# Fuel Requirements for Black Start Resources

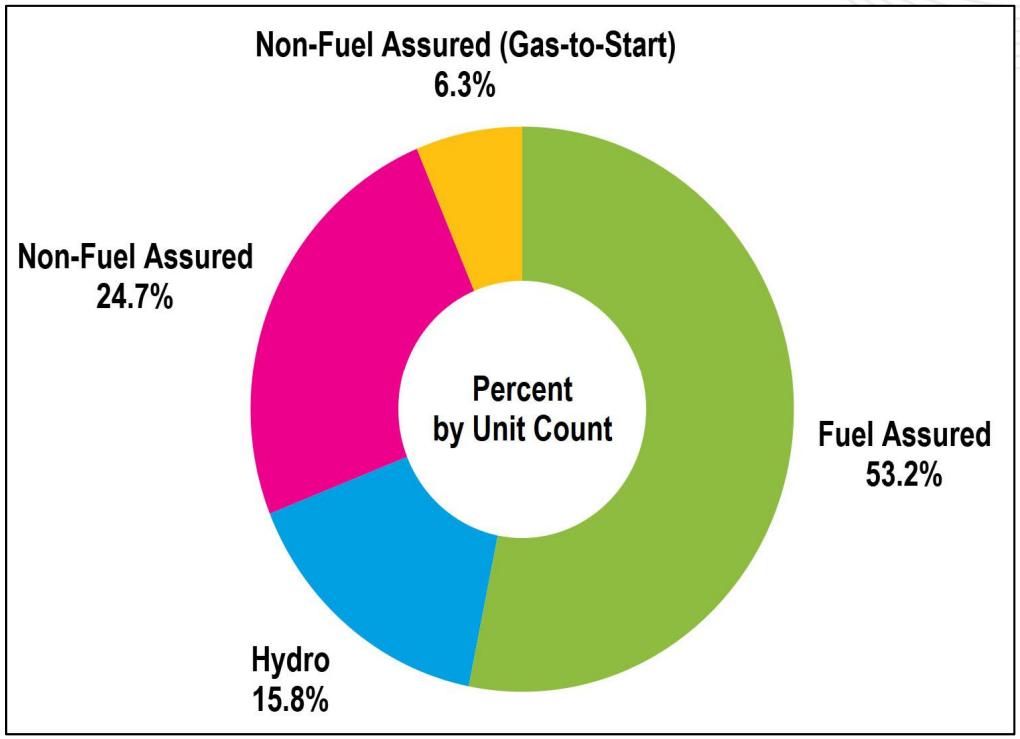
## Additional Education / Impact Analysis

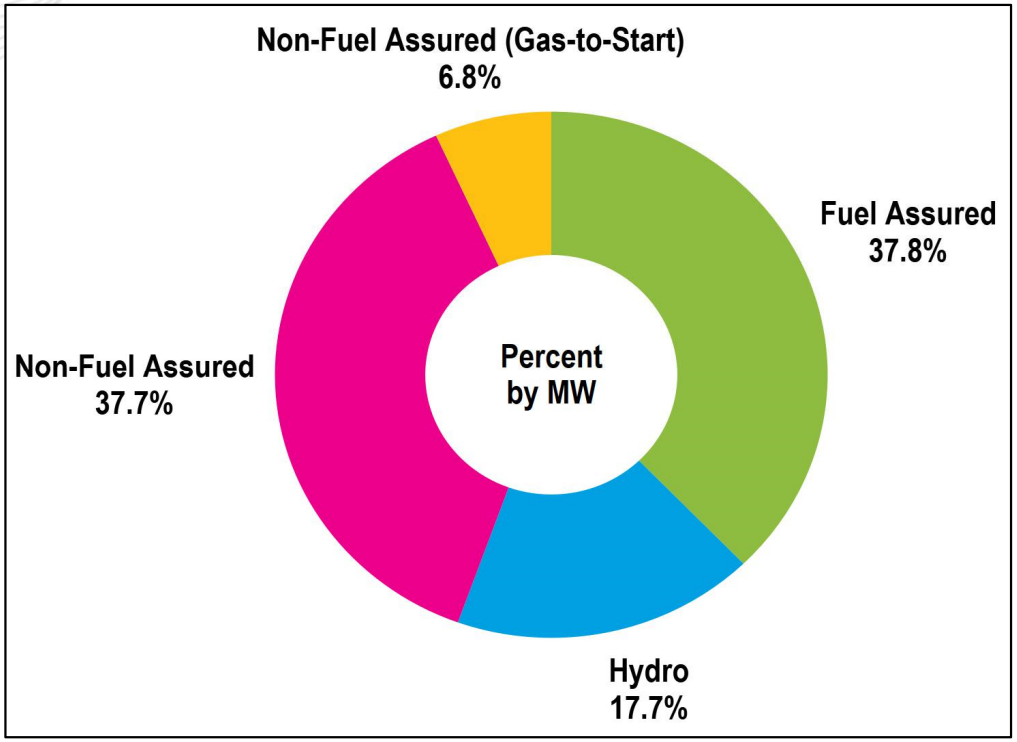
OC/MIC Special Session

6/11/2019

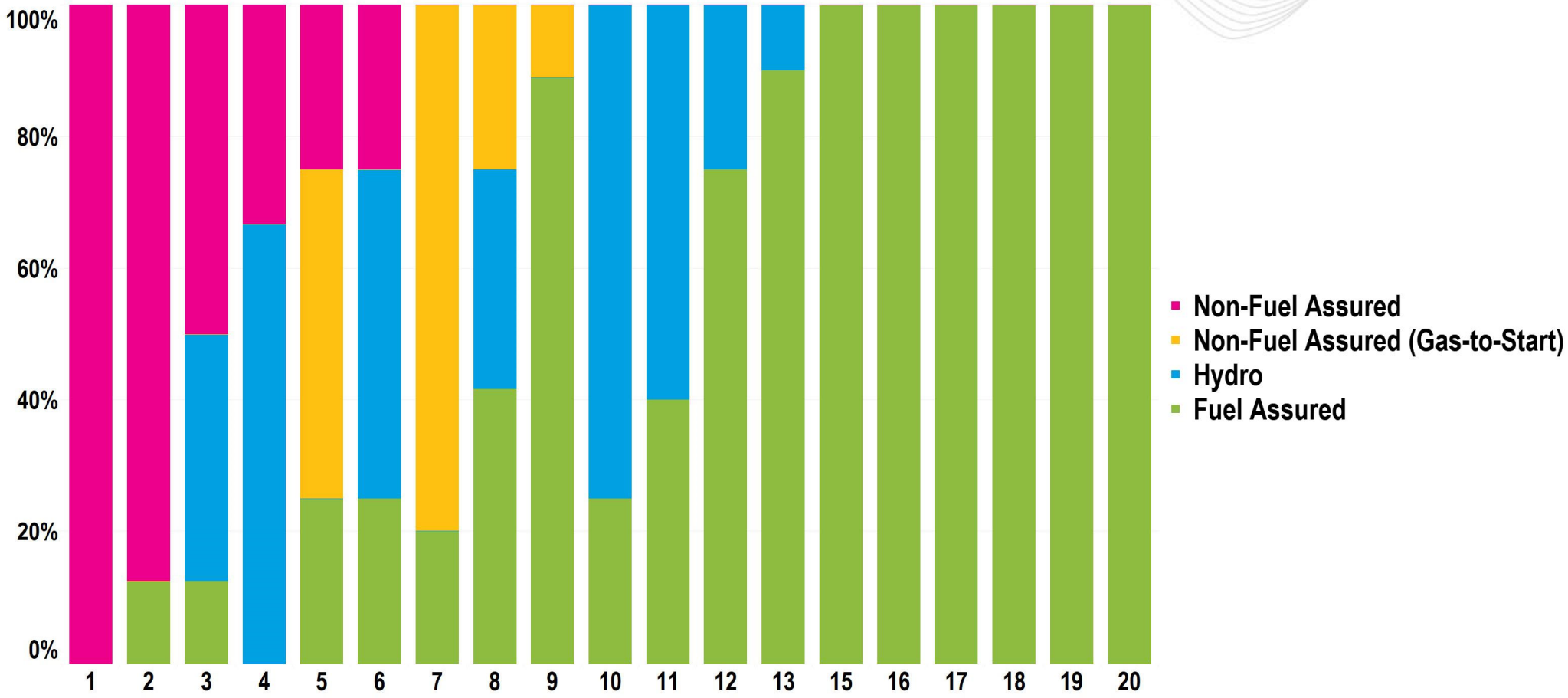
# Current Level of Fuel Assurance for Existing Black Start Resources in PJM

