Reliability Analysis Update

Transmission Expansion Advisory Committee

March 9, 2017

2016/17 RTEP Long Term Proposal Window

2016/17 RTEP Long Term Proposal Window

- Timeline
  - Window Opened: 11/1/2016
  - Window Closed: 2/28/2017
    - All documents and fees due
  - Scope
    - Market Efficiency Congestion
    - 15 Year Reliability Analysis

2016/17 RTEP Long Term Proposal Window

- 96 Proposals received from 20 entities/combinations addressing 19 target zones/combinations
  - 52 Greenfield
    - 5 of which are interregional
  - 44 Upgrades
    - 3 of which are interregional
- Additional detail and updates will be provided at future TEAC meetings

2016 RTEP Proposal Window #3/3A Update

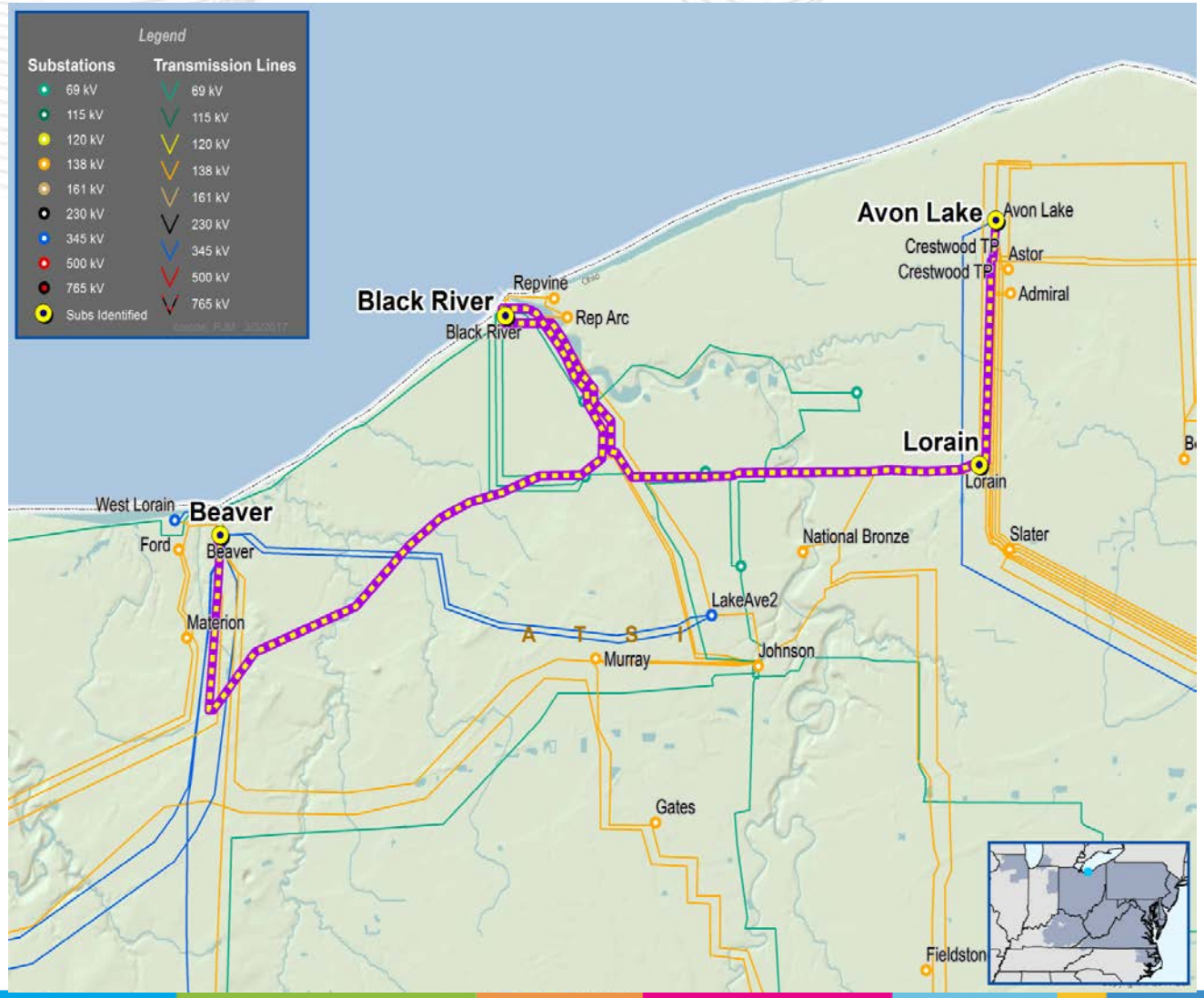
2016 RTEP Proposal Window 3/3A

- The Avon Lake – Black River – Beaver area had several flowgates identified as part of 2016 RTEP Window 3
- One of the flowgates found to be invalid due to incorrect modeling and as a result PJM posted and addendum to the 2016 RTEP Window 3
- There were several projects proposed to solve the flowgates listed below during the Window 3 and Window 3 Addendum
  - Window 2 (Summer Analysis) → FG # 915
  - Window 3 (Winter Analysis) → FG # 392, 393, 489, 490, 400, 493, 407 and 504
  - Window 3 Addendum (Winter Analysis → FG # 386
- PJM evaluated 13 stakeholder proposals

2016 RTEP Proposal Window 3/3A
ATSI Transmission Zone

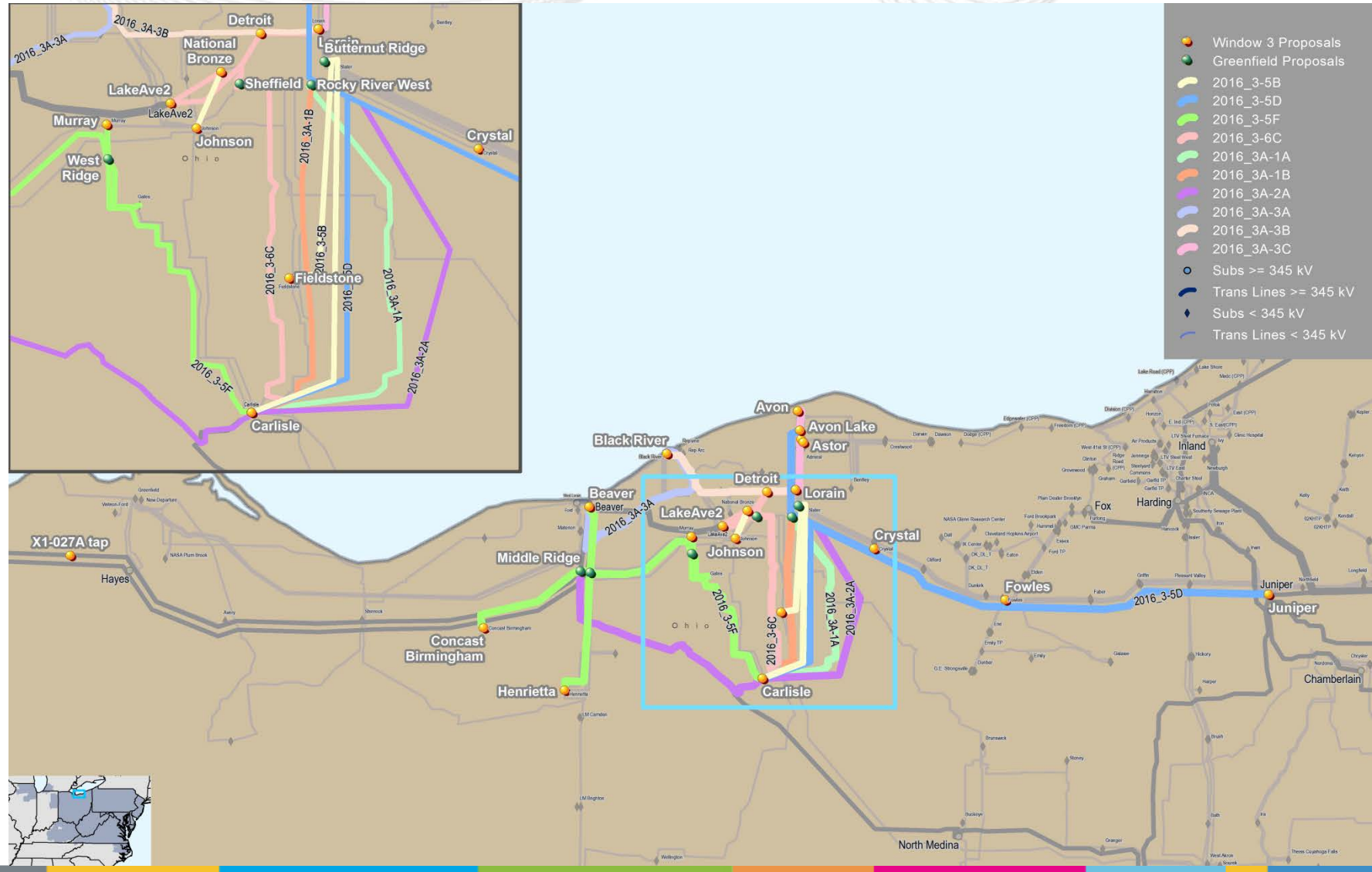
- **Common Mode Outage (FG# 392, 393, 400, 407, 489, 490, 493 and 504)** :
- Black River – Lorain - Avon 138 kV circuit is overloaded for tower outage loss of Avon – Lake Ave 345 kV circuits and line fault stuck breaker contingency loss of the Avon – Lake Ave 345 kV circuits.

- **Common Mode Outage (Summer - FG# 915 and Winter – FG# 386)** :
- The Beaver to Black River 138 kV circuit is overloaded for tower line contingency loss of the Lake Ave – Beaver 345 kV circuits .



