



Best Practices for Black Start Island Synchronization Using Real Time EMT Simulation

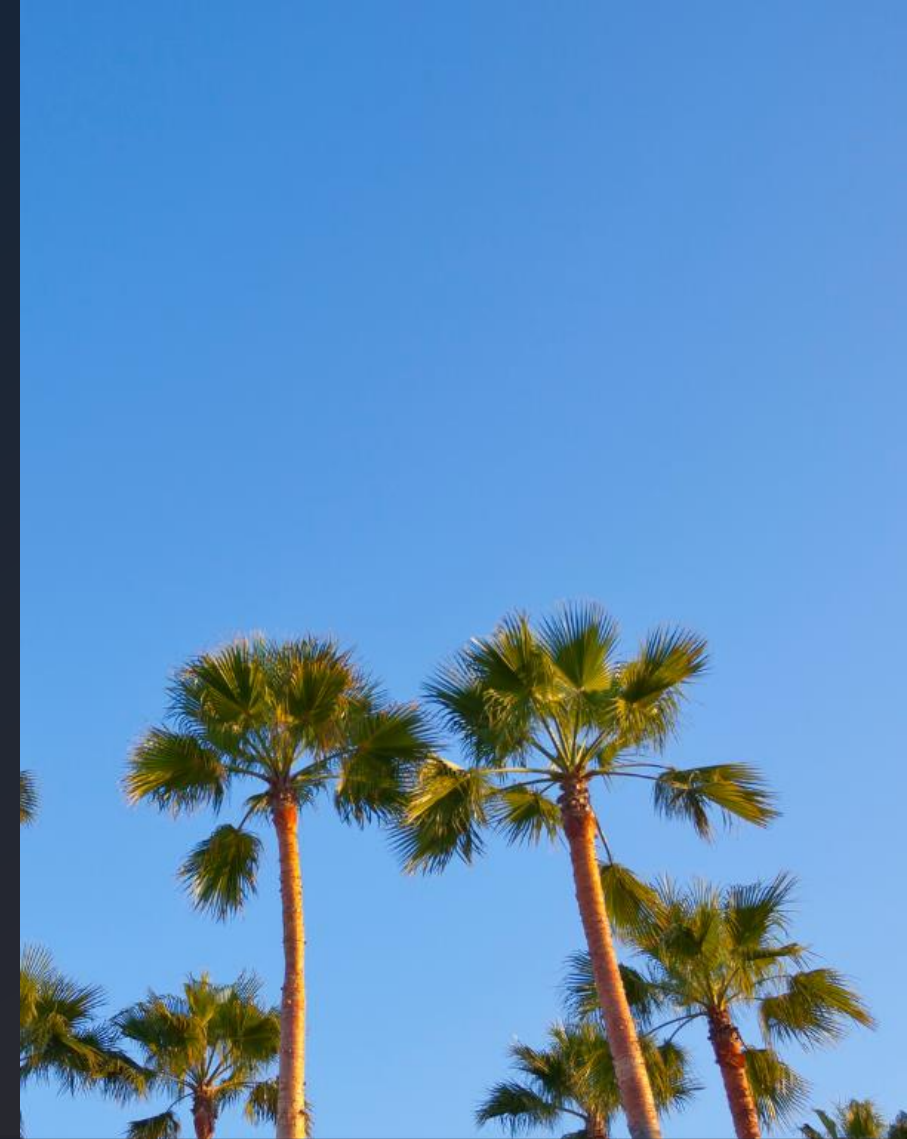
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Presented by:

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Senior Engineer

ET Planning and Strategic Initiatives – Special Studies

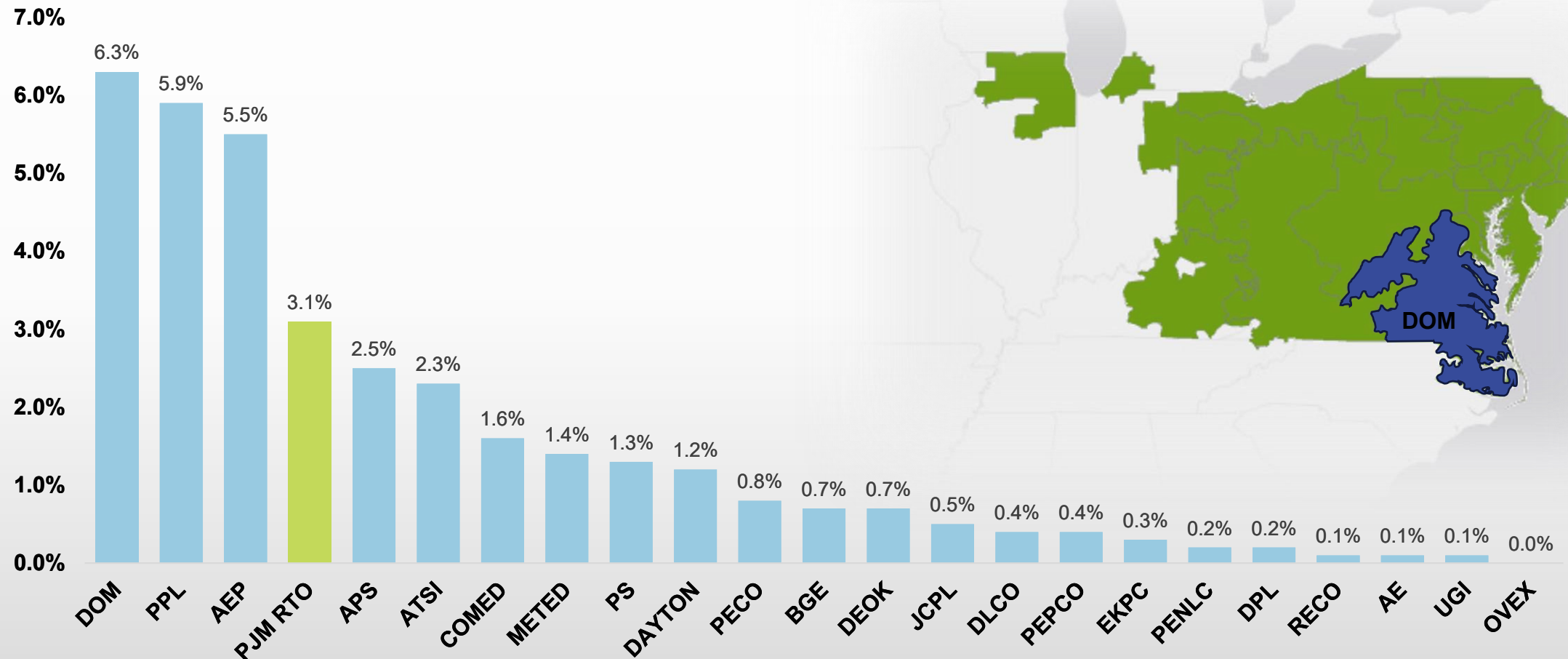


2026 APPLICATIONS & TECHNOLOGY CONFERENCE