# PJM Black Start Fuel Assurance Breakdown



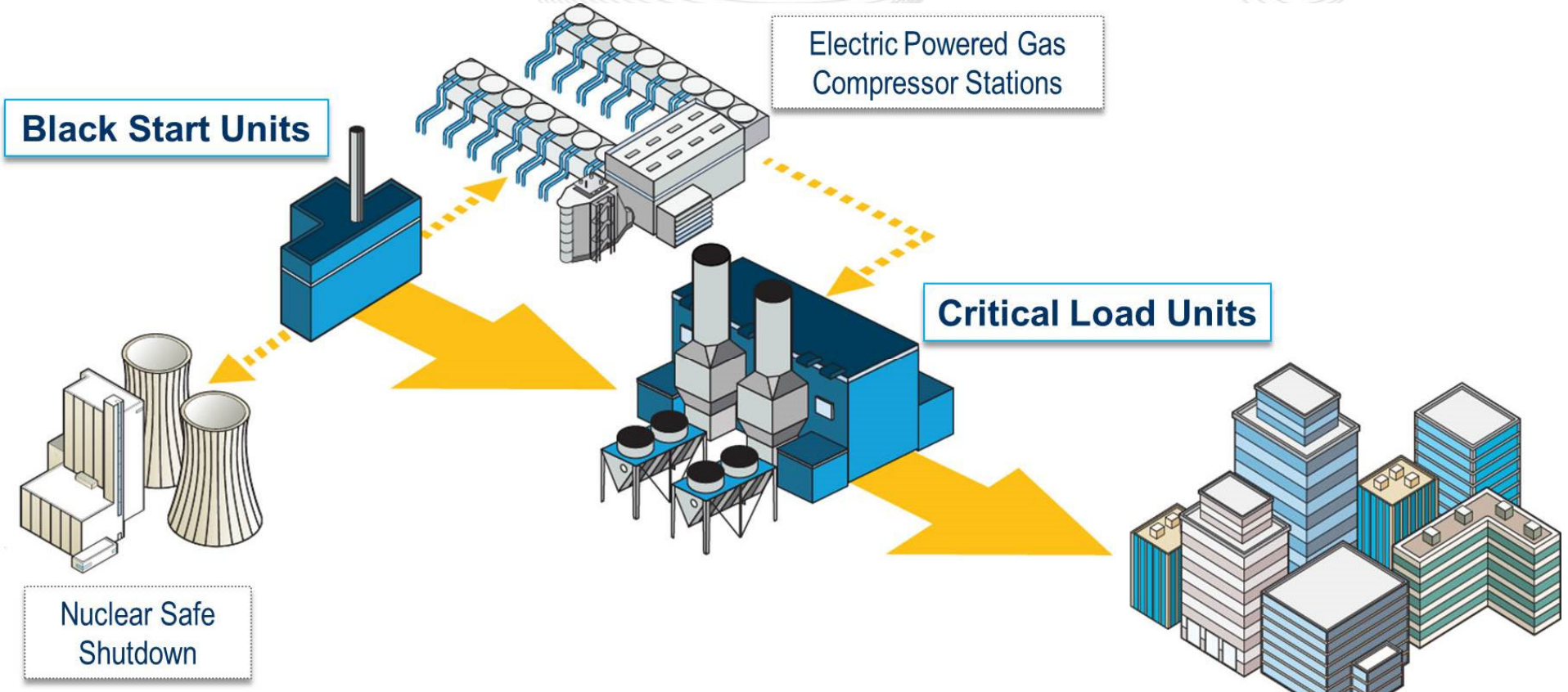



# PJM Fuel Assurance Breakdown by TO Zone



# System Restoration Impact Analysis

# How Black Start Units are Used



# Black Start Restoration Process

Start-up Black Start units

Energize cranking paths from Black Start (BS) to Critical Load (CL)

High voltages need to be controlled to avoid tripping or damaging equipment

- Reactive capabilities of online generators
- Non-generator reactive devices such as reactors, svc, etc
- Addition of load

Additional generation is brought online to support the building of cranking paths, voltage control, load pick-up, frequency, and reserves

# Black Start Restoration Process

## Primary cranking paths

- Typically the shortest electrical path (least amount of line charging) from BS to CL
- Shortest electrical path may not have the least number of substations or lines

## Alternate cranking paths

- Typically have increased line charging & higher line voltages
- **Typically require additional generation or load to control voltages which increases restoration times**

# Study Methodology

Analysis based on a sample of TO zones (4) with non-fuel assured black start sites and a different range of TO zone sizes

Impact of non fuel-assured gas black start units quantified by assessing incremental change in per unit value from primary cranking paths to alternate cranking paths for substations, transmission lines, generators, line charging, and load pick-up

Steady state/dynamic studies performed to validate alternate cranking paths

Alternate cranking paths and estimated times to energize buses and lines were provided by Transmission Owners

Projected incremental change in restoration times based on additional restoration complexity