2016 RTEP Proposal Window 3/3A
ATSI Transmission Zone

- **Alternatives considered:**
  - 2016_3-2C/ 2016_3A-1A
  - 2016_3-5B
  - 2016_3-5D
  - 2016_3-5F
  - 2016_3-6B / 2016_3A-3B
  - 2016_3-6C
  - 2016_3-6D/ 2016_3A-2C
  - 2016_3A-3A
  - 2016_3A-1B
  - 2016_3A-2A



Reliability Analysis Result Summary												
	Cost Estimate	FG #	FG #	FG #	FG #	FG #	FG #	FG #	FG #	FG #	FG #	Comment
Project ID	($ Million)	393	490	392	489	400	493	407	504	386	915	
2016_3-2C	44.9	O	O	O	O	O	O	O	O	O	O	Same as project 2016_3A-1A
2016_3-5B	19	O	O	O	O	O	O	O	O	X	X	
2016_3-5D	35.4	O	O	O	O	O	O	O	O	O	O	New 345 kV circuit overload. Beaver - Carlisle 345 kV (118%) for tower outage
2016_3-5F	12.4	X	X	X	X	X	X	X	X	X	O	
2016_3-6B	13.4	X	X	X	X	O	O	O	O	X	X	Same as project 2016_3A-3B
2016_3-6C	30.3					O	O	O	O			
2016_3-6D	3.2	O	O	O	O	X	X	X	X	X	X	Same as project 2016_3A-3C
2016_3A-1A	44.58	O	O	O	O	O	O	O	O	O	O	New 345 kV circuit overload. Beaver - Carlisle 345 kV (118%) for tower outage
2016_3A-1B	50.56											Analysis was differed due to the high cost
2016_3A-2A	62.8											Analysis was differed due to the high cost
2016_3A-3A	19.97	X	X	X	X	X	X	X	X	O	O	
2016_3A-3B	13.46	X	X	X	X	O	O	O	O	X	X	
2016_3A-3C	3.2	O	O	O	O	X	X	X	X	X	X	

Note:

- Blue shaded cells indicate the flowgates that were claimed to be solved by the Proposing Entity
- 'O' means yes, the proposed project solves the flowgate violation
- 'X' means no, the proposed project doesn't solve the flowgate violation

Proposals Comparison and Cost Summary							
	Proposing	Cost Estimate				Additional Cost	Total Cost
Project ID	Entity	($ Million)	Advantages	Disadvantages	Additional upgrade	($ Million)	($ Million)
2016_3-2C / 2016_3A-1A	Transource (Greenfield)	44.58	Solves all Flowgates	Causes a new violation. Requires a new ROW	Replace terminal equipments at the Beaver and Carlisle 345 kV stations	1	45.58
2016-3-5B	NTD (Greenfield)	19	Solves 8 Flowgates	2 unsolved flowgates	Upgrade FG # 386 and 915	Cost from 2016-3A-3A (19.97)	38.97
2016_3-5D	NTD (Greenfield)	35.4	Solves all Flowgates	Causes a new violation. Requires a new ROW	Replace terminal equipments at the Beaver and Carlisle 345 kV stations	1	36.4
2016_3-5F	NTD (Greenfield)	12.4	Solves one flowgate	9 unsolved flowgates	Upgrade FG # 386, 392, 393, 489 and 490, 400, 493, 407 and 504	Cost from 2016-3A-3A, 2016_3A-3B and 2016-3A-3C (36.63)	49.03
2016_3-6B / 2016_3A-3B	First Energy (Upgrade)	13.46	Solves 4 flowgates	6 unsolved flowgates	Upgrade FG # 386, 915, 392, 393, 489 and 490	Cost from 2016-3A-3A and 2016-3A-3C (23.17)	36.63
2016_3-6C	First Energy (Greenfield)	30.3	Solves 4 flowgates	6 unsolved flowgates	Upgrade FG # 386, 915, 392, 393, 489 and 490	Cost from 2016-3A-3A and 2016-3A-3C (23.17)	53.47
2016_3-6D / 2016_3A-3C	First Energy (Upgrade)	3.2	Solves 4 flowgates	6 unsolved flowgates	Upgrade FG # 386, 915, 400, 493, 407 and 504	Cost from 2016-3A-3A and 2016_3A-3B (33.43)	36.63
2016_3A-3A	First Energy (Upgrade)	19.97	solves 2 flowgates	8 unsolved flowgates	Upgrade FG # 392, 393, 489 and 490, 400, 493, 407 and 504	Cost from 2016_3A-3B and 2016-3A-3C (16.66)	36.63

2016 RTEP Proposal Window 3/3A
ATSI Transmission Zone

- The First Energy Combined proposals (2016_3A-3A, 2016_3A-3B and 2016_3A-3C) total cost is the lowest of any of the proposed solutions, with the exception of the 2016-3-5D,
- First Energy projects (2016_3A-3A, 2016_3A-3B and 2016_3A-3C) are upgrade to an existing facilities and therefore no risk for siting or permitting.

- **Preliminary Recommendation:**
  - Rebuild/Reconductor the Black River – Lorain 138 kV circuit. (2016_3A-3B)
  - Reconductor the Avon – Lorain 138 kV section and (2016_3A-3C)
  - Reconductor the Beaver - Black River 138kV) with 954Kcmil ACSS conductor and upgrade terminal equipment on both stations. (2016_3A-3A)

- **Estimated Project Cost:**
  - 2016_3A-3B → $ 3.2 M
  - 2016_3A-3C → $ 13.46 M
  - 2016_3A-3A → $ 19.97 M

- **Required IS Date:** 6/1/2021

PSE&G End Of Life Assessment
Newark Switch Review

PSE&G End Of Life Assessment
Newark Switch Review

- Refer to PSE&G criteria:

  VII. EQUIPMENT ASSESSMENT AND STORM HARDENING

  http://www.pjm.com/~/media/planning/planning-criteria/PSE&G-planning-criteria.ashx

  - Risk of a transformer fire that may result in the entire building on fire and thus the loss of ~>300 MVA of load for a long duration. Nearby school/church & healthcare facility.
  - Several common mode of failures

Newark Switch

- Age: Substation: 1957
- T1: 1972 – T2 & T3: 1958
- Spare: 1992
- Special transformer: Dual ratio (138/26/13)
  - Wye-Wye 13 kV All PSEG 13 kV transformers are delta-wye (30°)
- Maintenance and Maintenance outages
- Rooftop transmission system
- Lower level indoor transformers
- Critical Station (City of Newark - Downtown) ~300 MVA Load
  - Financial buildings
  - City Hall
  - Other Government Buildings
  - NJIT, Rutgers
  - PATH Train, NJ Transit
  - 26kV and 13kV Source station
  - Several Data Centers
  - Downtown Newark
  - Prudential Arena, NJ Performing Arts Center
  - United States Citizenship and Immigration Services (USCIS)

Newark Switch – Existing Station Layout

- Basement: Oil rooms, 13 & 26 kV feeders & transmission lines entering the station
- 1st Floor: 26 kV switchgear & Transformers' vaults
- 2nd floor: Distribution reactors
- 3rd floor: Control room/AUX power rooms
- Roof: 138 kV Yard

Newark Switch – Existing Station Age and Condition

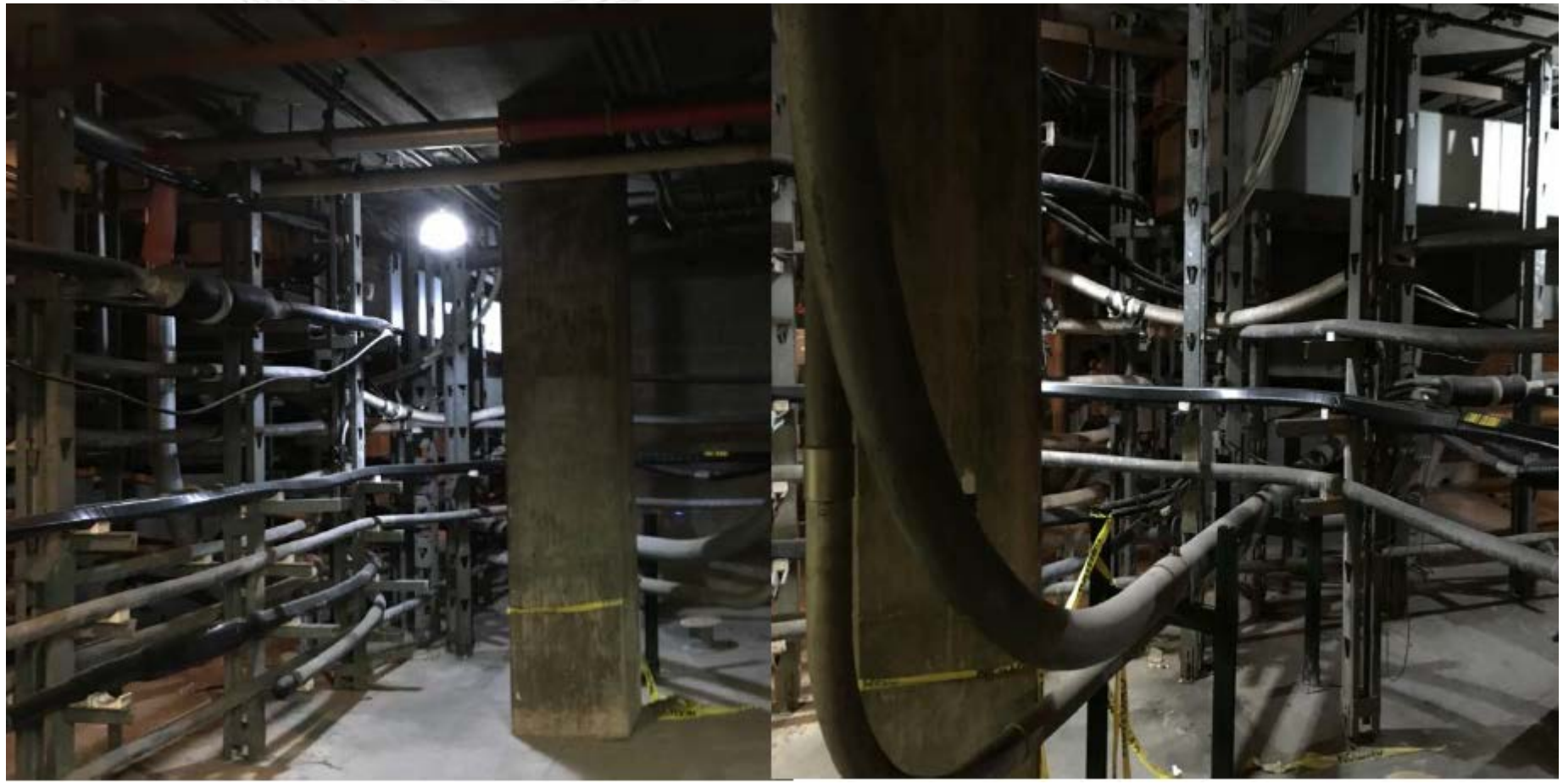
- Station age and condition
  - Based on unique design, aged equipment and obsolete equipment Newark Switch is considered at end-of-Life.
- Potential risks and consequences
  - Any transformer fire or catastrophic failure would result in the destruction of the whole facility and the loss of 300 MVA of critical load for an extended period of time.
- 26/13 kV bus faults
- Other risks and common modes of failure
- Environmental/structural concerns

Newark Switch – Current Property

- Urban location
- Proximity to existing transmission system

Newark Switch – Current Property

- Distribution feeds below transformer vaults



Newark Switch – Existing Equipment and Transformers

- Transformers located below the 138 kV rooftop switchyard.