IRWINDALE, CALIFORNIA, USA



Dominion Energy System Overview

Load Growth

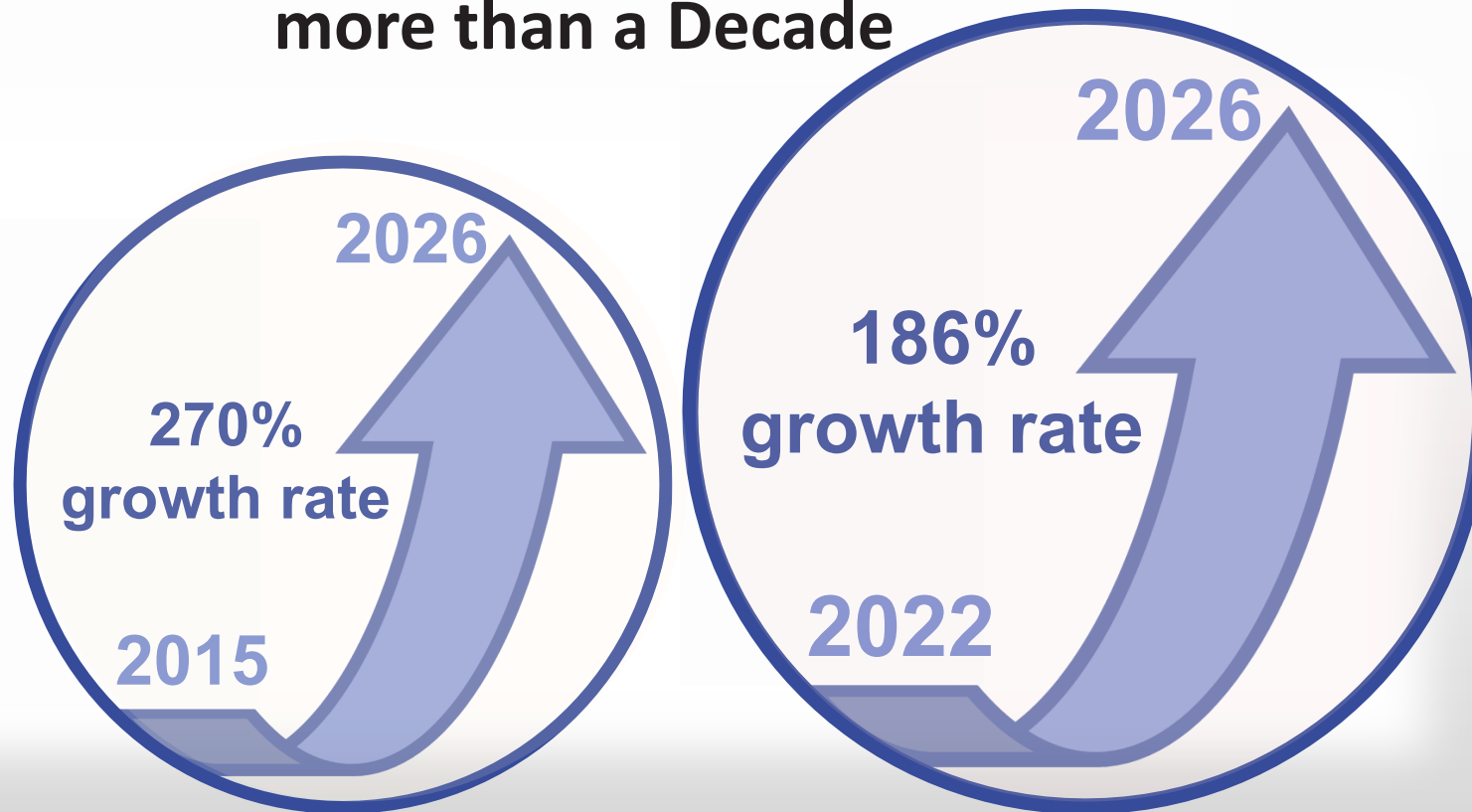
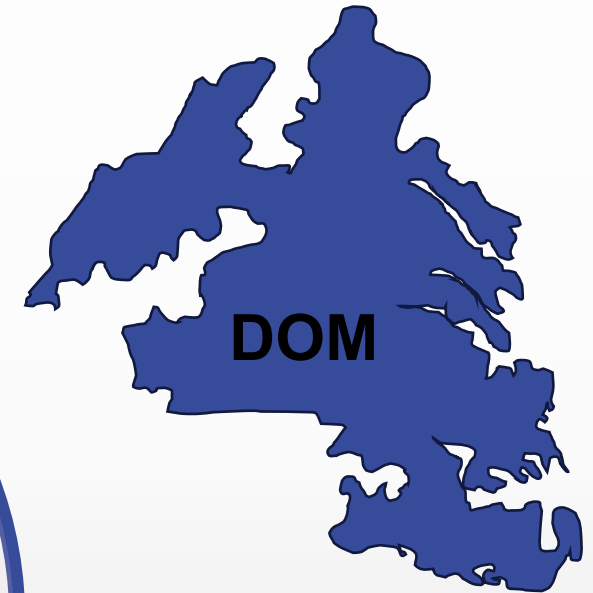


PJM Yearly Summer Peak Load Growth Rate (2026 - 2036)