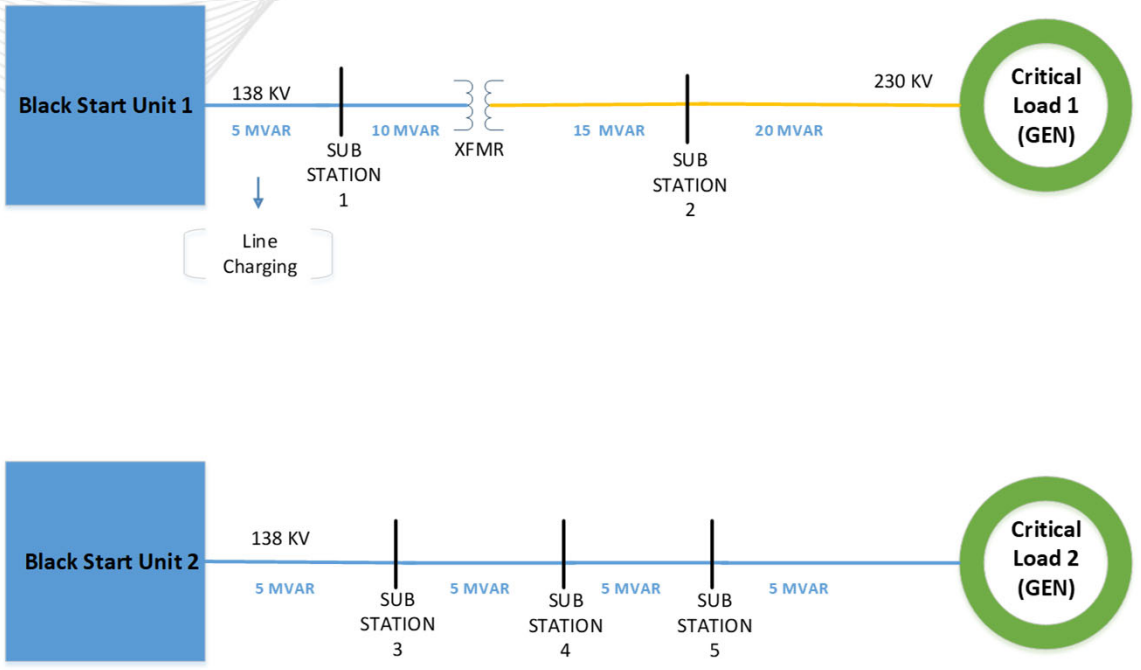
# Study Assumptions

- A subset of non-fuel assured black start sites are unavailable due to a gas pipeline issue
- Unavailable non-fuel assured gas black start sites replaced by another black start site that may or may not be fuel assured
- All critical loads are available
- All cranking paths have been assessed and cleared
- All equipment/communications are available for SCADA control
- Amount of time to energize the following assumed to be the same for each attribute for primary and alternate paths: Lines, Substations, Units, Load

# Primary Cranking Paths

| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
|---|---|---|---|---|---|
| Primary Path 1: BS 1 to CL 1 | 2 | 4 | 1 | 50 | 0 |
| Primary Path 2 : BS 2 to CL 2 | 3 | 4 | 1 | 20 | 0 |

| Per Unit | | | | | |
|---|---|---|---|---|---|
| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
| Primary Path 1: BS 1 to CL 1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Primary Path 2 : BS 2 to CL 2 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |

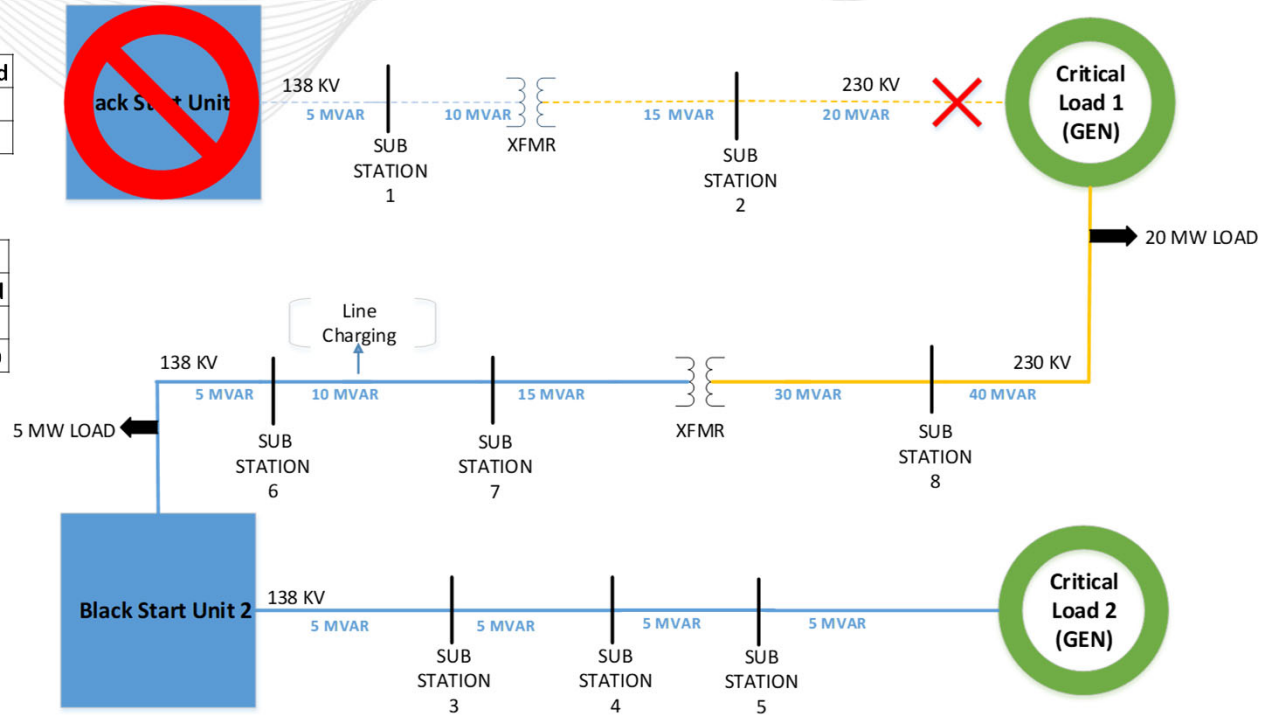



Primary Cranking Paths represent existing paths

# Alternate Cranking Path Example 1: Load Pick-up

| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
|---|---|---|---|---|---|
| Primary Path 1: BS 1 to CL 1 | 2 | 4 | 1 | 50 | 0 |
| Alternate Path 1: BS 2 to CL 1 | 3 | 5 | 1 | 100 | 25 |

| Per Unit | | | | | |
|---|---|---|---|---|---|
| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
| Primary Path 1: BS 1 to CL 1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Alternate Path 1: BS 2 to CL 1 | 1.5 | 1.3 | 1.0 | 2.0 | 25.0 |