- A transformer fire would be significant and result in catastrophic loss

* PSE&G Pierson transformer fire

* Newark Switch transformer

Design Concept Alternative #1 Reviewed August 2016

Potential Project Scope: Build new Newark GIS station in a building located adjacent to the existing Newark Switch and demolish the existing Newark Switch

- New layout is five bay breaker and a half GIS on same property
- 26kV feeders above transformers would move to new GIS building
- 13kV feeders would move to new GIS building
- New (3) story building would require notching out corner of existing building
- Gas Insulated bus (GIB) would run from GIS back through old building
- 13kV and 26kV conductors would run in building to new feeders above GIS back down to underground splices
- Long transformer outages required for cutovers
- Selective demolition of existing building would be done around remaining transformers and new GIB

Anticipated Project Risks

- Construction/demolition in and around live equipment
- Possible extensive structural modifications to support work in building
- Little to no construction laydown
- Long cutover outages on existing circuits
- No stormwater retention to meet city requirements

Cost Estimate

- $353M

PSE&G Transmission Zone
Newark Switch

Other Alternatives Considered:

Alternative #2: Find a large property and build a new substation challenges: No large property available in the city of Newark

- Find new property
  - Challenge: No large property available in the city of Newark
- Relocate four (4) 138 kV transmission lines
- Relocate over thirty 26 & 13 kV distribution feeders.
- Requires extended transmission & distribution outages
- Assuming available property, the cost to relocate and rebuild Newark Switch will be ~$458M (September 2016)

Alternative #3:

- Status quo: Risk of a transformer fire that may result in the loss of entire building and station. The result is the loss of ~>300 MVA of load for a long duration.

Additional Alternative Development Efforts
August 2016 to January 2017

PSE&G hired a third party consultant to refine scope

- Evaluate placing new transformers adjacent to new GIS building
- Develop new building design
- Address stormwater retention
- Validate costs and quantify risk

Contacted GIS and switchgear suppliers for alternate equipment configurations

- Validate compact GIS design
- Obtained switchgear/LCC layouts

Conducted constructability reviews

- Developed construction sequencing plan and laydown needs

Public Outreach

- Contacted adjacent property owners regarding expansion
- Continued to evaluate alternates sites for construction laydown
- Met with Mayor and City Council members to identify concerns

Estimate

- Refined costs and modified risk and contingency

Design Concept Alternative #1A
January 2017

Build new Newark GIS station in a building located adjacent to the existing Newark Switch and demolish the existing Newark Switch

Previous Scope from Alternative #1

- New layout is five bay breaker and a half GIS on same property
- 13kV feeders would move to new GIS building

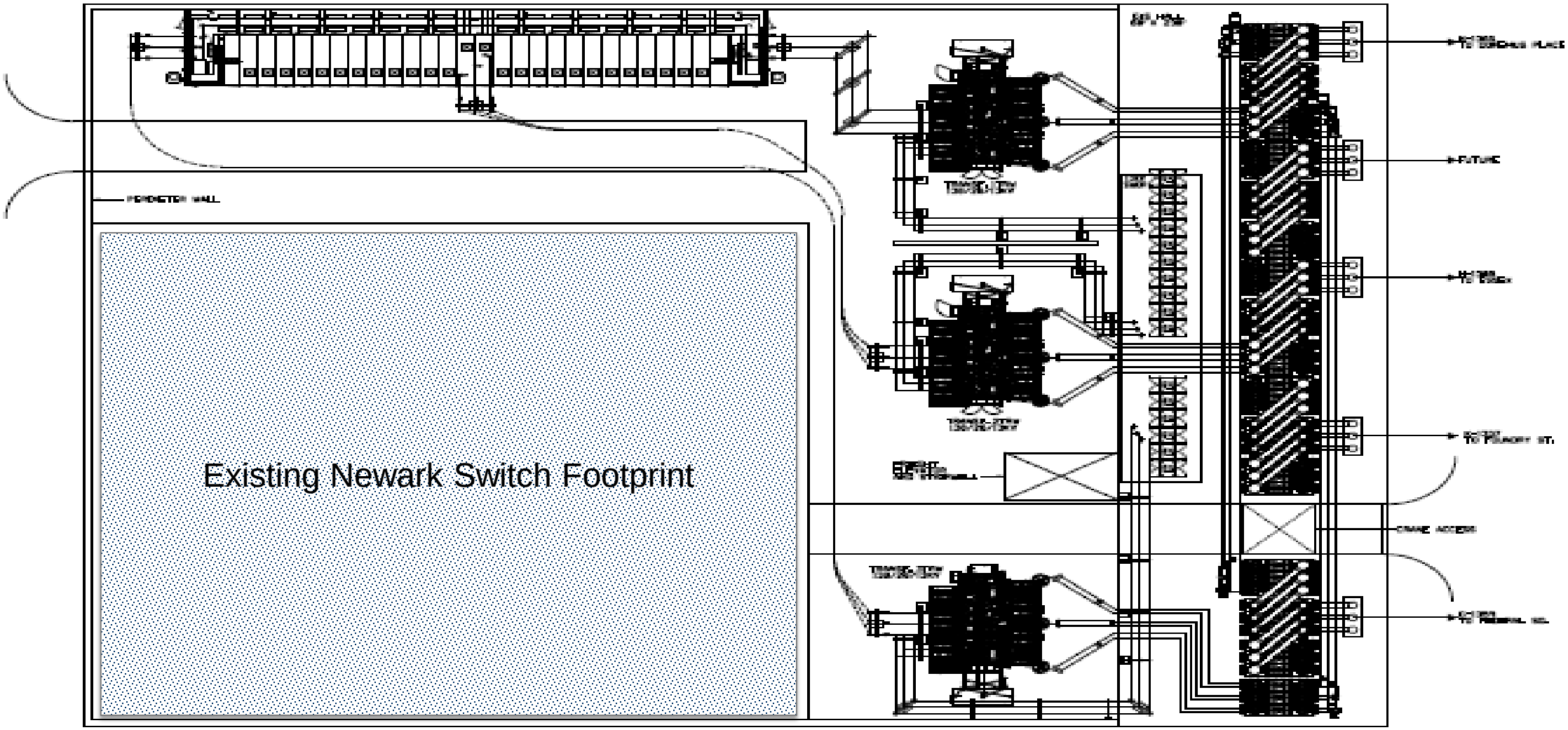
Updated Project Scope for Alternative #1A

- Purchase 3 new dual ratio transformers and place outside of existing building
- 26kV feeders above transformers would move outside on ground level adjacent to new access driveway
- Arrange GIS in compact layout making building narrower, longer and lower
- Build new (3) story building isolated from existing Station building with sub-basement for storm water retention
- GIB is entirely within new building
- 13kV and 26kV feeders are at ground level
- Transformer outages required for cutovers are not as long
- Use conventional demolition methods