Dominion Energy System Overview

Load Growth

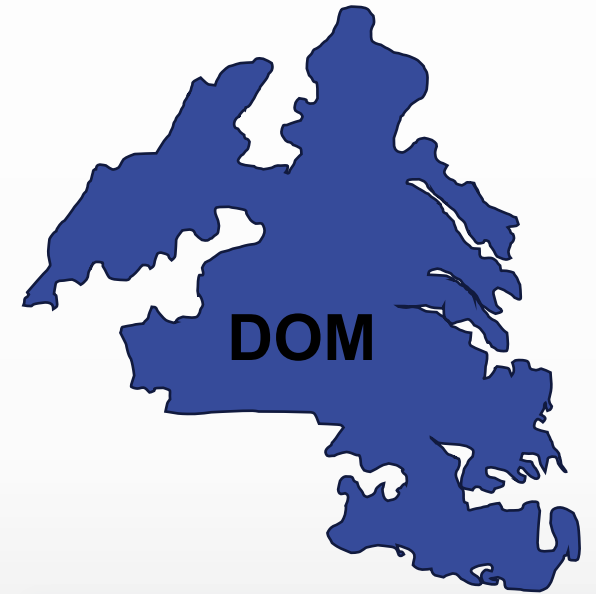
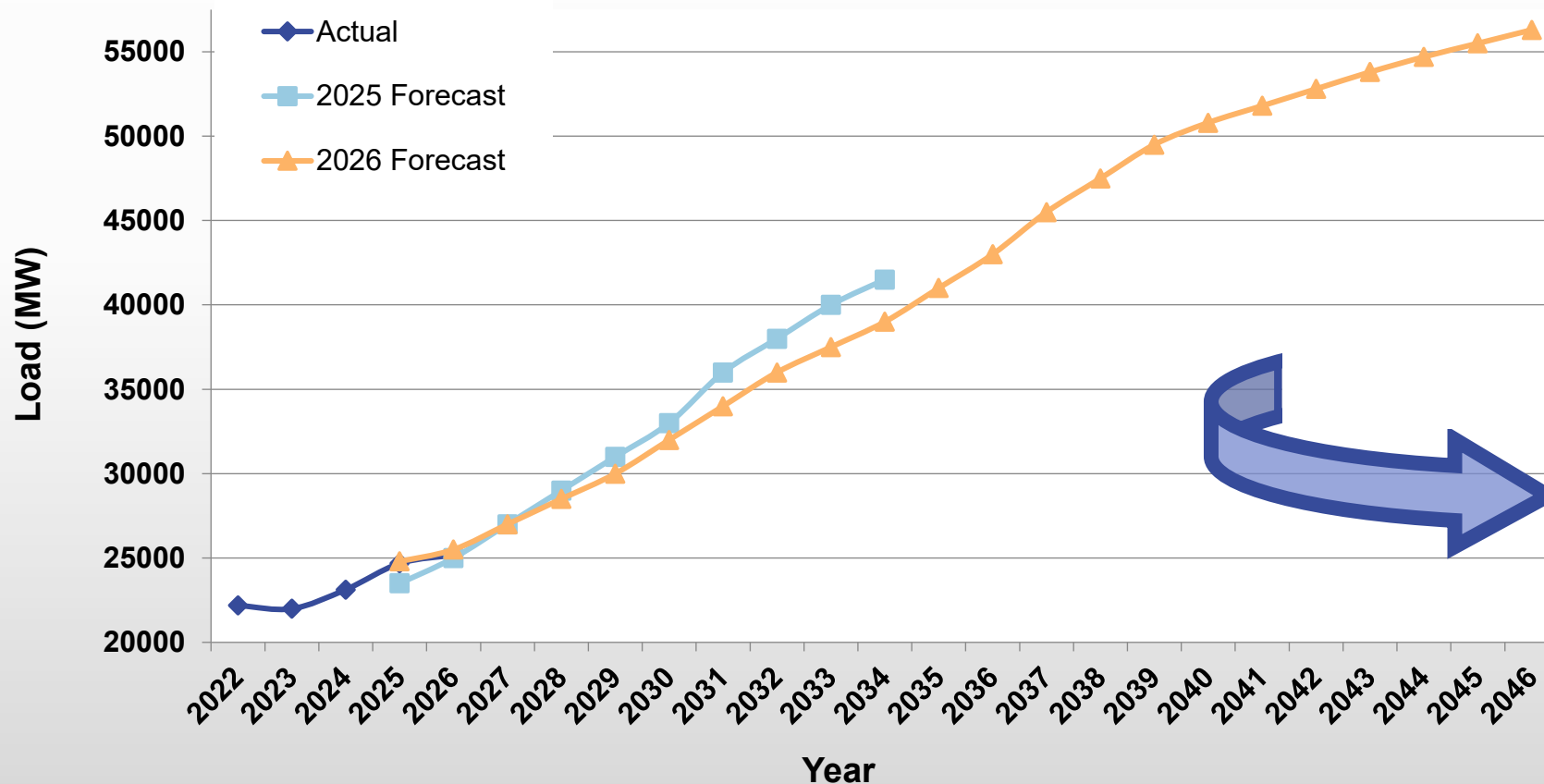
Fastest growing service area in PJM for more than a Decade