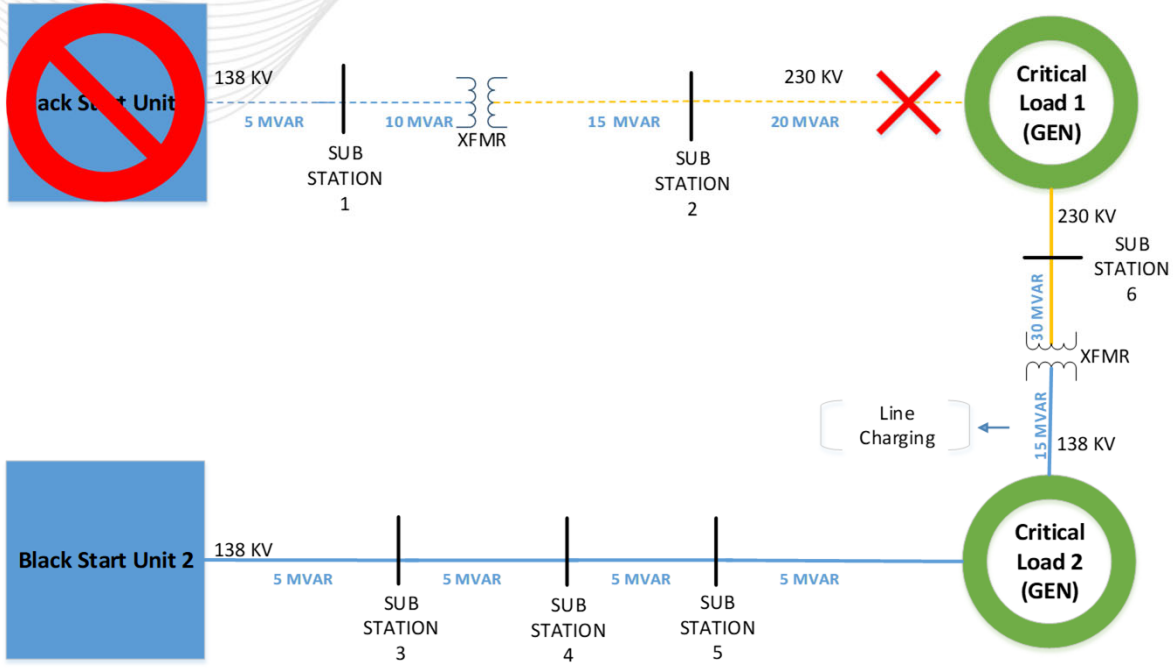



In this example, additional load is required to control voltage issues

# Alternate Cranking Path Example 2: Additional Generation

| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
|---|---|---|---|---|---|
| Primary Path 1: BS 1 to CL 1 | 2 | 4 | 1 | 50 | 0 |
| Alternate Path 2: BS 2 to CL 1 | 4 | 7 | 2 | 65 | 0 |

| Per Unit | | | | | |
|---|---|---|---|---|---|
| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
| Primary Path 1: BS 1 to CL 1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Alternate Path 2: BS 2 to CL 1 | 2 | 1.8 | 2.0 | 1.3 | 1.0 |