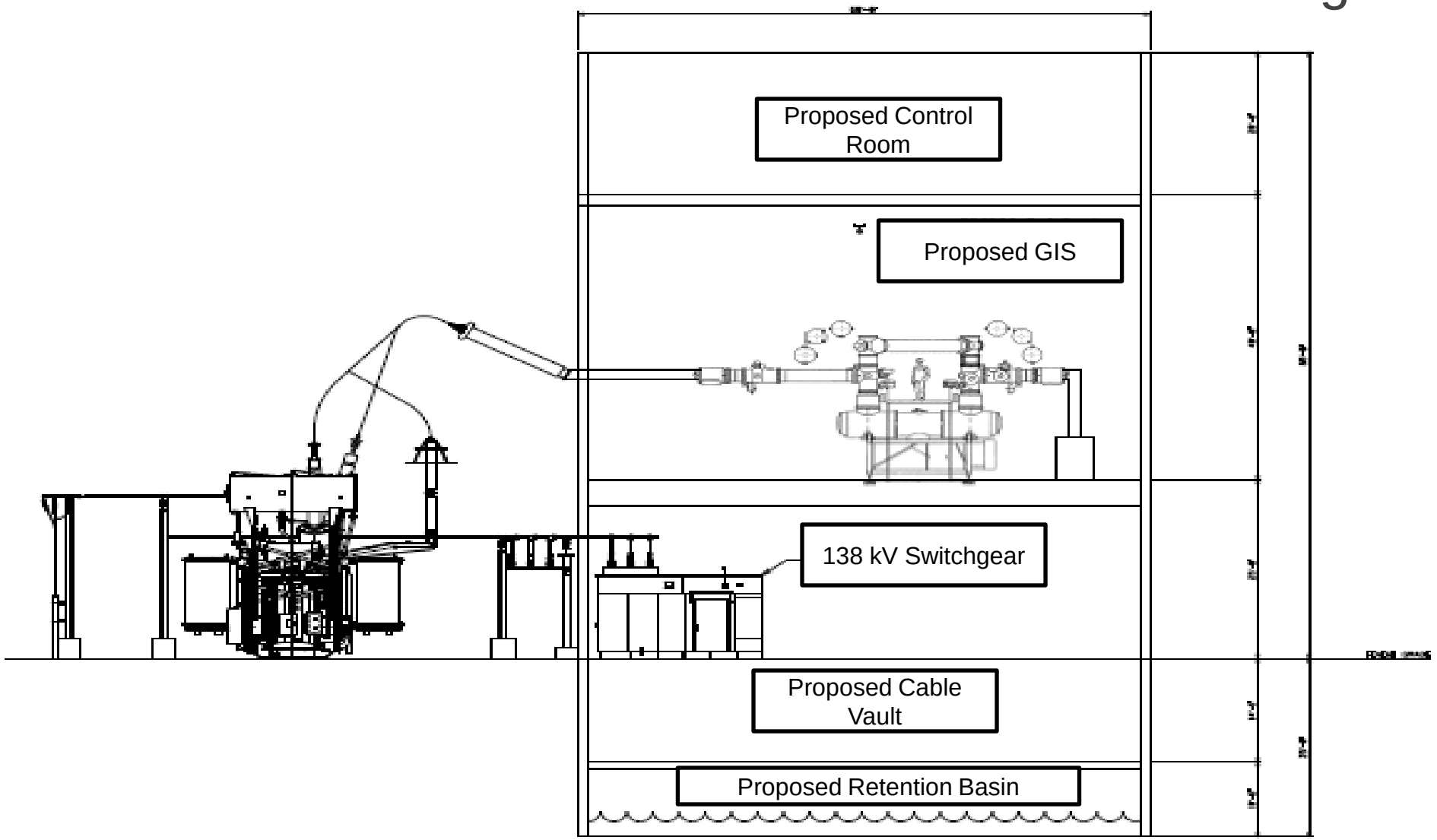
Alternative #1A Cost Estimate

- $275M

PSE&G Transmission Zone
Newark Switch New Design Concept



PSE&G Transmission Zone
Newark Switch New Design Concept



Alternative #1A Details
February 2017

- Alternate 1A new scope & layout has less constructability concerns than the previous alternative 1 approach
  - All new construction is completely outside of existing building
  - Work can be done on standard work day schedules, reducing construction productivity risks due to construction during outages (i.e. GIB and transformer bushing work)
  - No longer necessary to build GIB over existing transformers
  - Additional property facilitates staging of equipment deliveries

- Transformer arrangement meets standard fire protection criteria and oil-filled cables are no longer next to transformers
  - GIB is no longer over energized equipment in existing building

- Transformer outage cutovers are reduced
  - GIS and GIB can be fully tested prior to starting cutovers

- Reduction in cost estimate of $78M
  - $18M in direct costs
  - $60M in risk/contingency

- Property negotiations are underway

- All equipment fully energized by June 2021

PSE&G Transmission Zone

Problem:

PSE&G FERC 715 Transmission Owner Criteria

Newark Switch Aging Infrastructure

PSE&G FERC 715 Transmission Owner Criteria

- Age
  - Substation: 1953
  - Transformer 1: 1972
  - Transformer 2&3: 1958
  - Spare: 1992
- Housed in an urban building
- Equipment condition assessment
- Equipment has reached its end of life

Alternatives Considered:

1. Build new Newark GIS station in a building (layout #1) located adjacent to the existing Newark Switch and demolish the existing Newark Switch

1A. Build new Newark GIS station in a building (layout #1A) located adjacent to the existing Newark Switch and demolish the existing Newark Switch

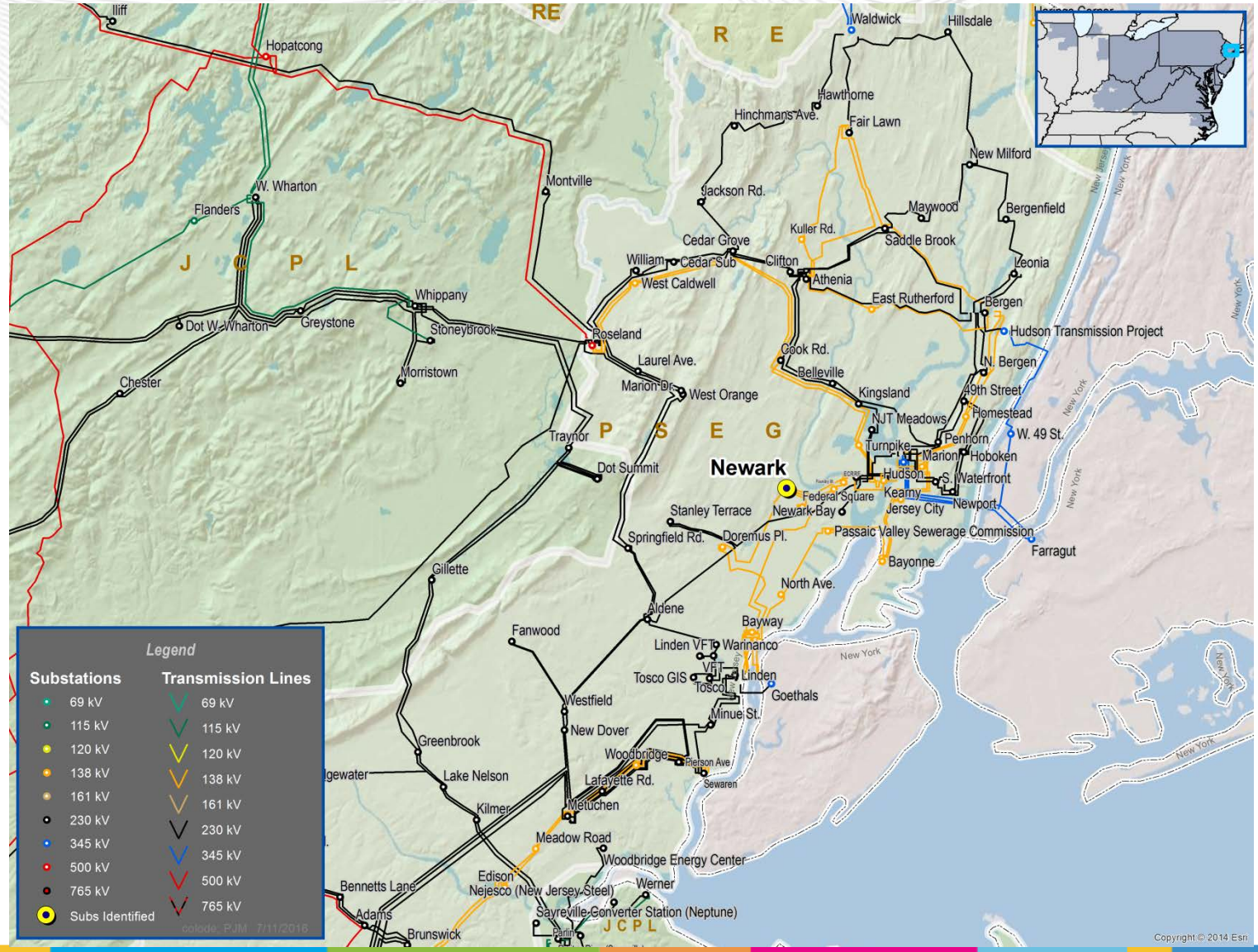
3. Build a new Newark GIS station elsewhere in Newark and relocate all transmission and distribution cables and protection equipment

4. Status quo, do nothing.

Recommended Solution:

Alternative #1A - Build new Newark GIS station in a building (layout #1A) located adjacent to the existing Newark Switch and demolish the existing Newark Switch

Current Alternative #1 Estimated Cost: In-progress : $275 M (January 2017)



Short Circuit

AE Transmission Area

Problem: Short Circuit

- The Sickler 69kV breakers “H,” “M,” and “A” are overstressed

Immediate Need:

- Due to the immediate need, the timing required for an RTEP proposal window is infeasible. As a result, the local Transmission Owner will be the Designated Entity.

Alternatives Considered:

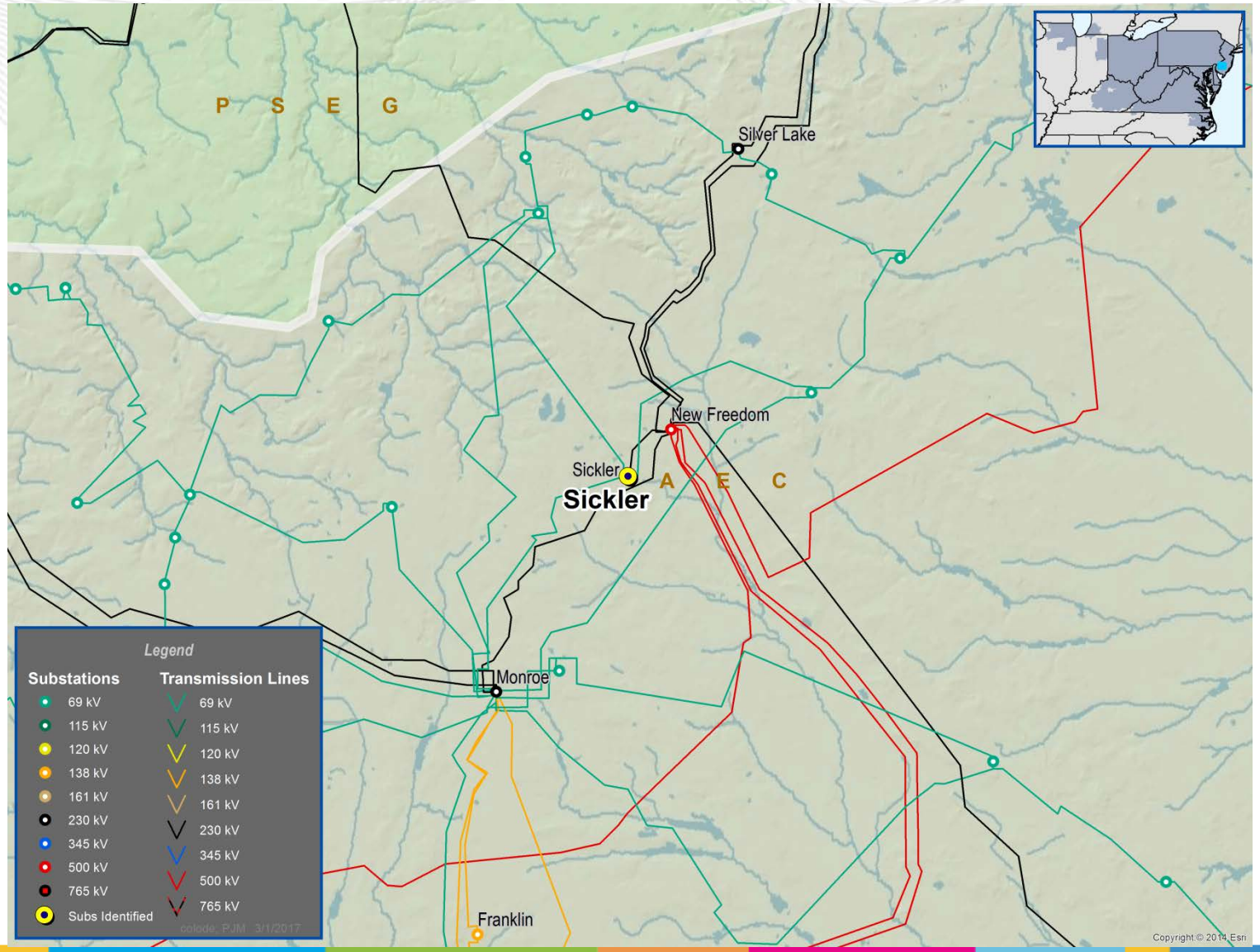
- Due to the immediate need of the project no alternatives were considered