Dominion Energy System Overview

Load Growth

Peak load growth projection through 2046

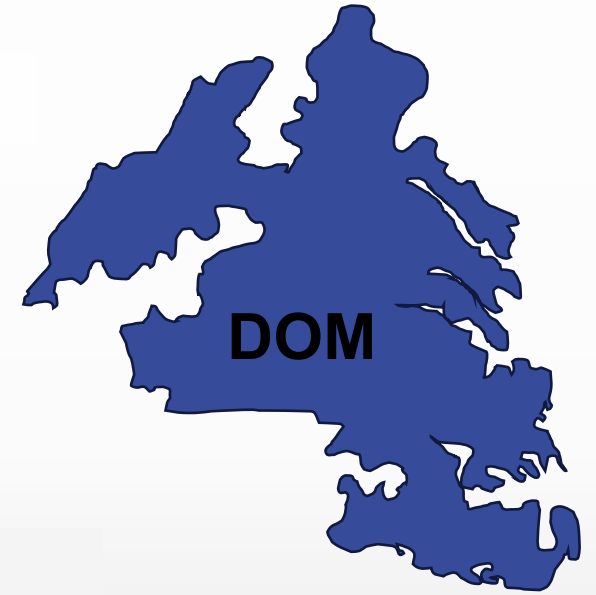
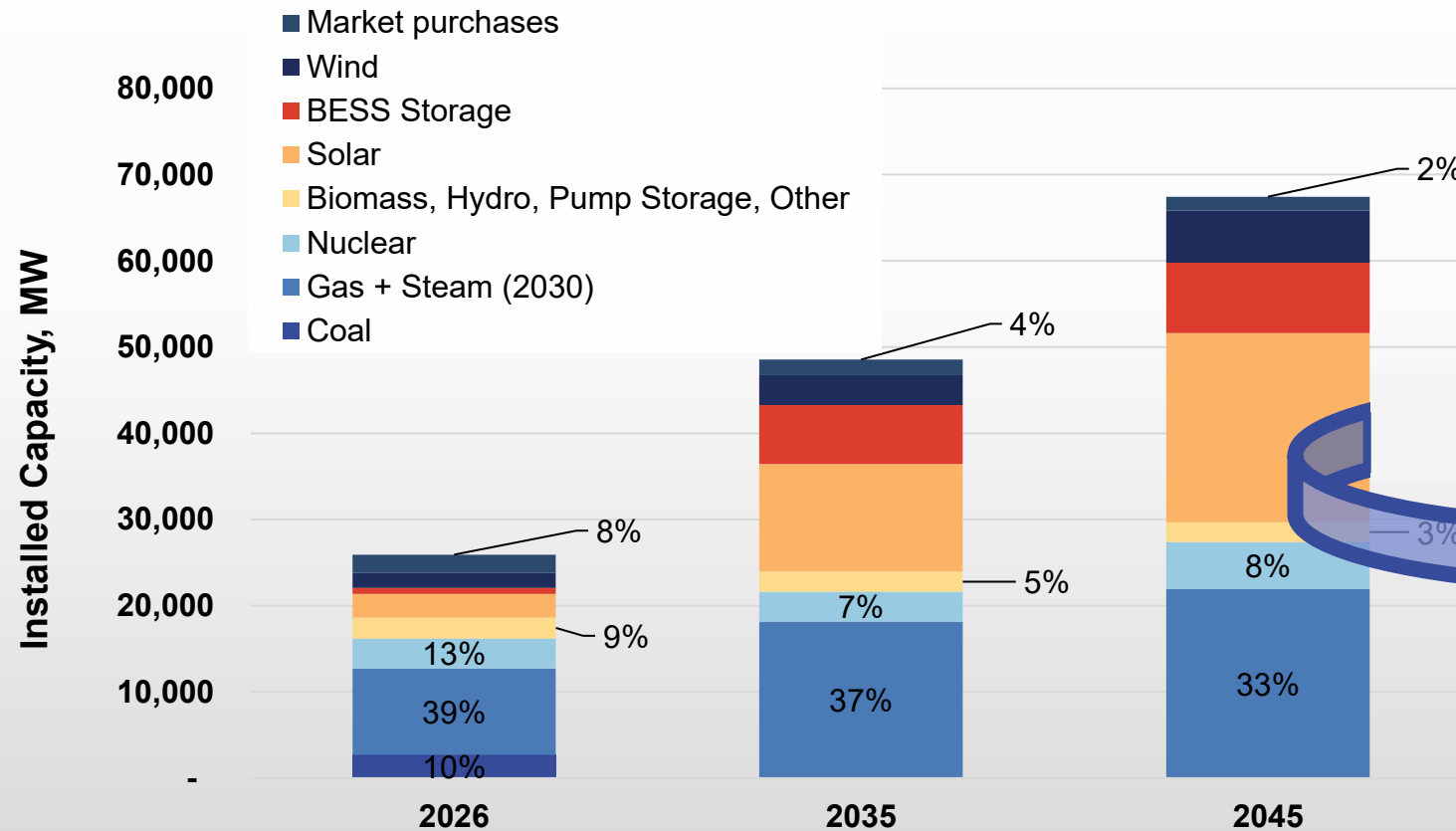


These trends are driving the need for new planning approaches, transmission expansion, and advanced studies.

Dominion Energy System Overview

Generation Portfolio Transition

Increase in Renewable-based Resources



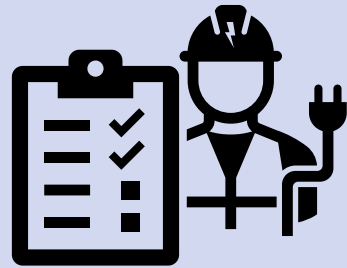
This transition is driving new real-time operational challenges that require advanced simulation and analysis.