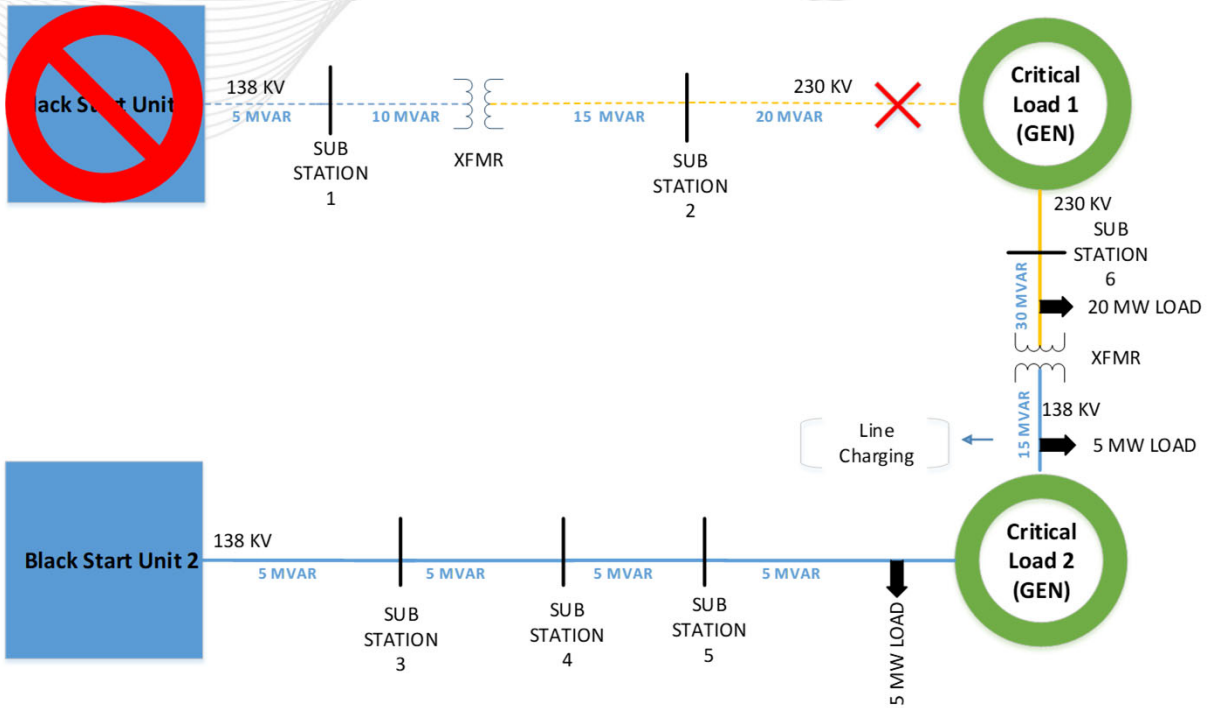



In this example, additional generation is required to control voltage issues

# Alternate Cranking Path Example 3: Load Pick-up & Additional Generation

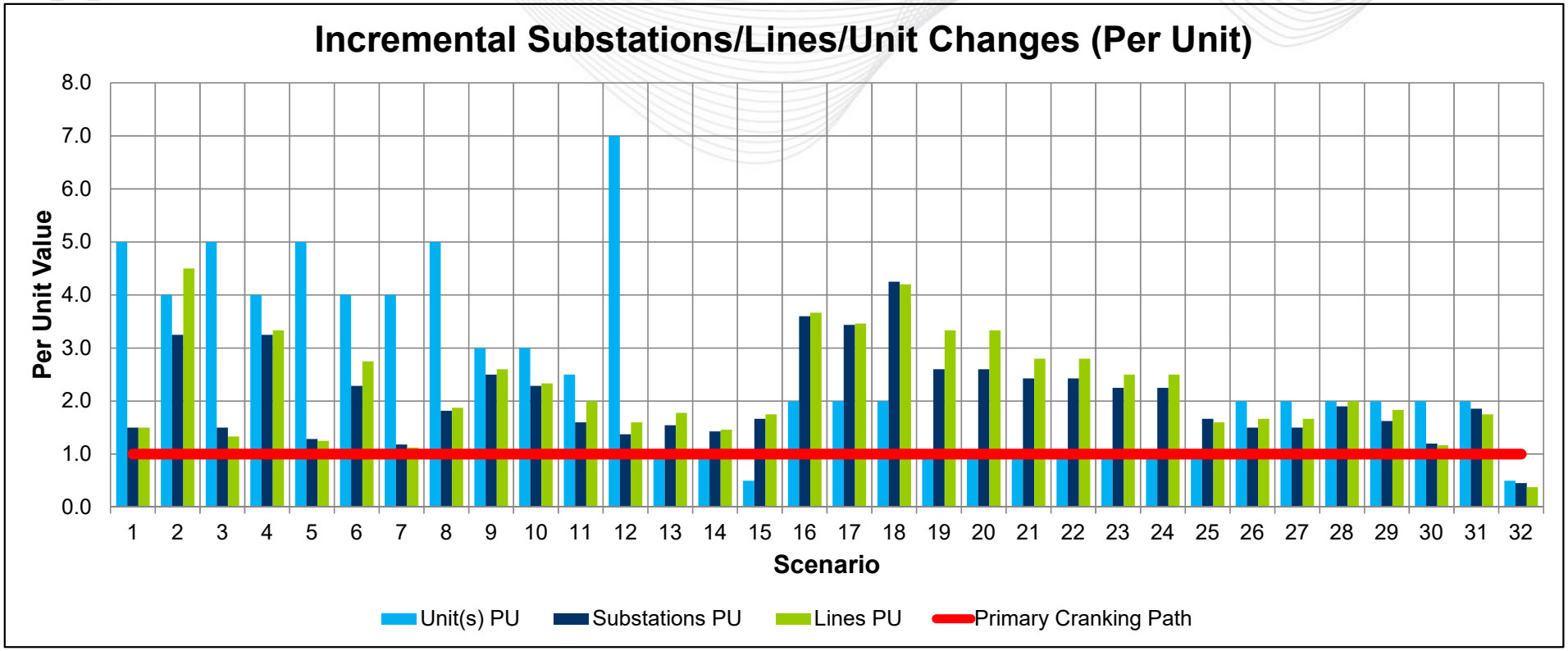
| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
|---|---|---|---|---|---|
| Primary Path 1: BS 1 to CL 1 | 2 | 4 | 1 | 50 | 0 |
| Alternate Path 3: BS 2 to CL 1 | 4 | 7 | 2 | 65 | 30 |

| Per Unit | | | | | |
|---|---|---|---|---|---|
| Cranking Path | Substations | Lines | Generators | Line Charging | Load |
| Primary Path 1: BS 1 to CL 1 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Alternate Path 3: BS 2 to CL 1 | 2.0 | 1.8 | 2.0 | 1.2 | 30.0 |



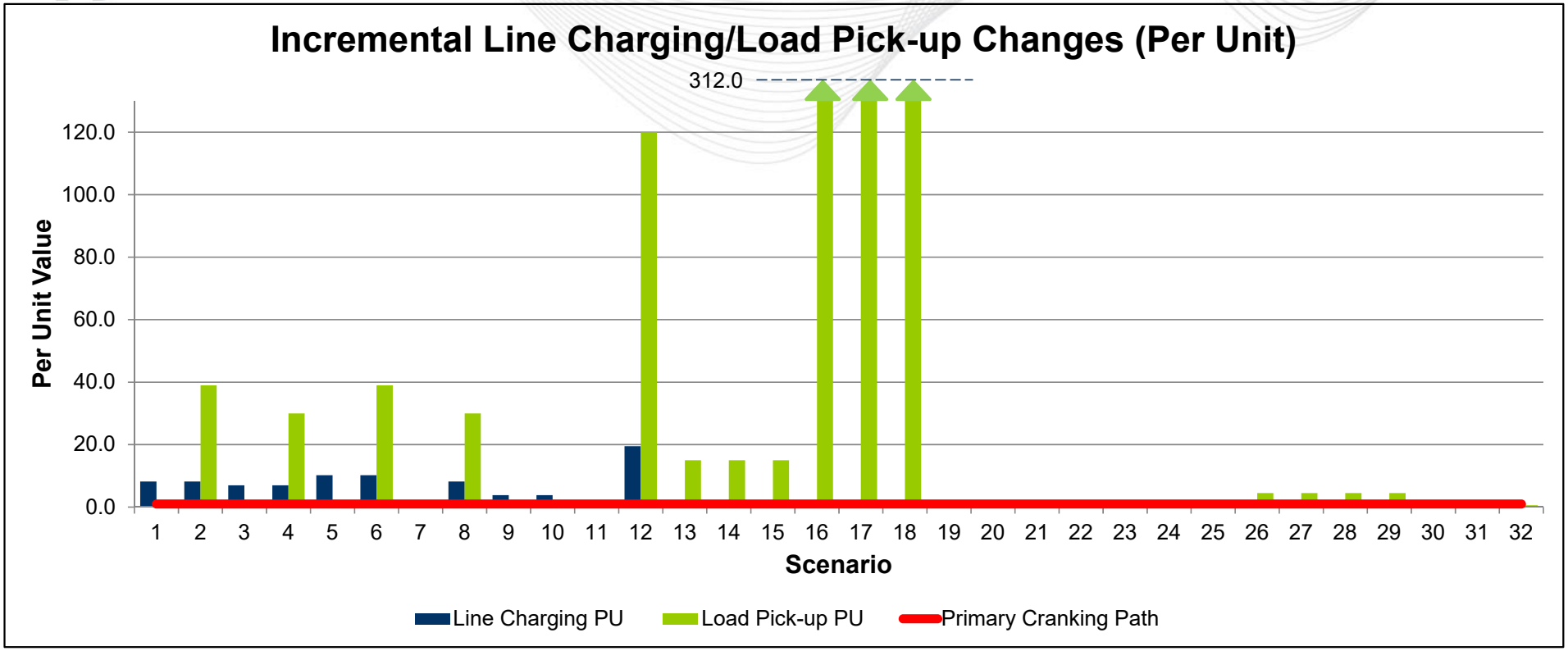

In this example, additional generation and load pick-up is required to control voltage issues