Proposed Solution:

- Replace the Sickler 69kV breakers “H,” “M,” and “A” with 63kA breakers (b2839-2841)

Estimated Project Cost: $321.67 K (per breaker)

Required IS Date: June 1, 2019



AEP Transmission Zone

Problem: Short Circuit

- Eleven Kammer 138kV breakers are overstressed

Significant Driver: George Washington Area Project (b2753)

- Build double circuit 138 kV line from Dilles Bottom - Holloway 138 kV and a George Washington - Holloway 138 kV.

Immediate Need:

- Due to the immediate need, the timing required for an RTEP proposal window is infeasible. As a result, the local Transmission Owner will be the Designated Entity.

Alternatives Considered:

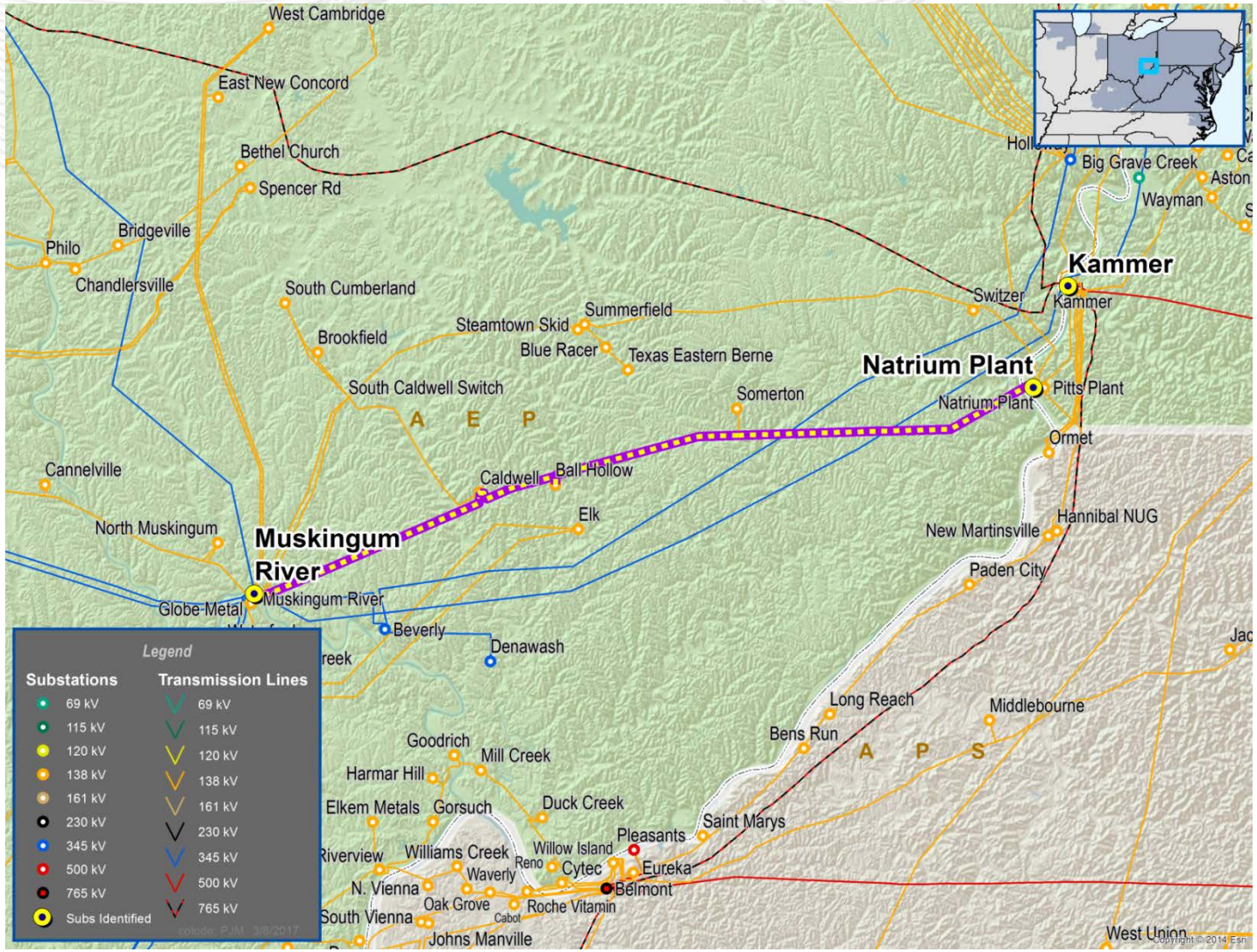
- Due to the immediate need of the project no alternatives were considered

Proposed Solution:

- Remove/Open Kammer 345/138 kV transformer #301 (b2753.9)
- Convert s1197 to a baseline upgrade (b2753.10)
  - S1197: Complete sag study mitigation on the Muskingum – Natrium 138 kV line

Estimated Project Cost: $2.8 M

Required IS Date: January 1, 2019



ATSI Transmission Area

Problem: Short Circuit

- The Crossland 138kV breaker “B-16” is overstressed

Immediate Need:

- Due to the immediate need, the timing required for an RTEP proposal window is infeasible. As a result, the local Transmission Owner will be the Designated Entity.

Alternatives Considered:

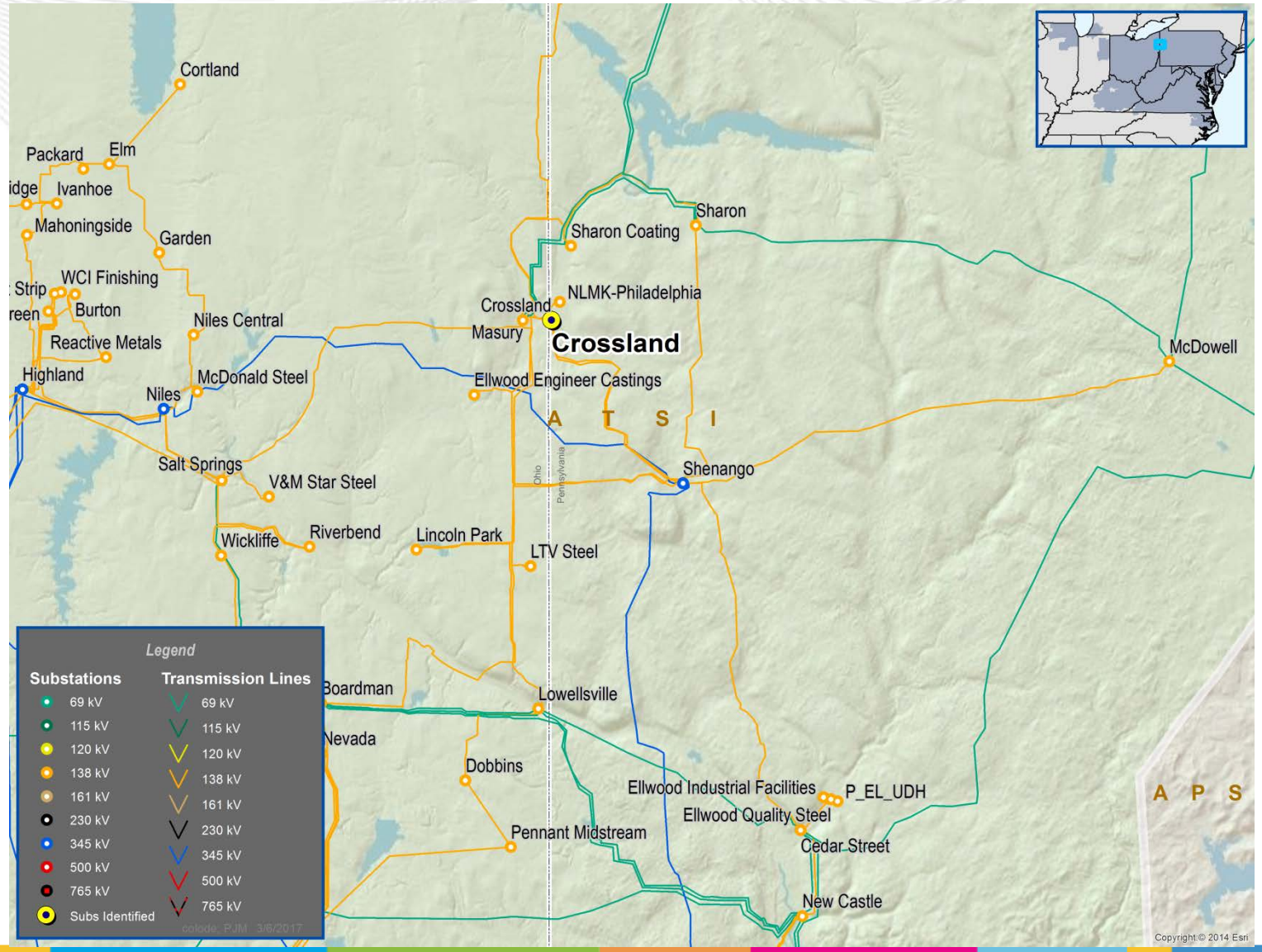
- Due to the immediate need of the project no alternatives were considered

Proposed Solution:

- Replace the Crossland 138kV breaker “B-16” with 40 kA breaker (B2869)

Estimated Project Cost: $250 K

Required IS Date: June 1, 2019



Dominion Transmission Area

Problem: Short Circuit

- Seven of the Mt. Storm 500kV breakers are overstressed

Immediate Need:

- Due to the immediate need, the timing required for an RTEP proposal window is infeasible. As a result, the local Transmission Owner will be the Designated Entity.