Source: *2025 VA/NC Integrated Resource Plan Update*, adapted from Table 5.1.1.1 and Figure 5.1.1.3

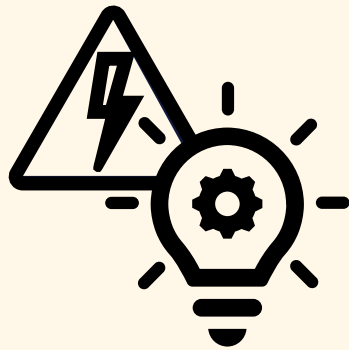


**Safe, resilient, and
reliable operation of
modern grid**

Modern Grid Support Requirement



Safe,
reliable, and
resilient
operation



Modern Grid Support Requirement

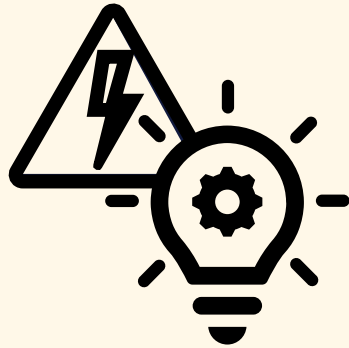


Equipment Validation and Commissioning Support

- Test new technologies before deployment
- Validate performance under real conditions
- Train crews and commissioning teams using realistic scenarios



**Safe,
reliable, and
resilient
operation**



Modern Grid Support Requirement



Equipment Validation and Commissioning Support

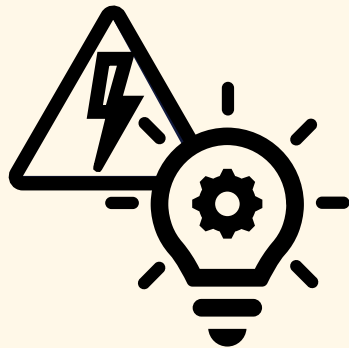
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Investigation and Analysis



- Replicate actual field events
- Identify root causes of equipment misoperation
 - Improve system and operating procedures

**Safe,
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Modern Grid Support Requirement



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Operational Risk Mitigation

- Test worst-case operating scenarios
- Identify failure modes and system limits
- Evaluate mitigation strategies safely



Modern Grid Support Requirement



Equipment Validation and Commissioning Support

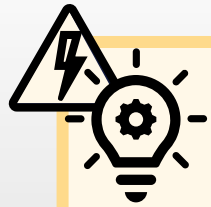
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Operational Risk Mitigation

- Test worst-case operating scenarios
- Identify failure modes and system limits
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System Preparedness



- Improve restoration readiness
 - Assess system response during blackouts
- Support informed operational decisions during emergencies

Modern Grid Support Requirement



Equipment Validation and Commissioning Support

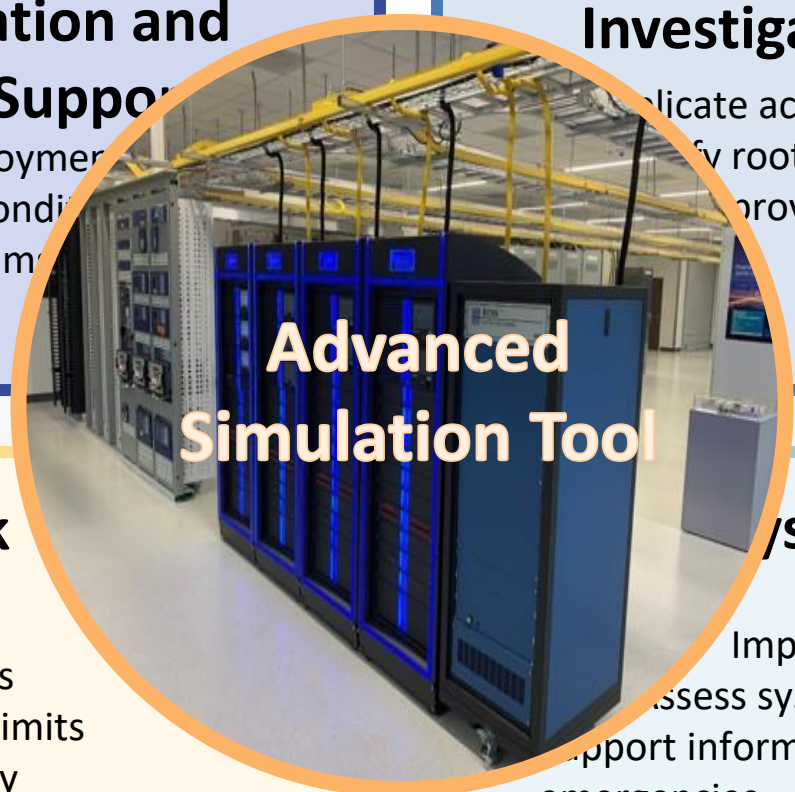
- Test new technologies before deployment
- Validate performance under real conditions
- Train crews and commissioning teams on realistic scenarios