# Alternate Cranking Path Results



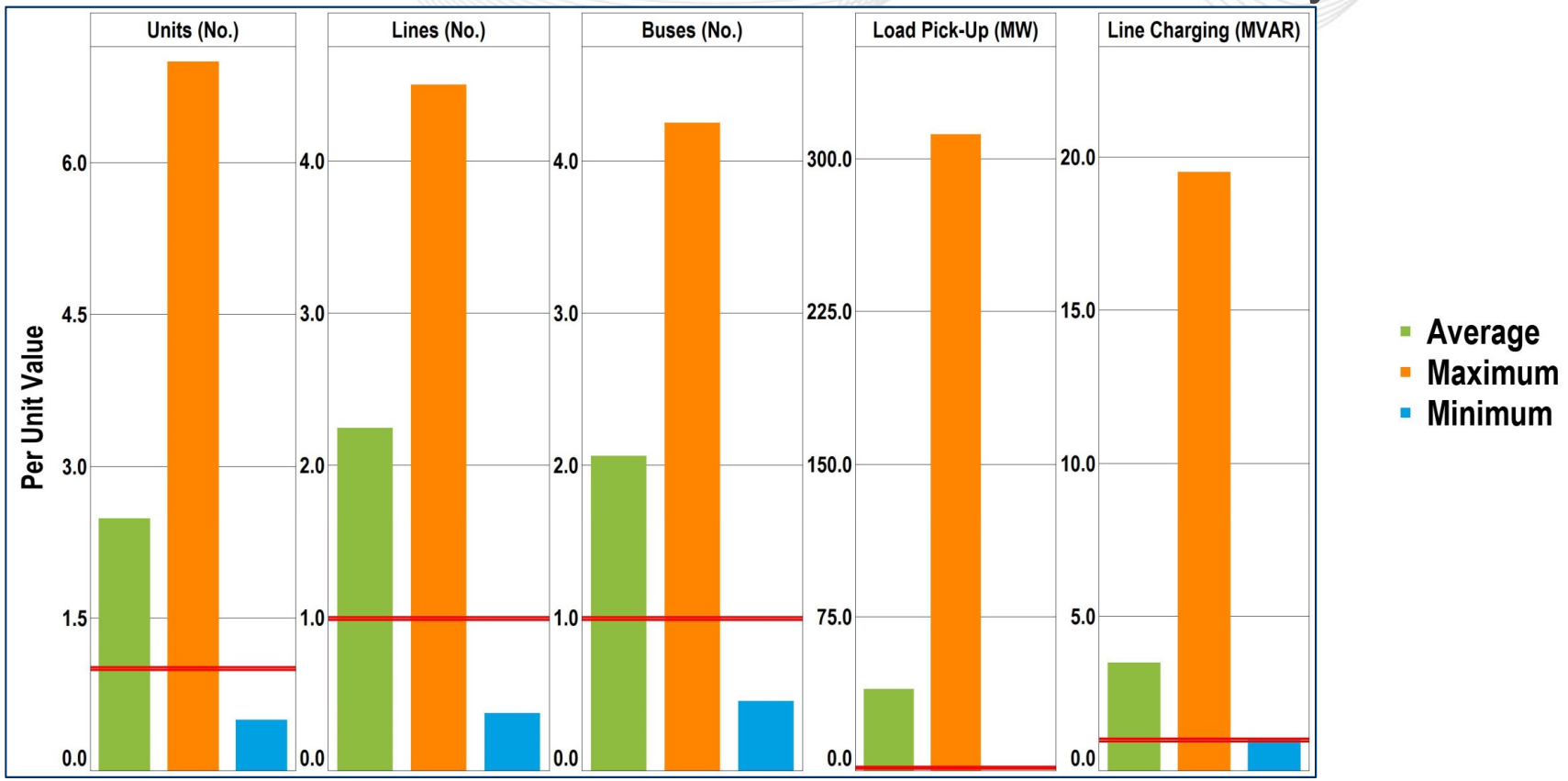

1. Red line represents the required number units or buses or lines needed for primary cranking paths in per unit values
2. Bars indicate the required number of units or buses or lines for alternate cranking paths in per unit values
3. Bars above the red line indicate an increase in the required number of units or buses or lines for alternate cranking paths

# Alternate Cranking Path Results



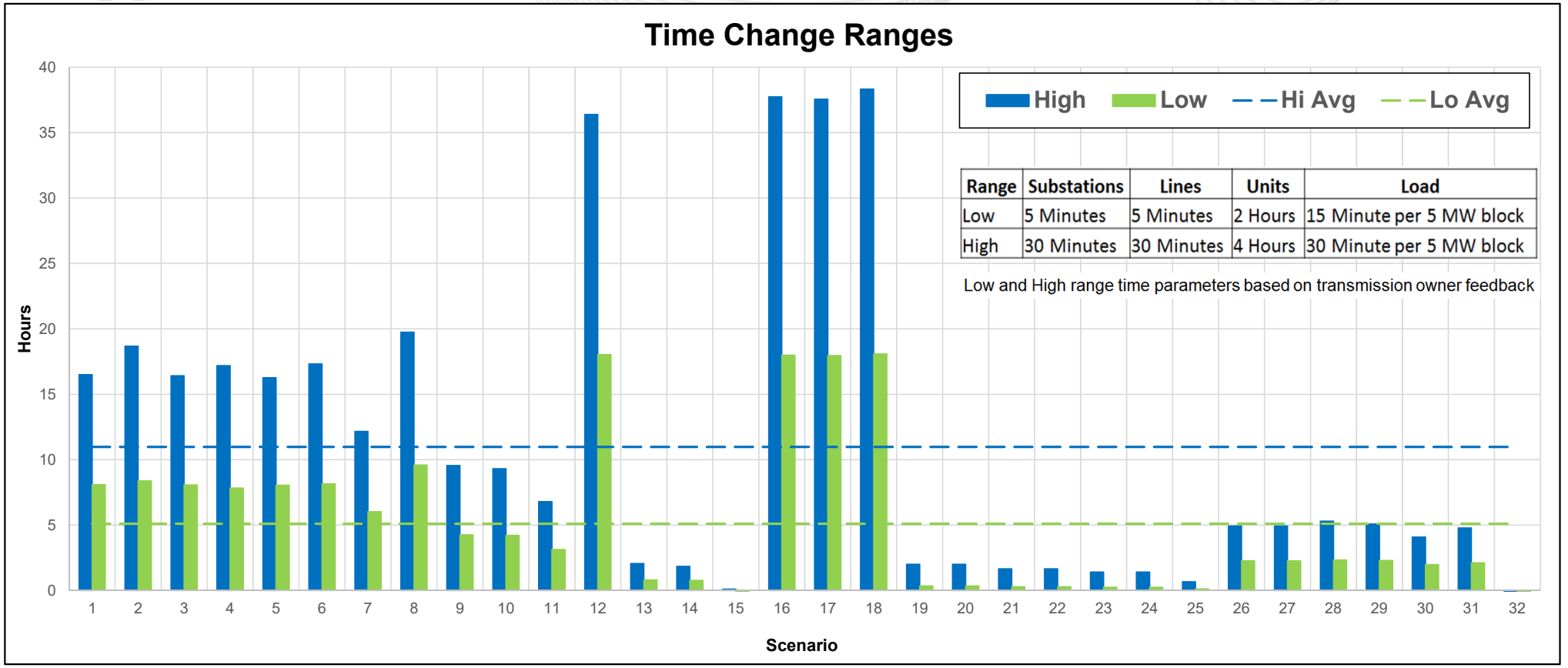

1. Red line represents the amount of line charging(MVAR) and load pick-up(MW) for primary cranking paths in per unit values
2. Bars indicate the amount of line charging(MVAR) and load pick-up(MW) for alternate cranking paths in per unit values
3. Bars above the red line indicate an increase in the amount of line charging(MVAR) or load pick-up(MW) alternate cranking paths