Alternatives Considered:

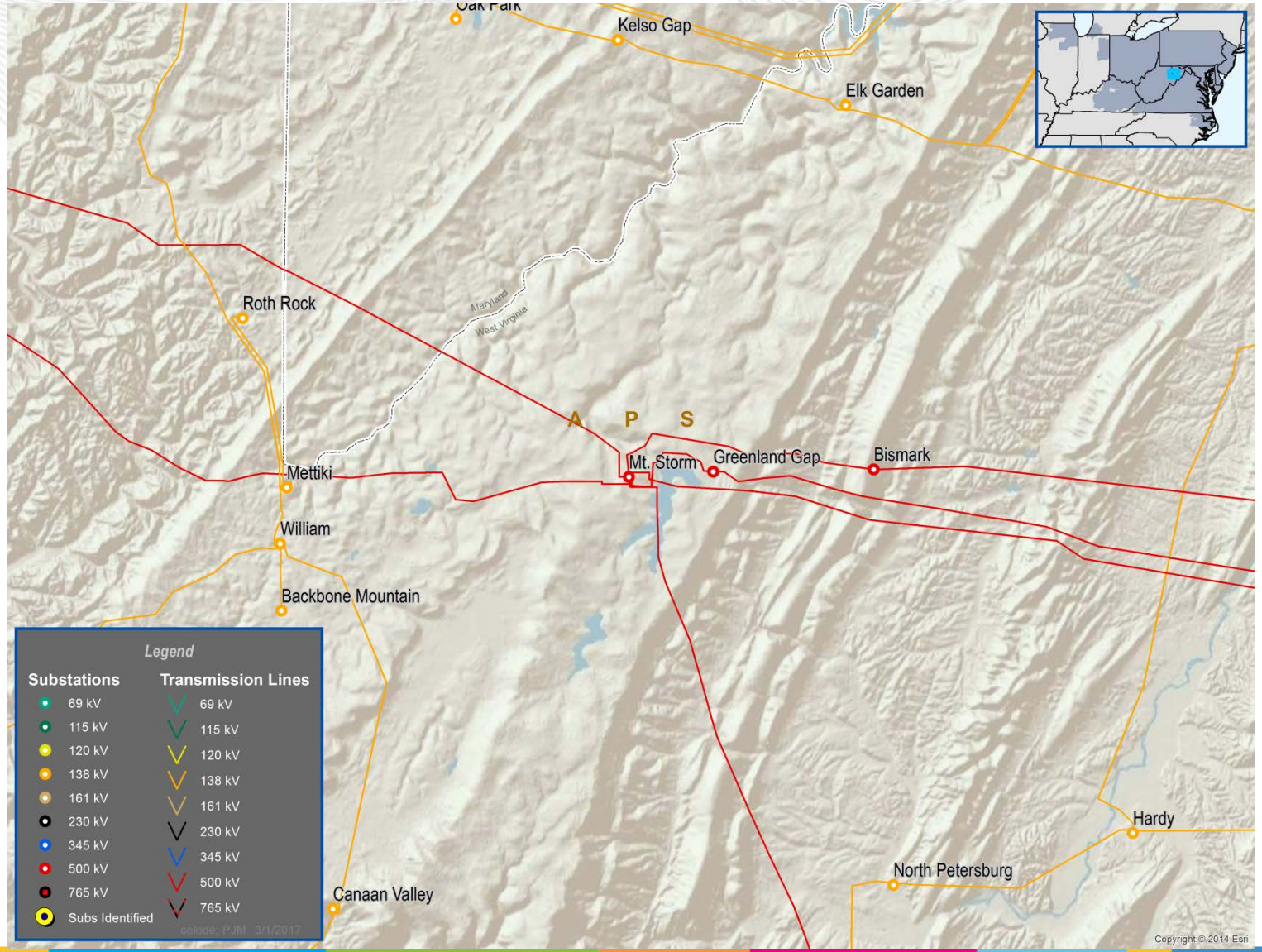
- Due to the immediate need of the project no alternatives were considered

Proposed Solution:

- Upgrade and replace the seven Mt. Storm 500kV with 50kA breakers (b2842-2848)

Estimated Project Cost: $2.708 M (total)

Required IS Date: June 1, 2019



PECO Transmission Area

Problem: Short Circuit

- Sixteen breakers at Parrish, Plymouth Meeting, Grays Ferry, Eddystone, Waneeta, Chichester, and North Philadelphia 230kV substations are overstressed

Immediate Need:

- Due to the immediate need, the timing required for an RTEP proposal window is infeasible. As a result, the local Transmission Owner will be the Designated Entity.

Alternatives Considered:

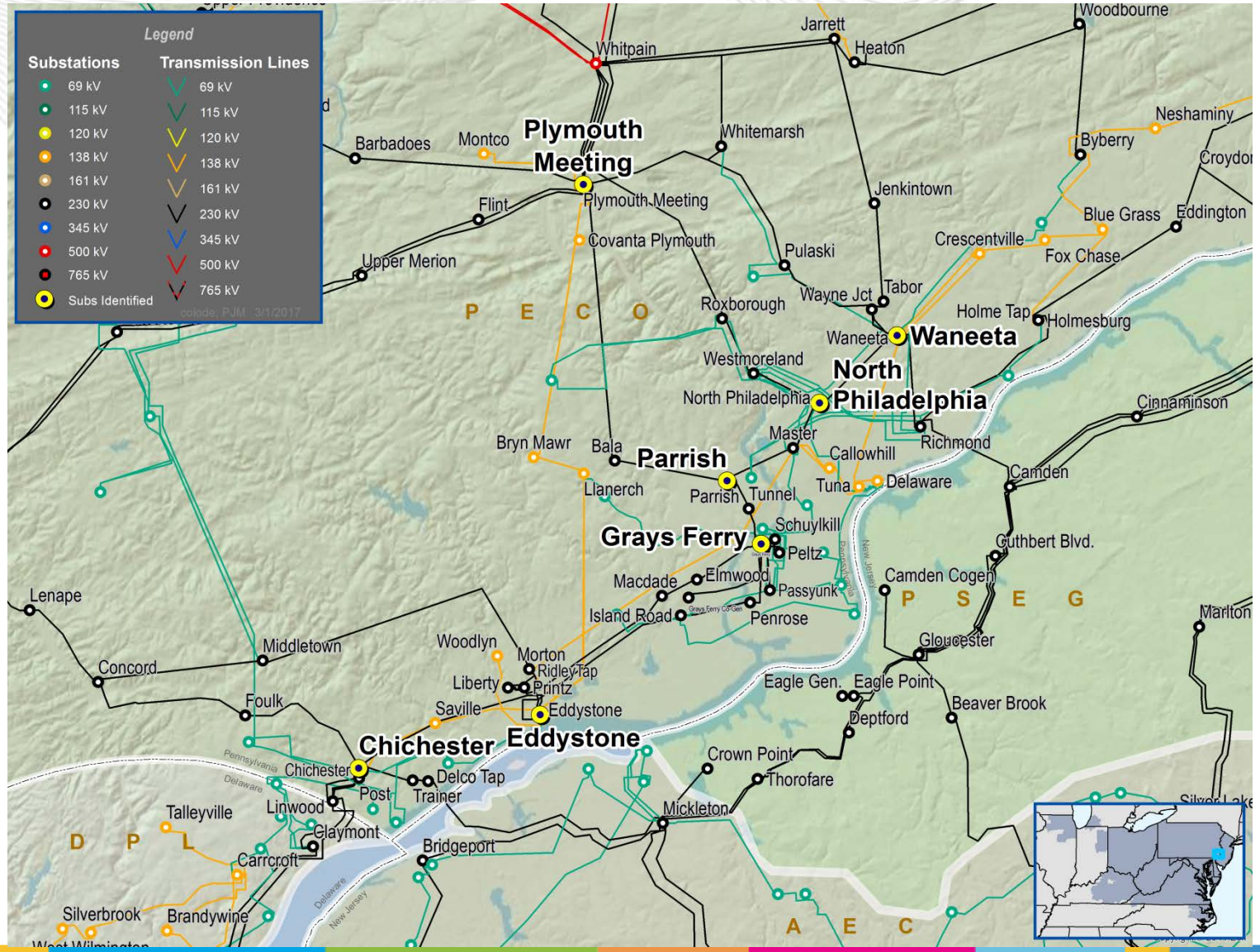
- Due to the immediate need of the project no alternatives were considered

Proposed Solution:

- Replace the Sixteen breakers at Parrish, Plymouth Meeting, Grays Ferry, Eddystone, Waneeta, Chichester, and North Philadelphia 230kV substations with 63kA breakers (b2849-2864)

Estimated Project Cost: $375 K(per breaker)

Required IS Date: June 1, 2019



Penelec Transmission Area

Problem: Short Circuit

- The Seward 138kV breakers “Jackson Road,” “Conemaugh N,” “Conemaugh S,” and “No. 8 XFMR” are overstressed

Immediate Need:

- Due to the immediate need, the timing required for an RTEP proposal window is infeasible. As a result, the local Transmission Owner will be the Designated Entity.