Investigation and Analysis



- Replicate actual field events
- Identify root causes of equipment misoperation
- Improve system and operating procedures

Advanced Simulation Tool

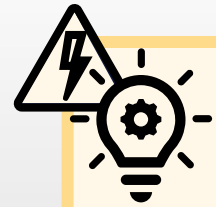


Operational Risk Mitigation

- Test worst-case operating scenarios
- Identify failure modes and system limits
- Evaluate mitigation strategies safely

System Preparedness

- Improve restoration readiness
- Assess system response during blackouts
- Support informed operational decisions during emergencies



Dominion Energy HIL Facility

DETECT Laboratory – RTDS Testbed

**Dominion
Electric
Transmission
Energy
Center for
Grid
Transformation**



1

Real-time-simulator

*4 cubicles
10 Novacor racks
85 licensed cores
1 GTSOC*

2

Facts controller replicas

*3 STATCOMs
1 SVC
1 Fixed Series Capacitors*

3

Protection devices

*Relays
Amplifiers*

DETECT
LABORATORY

Dominion Energy HIL Facility

DETECT Laboratory – RTDS Testbed

Dominion
Electric
Transmission
Energy
Center for
Grid
Transformation



Advanced, research-based studies



Equipment Validation and
Commissioning Support



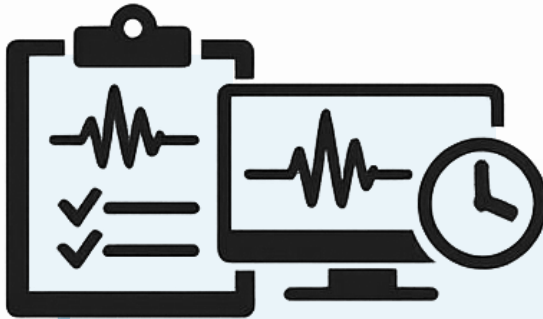
Investigation and Analysis



Operational Risk Mitigation



System Preparedness

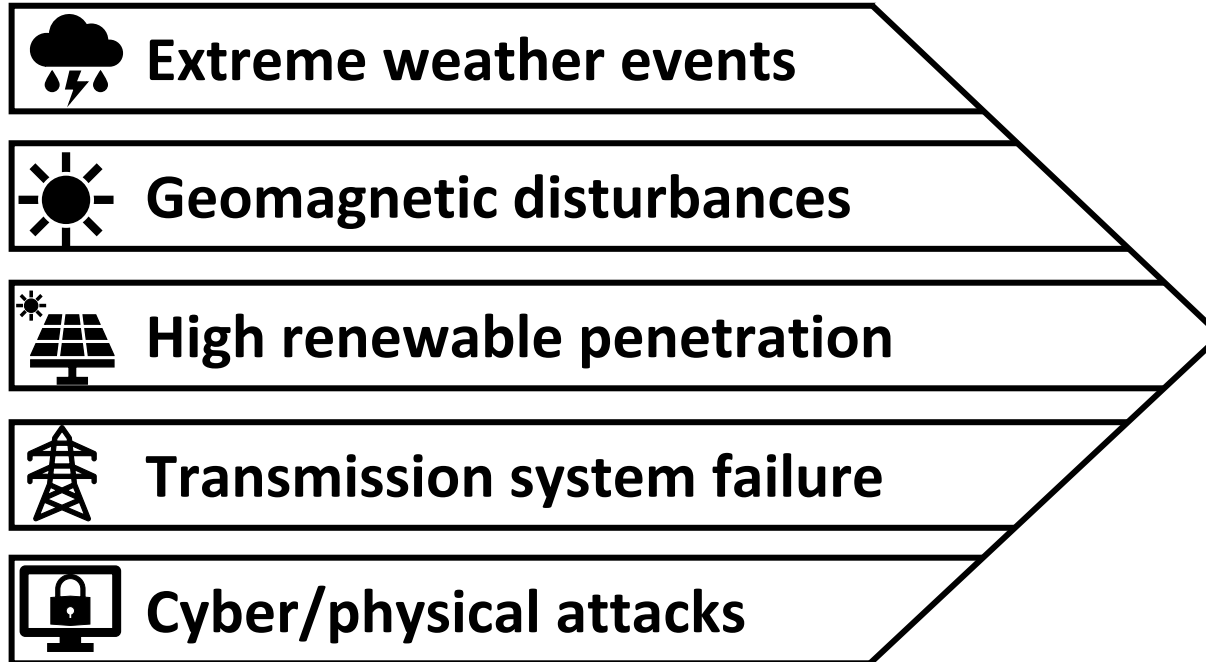


System Preparedness

Best Practices for Black Start Island Synchronization

Blackout Risk in Modern Grid

Cause and emerging risks



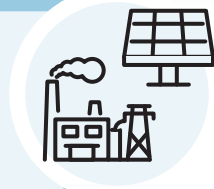
Black Start in Modern Grid

Black start is the process of restoring parts of the power system without relying on the external power transmission network to recover from a blackout.