# Average/Minimum/Maximum Incremental Change by Attribute




Red line represents the number of units, buses, lines or load needed for primary cranking paths in per unit values

# Incremental Restoration Time Change Concept




| Range | Substations | Lines | Units | Load |
|---|---|---|---|---|
| Low | 5 Minutes | 5 Minutes | 2 Hours | 15 Minute per 5 MW block |
| High | 30 Minutes | 30 Minutes | 4 Hours | 30 Minute per 5 MW block |

Low and High range time parameters based on transmission owner feedback

Average time increase per cranking path ranged from 5.1 hours to 10.9 hours, but there were scenarios with high and low range times significantly higher

# Analysis Results Summary

**Almost all alternate paths resulted in increased restoration complexity**

- Increased restoration complexity results in increased restoration times

**Approximately 10% of alternate paths failed, primarily due to stability studies, requiring more complex alternate paths**

**Average incremental time increase per cranking path ranged from approximately 5 hours to 11 hours, but there where some scenarios with significantly higher time ranges**

- Applied to cranking paths across TO zones with non-fuel assured black start resources, these time ranges could be significant

# Fuel Assurance Requirements for Black Start Resources
# Preliminary Cost Impact

# Black Start Fuel Assurance
# Projected Cost Impact Assumptions

**Analyzed current and projected Black Start Resources as of 2020/2021 DY**

**Black Start Units without onsite fuel storage**

- Additional projected costs for onsite fuel (conversion/storage)

**Black Start Units requiring changes to startup fuel**

- Additional projected costs to add capability to start with onsite fuel

**No additional capital cost for existing Black Start Units with onsite fuel and onsite fuel start capability**

**Conversion capital costs based on estimates provided via 2018 RTO RFP**

- Projected costs scaled to number of units per site and unit size

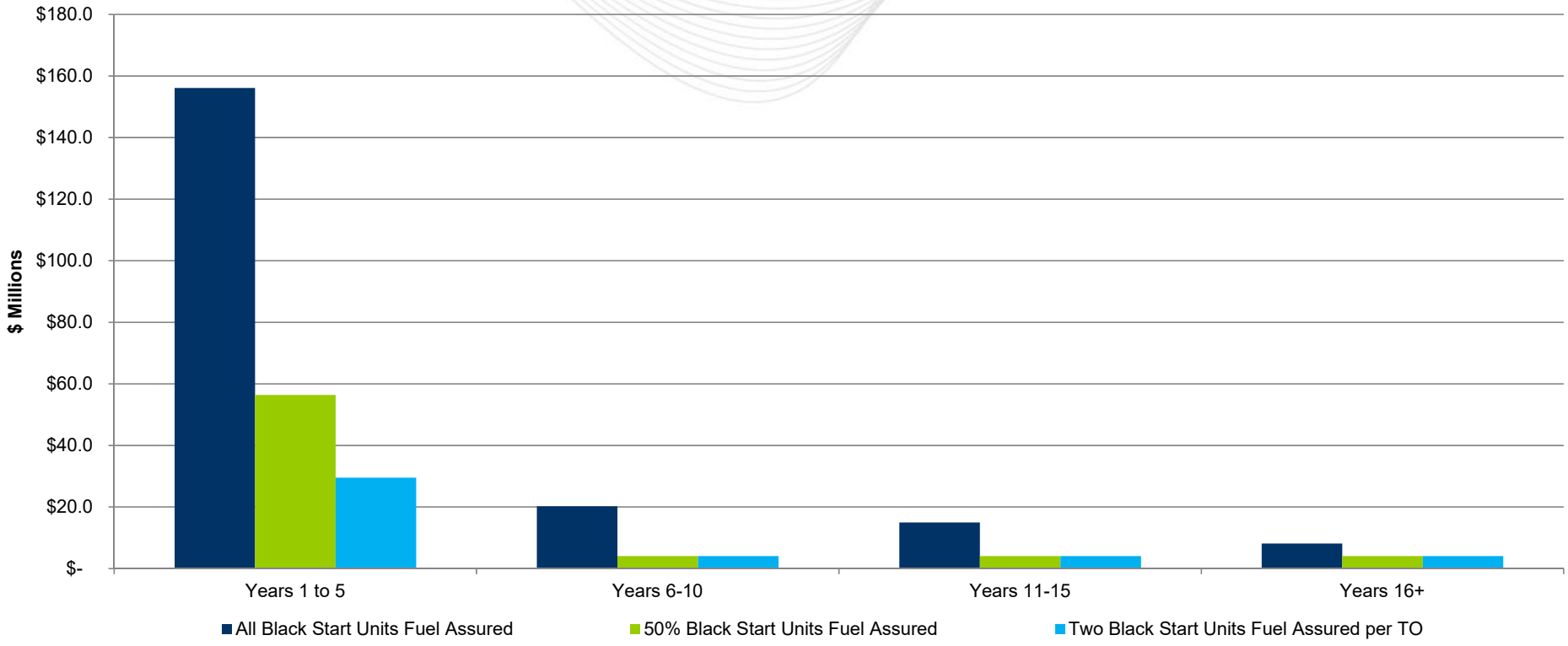
# Black Start Fuel Assurance - Projected Cost Impact

| | |
|---|---|
| $513M | • Estimated Capital Cost to convert all non fuel assured black start units to black start fuel assured |
| $156M | • Increase in Annual Black Start Revenue Requirements |