Alternatives Considered:

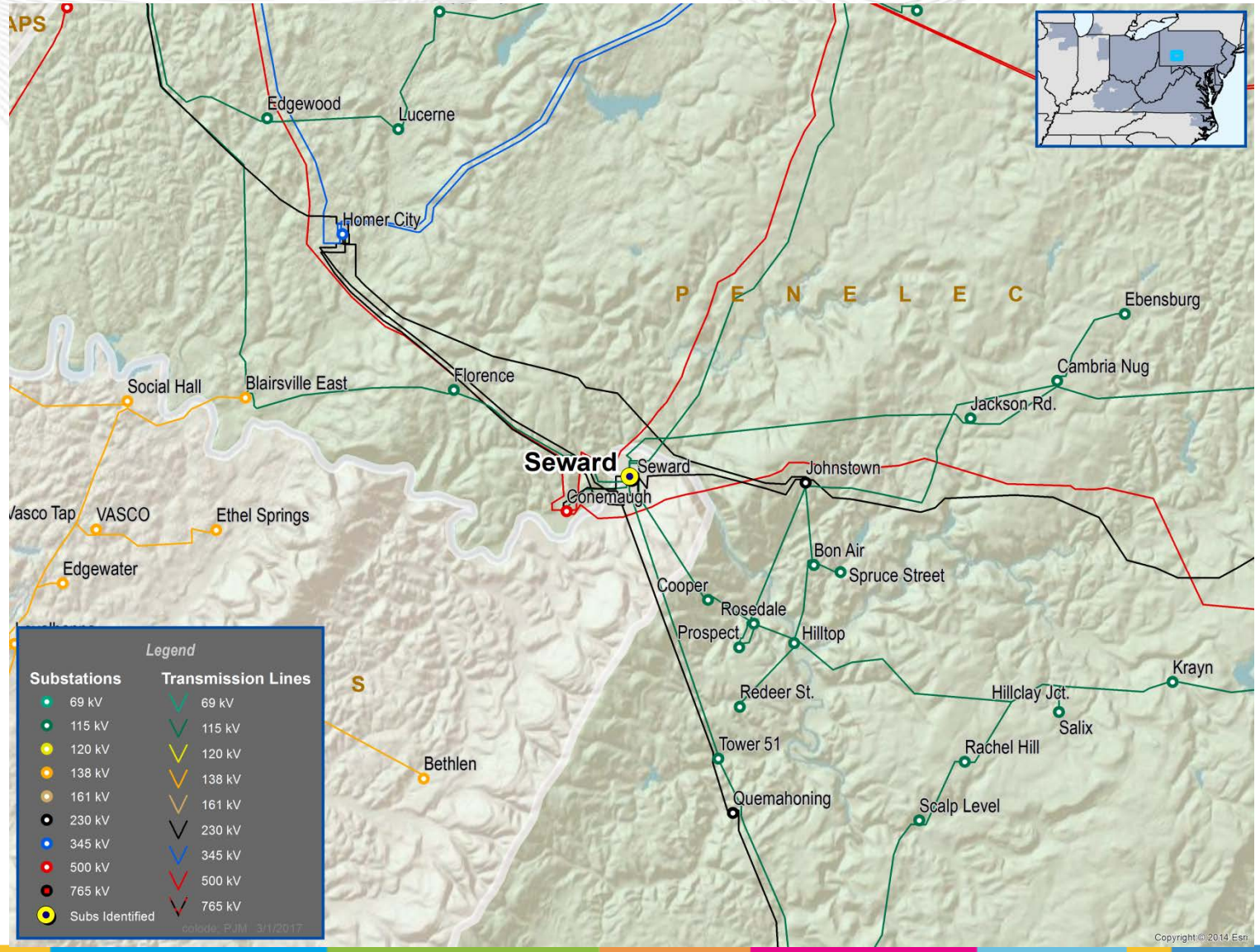
- Due to the immediate need of the project no alternatives were considered

Proposed Solution:

- Replace the Seward 138kV breakers “Jackson Road,” “Conemaugh N,” “Conemaugh S,” and “No. 8 XFMR” with 63kA breakers (b2865-2868)

Estimated Project Cost: $302.1 K (per breaker)

Required IS Date: June 1, 2019



Penelec Transmission Area

Problem: Short Circuit

- The six of the Keystone 500kV breakers are overstressed

Significant Driver: Market Efficiency Project 9A - West (b2743)

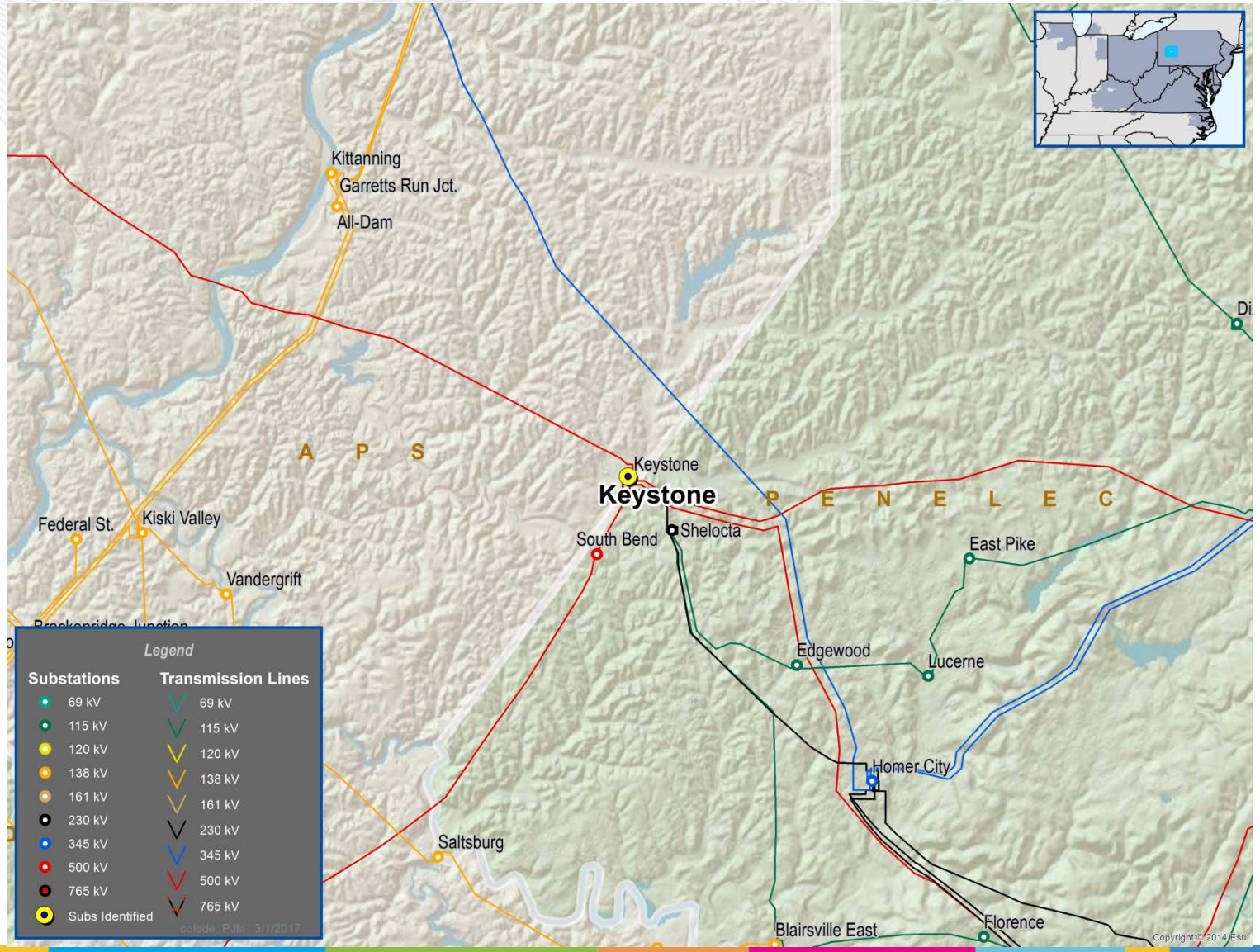
- Tap the Conemaugh - Hunterstown 500 kV line and tie in new Rice 500 kV station
- Build new 230 kV double circuit line between Rice and Ringgold 230 kV

Proposed Solution:

- Replace six of the Keystone 500kV breakers with 50kA breakers (b2743.9-b2743.14)

Estimated Project Cost: $7.4625 M (total)

Required IS Date: June 1, 2020



Supplemental Projects

ComEd Transmission Area

Supplemental Project

Previously Presented: Dec. 15, 2016

Problem Statement:

- 765 kV line 11215 from Wilton Center to Dumont has a 150 MVAR shunt inductor at Wilton Center and a 300 MVAR shunt inductor at Dumont in AEP. The AEP inductor will have a circuit breaker installed under b2231 (Install 765 kV reactor breaker at Dumont 765 kV substation on the Dumont - Wilton Center line).
- The Wilton Center inductor is bolted to the line with no switching device.
- This line has a large impact on the PJM market.
- The inductor is removed in summer months for voltage support and returned to service in the fall. Each time it is switched requires a day long outage to bolt or unbolt the connections.
- Installing a CB on the inductor will have several benefits:
  - No more line outages required for seasonal switching.
  - The inductor can be switched in and out as conditions change instead of being switched seasonally
  - The inductor will automatically close in the event of a high voltage condition.
  - Line will stay in service for inductor faults

