV Voltage*



* Post contingency voltage for an N-1 initial condition with an additional N-1 fault (combination CEII)

Voltage Recovery Analysis

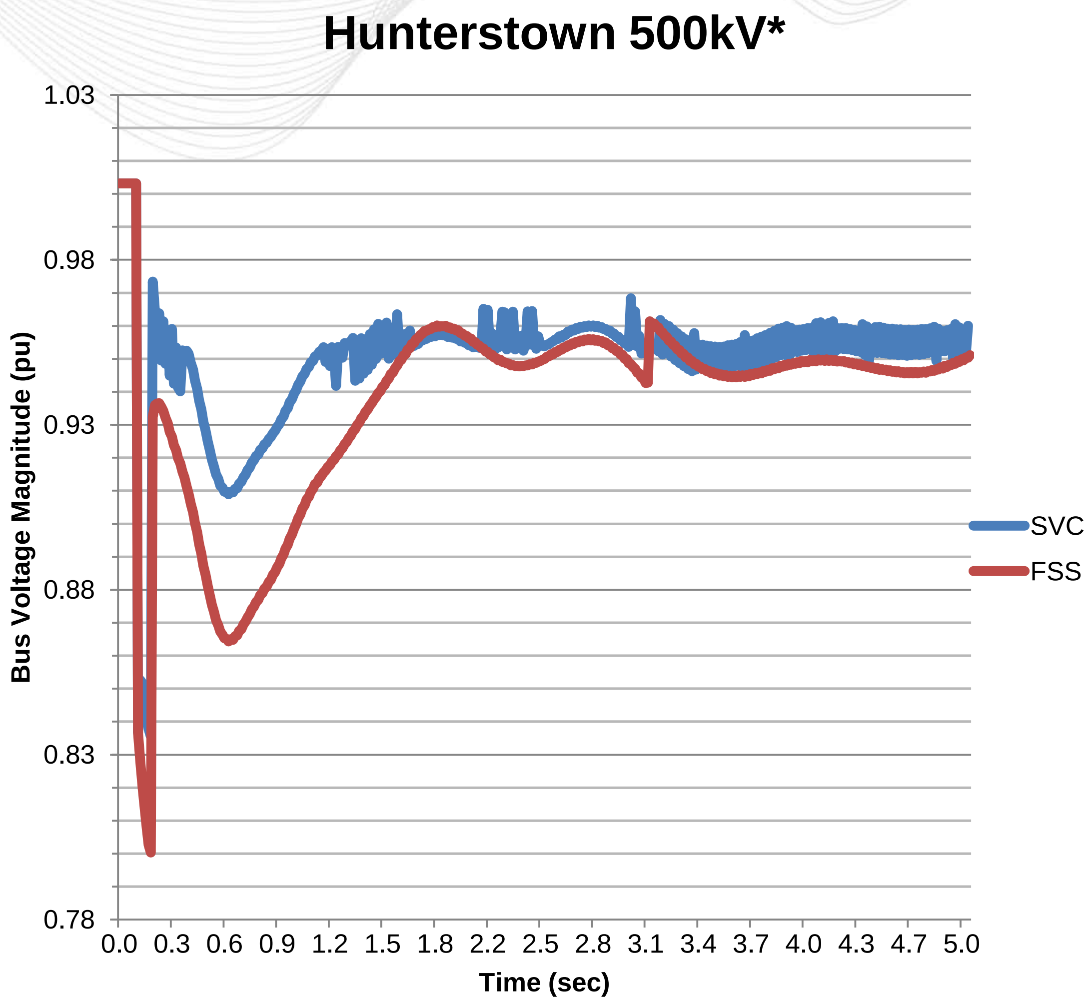
- Voltage Recovery Analysis
- 2015 MAAC peak load stability case
- Performance
  - SVC
  - Fast Switched Shunt



*Post contingency voltage for an N-1 initial condition with an additional N-1 fault (combination CEII)

Voltage Recovery Analysis

- Voltage Recovery Analysis
- 2015 MAAC peak load stability case
- Performance
  - SVC
  - Fast Switched Shunt



*Post contingency voltage for an N-1 initial condition with an additional N-1 fault (combination CEII)

SVC Drivers

- Previous slides show the superior performance of the SVC compared to either Fast Switched Shunts or Static Capacitors
- Steady state analysis shows how the reactive output of the SVC would automatically change post contingency
- Dynamic analysis shows the benefits of SVC to recover voltages post contingency
- Ability of SVC to absorb reactive power will help to improve system voltage profile during light load periods
- SVC will help to improve dynamic stability
- SVC will help to replace dynamic reactive capability lost due to generation deactivations

- Install a 500 MVAR SVC at Hunterstown 500 kV
  - Assign construction responsibility to First Energy
- Install a 600 MVAR SVC at Rio 500 kV
  - Assign construction responsibility to Primary Power

- Review results with PJM Board on February 7th
- Schedule a PJM Board conference call after March 1st to consider recommendations
- Comments can be sent to RTEP@pjm.com