# Fuel Requirements for Black Start Resources
# Preliminary Cost Projections

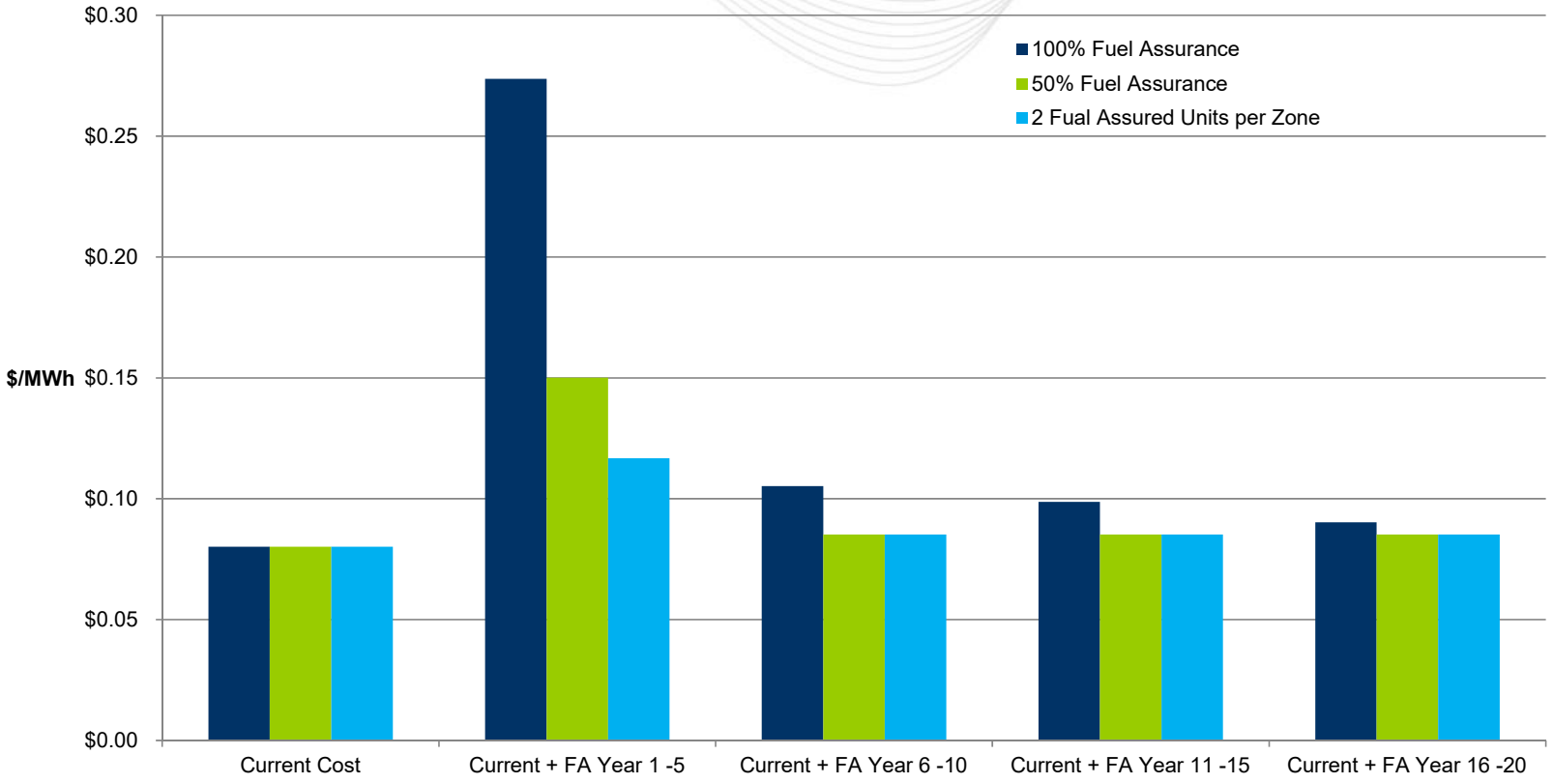
| Level of Fuel Assurance | Capital Cost to convert Black Start fuel assured units | Increase in Annual Revenue Requirement for Capital Recovery Period *(Note: Current BS Annual Revenue Requirement = $65M/yr.)* |
|---|---|---|
| All black start resources allocated to a TO zone must be fuel assured | $513M | $156M/yr. |
| 50% of black start resources allocated to a TO zone must be fuel assured | $177M | $56M/yr. |
| Minimum of two black start resources allocated to the TO zone at separate sites must be fuel assured | $103M | $30M/yr. |

# Projected Capital Costs
## Incremental Amount Above Annual Revenue Requirement

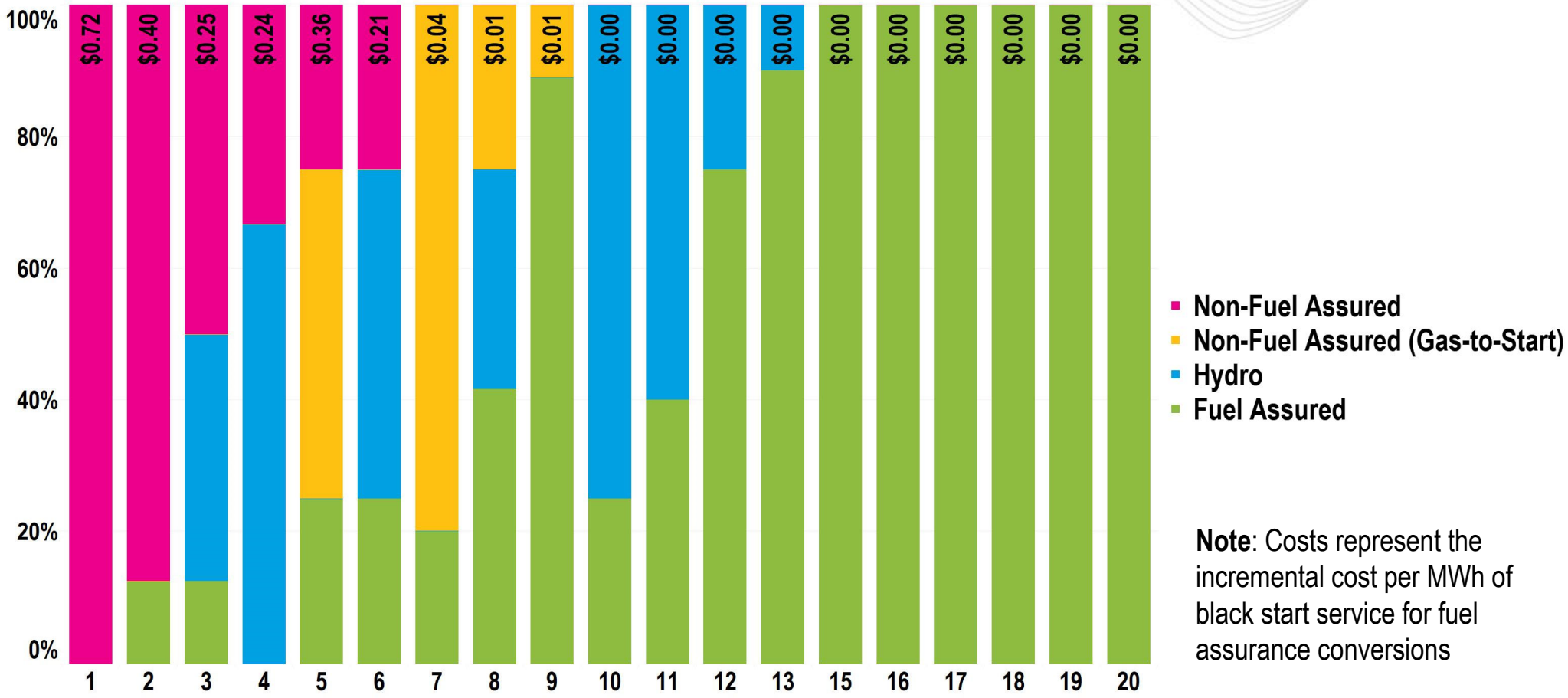


# Fuel Assurance Cost Impact

## Impact Of Black Start Fuel Assurance on Current Annual Revenue Requirements for PJM



# PJM Fuel Assurance Breakdown by TO Zone




**Note**: Costs represent the incremental cost per MWh of black start service for fuel assurance conversions