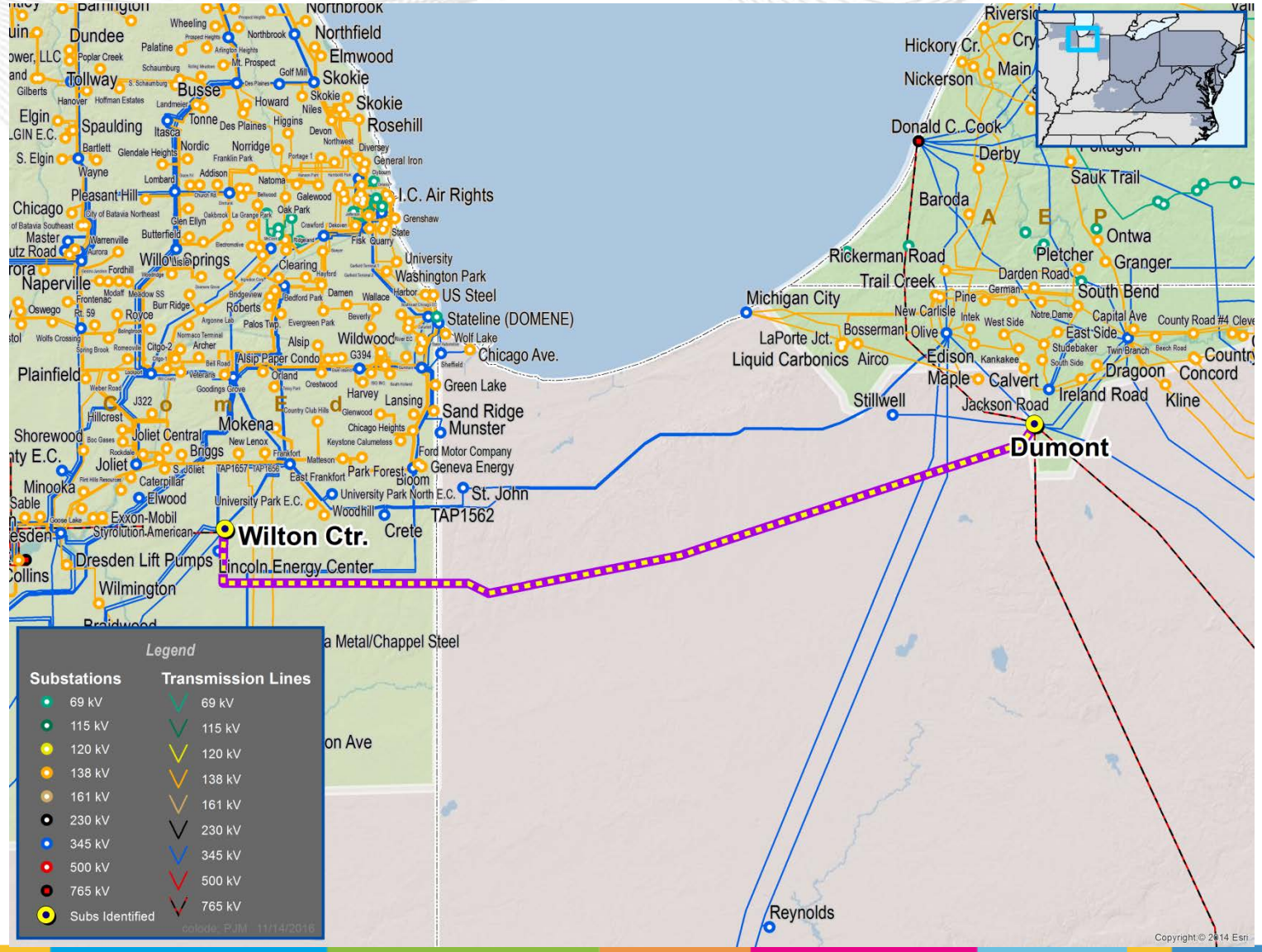
Selected Solution:

Install 765 kV CB at Wilton Center 765kV substation on line 11215 (Wilton Center – Dumont 765kV line) shunt inductor (S1204)

Estimated Project Cost: $5.8M

Projected IS Date: 6/1/2018

Project Status: Engineering & Procurement



ComEd Transmission Area

Supplemental Project
Previously Presented: Dec. 15, 2016

Problem Statement:

- Presently Pontiac transformer 82 shares a 345 kV ring bus position with 345 kV line 8014 (Pontiac – Dresden).
  - There is no high-side circuit breaker on transformer 82, so any transformer fault trips line 8014.
  - The line must be switched out of service to switch the transformer off.
  - A line fault on 8014 trips transformer 82.

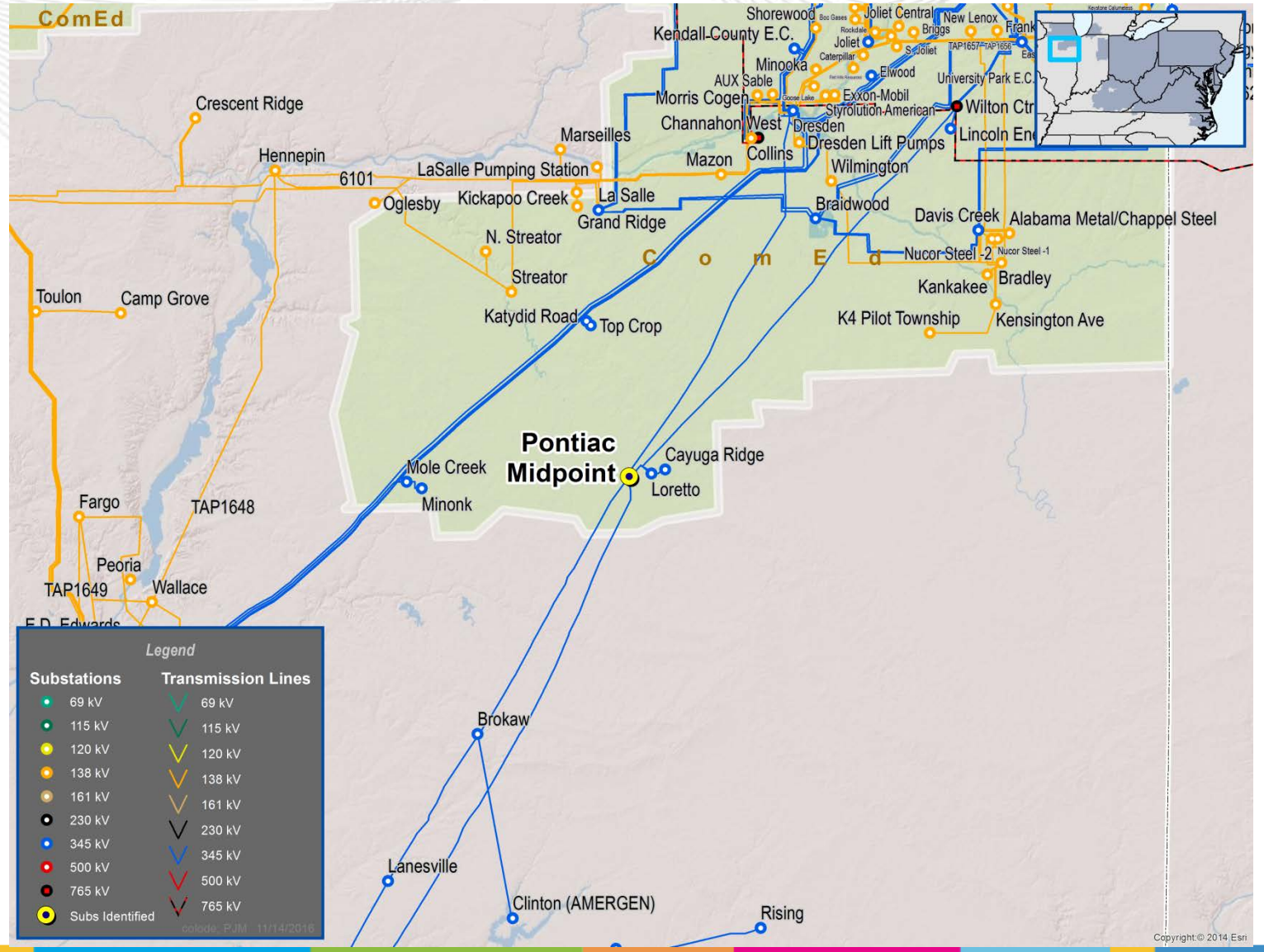
Selected Solution:

At Pontiac 345kV station, install 345 kV bus tie 6-7 to separate the transformer and line onto their own bus sections and Install a high side circuit breaker on transformer 82 to bring it up to current standards. (S1205)

Estimated Project Cost: $4.1M

Projected IS Date: 12/31/2018

Project Status: Engineering & Procurement



RTEP Anticipated Schedule

Preliminary 2017 RTEP Schedule

- Finalize Models
- Analysis
  - 2022 Baseline N-1
  - 2022 Summer Generator Deliverability and Common Mode Outage
  - 2022 Light Load Reliability Analysis
  - 2022 Winter Generator Deliverability and Common Mode Outage
  - 2022 Winter Load Deliverability
  - 2022 Winter N-1-1
  - 2022 Summer Load Deliverability
  - 2022 Summer N-1-1
  - Short Circuit Analysis
  - Annual Stability Assessment
  - Transmission Owner Criteria

RTEP Next Steps

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- Finalize 2017 Models
- Begin 2017 RTEP Analysis
- Lower Voltage Filing to be implemented with first 2017 RTEP Proposal Window
  - PJM will post the violations we expect to not go through a window consistent with filing

Questions?

Email: RTEP@pjm.com

- Revision History
  - V1 – 3/6/2017 – Original Version Posted to PJM.com
  - V2 – 3/7/2017
    - Updated Table on slide #9 – Cosmetic only
    - Updated Slides #10 and #11
    - Added slide #31 – AEP transmission zone short circuit
    - Added slides #37-#39 – 2 ComEd Supplemental Projects
  - V3 – 3/8/2017
    - Updated map on Slide #8
    - Added map to Slide #31
    - Updates to Slides #38 and #39 including formatting, status and IS date