This entails isolated power stations being started individually and gradually reconnected to one another to form an interconnected system again.

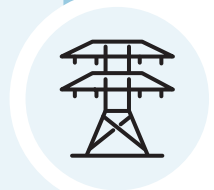
Black Start in Modern Grid

Black start



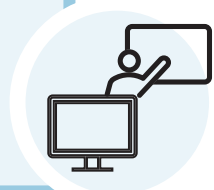
Black start-capable generation units

Traditional units and emerging technologies such as IBRs, BESS, and microgrids



Transmission system readiness and system restoration strategy

Predefined feasible cranking paths that follow all regulatory and operational standard



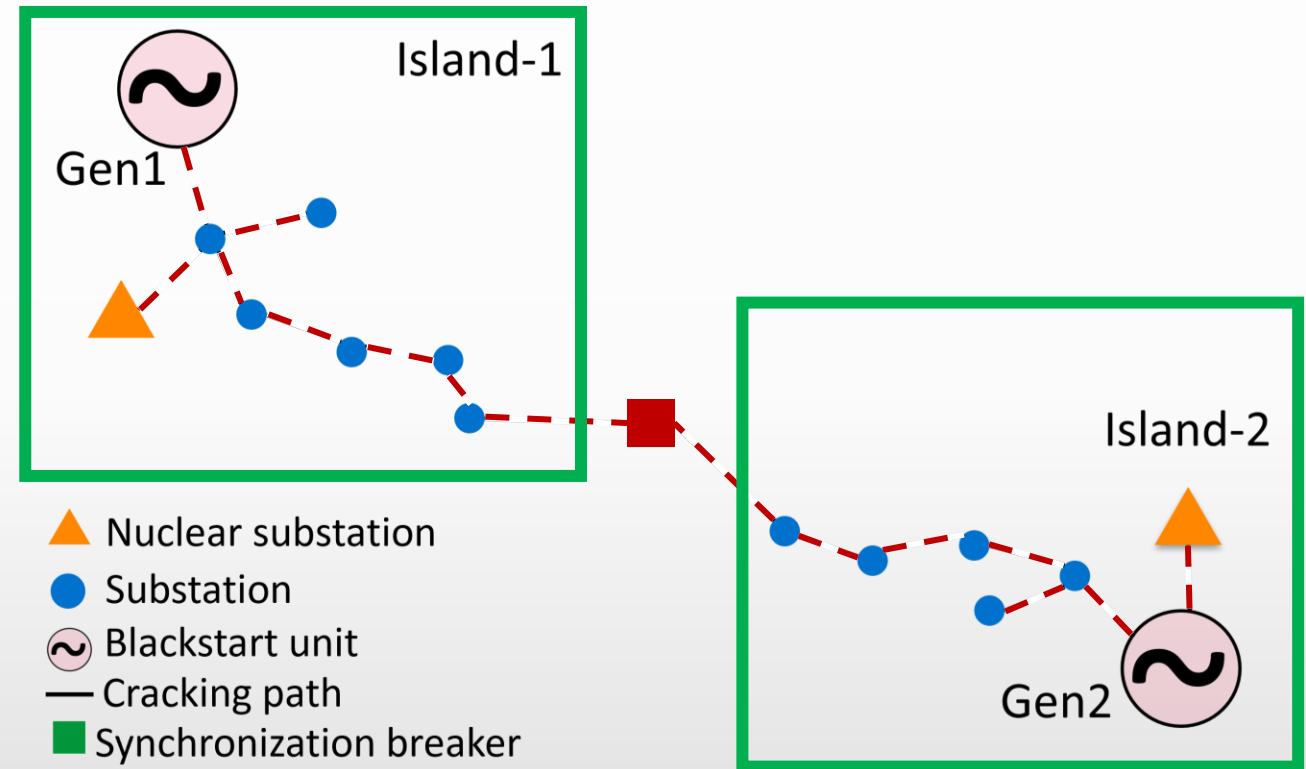
Simulation tools and trainings

For continuous improvement of the available black start strategies and effective decision-making during restoration.

Dominion Energy's System Restoration Plan

Core Island Approach

- 1 Start black start generators
- 2 Energize on a single path:
 - Transmission lines
 - Substations
 - Loads
- 3 Form strong islands
- 4 Synchronize two islands



Dominion Energy's System Restoration Plan

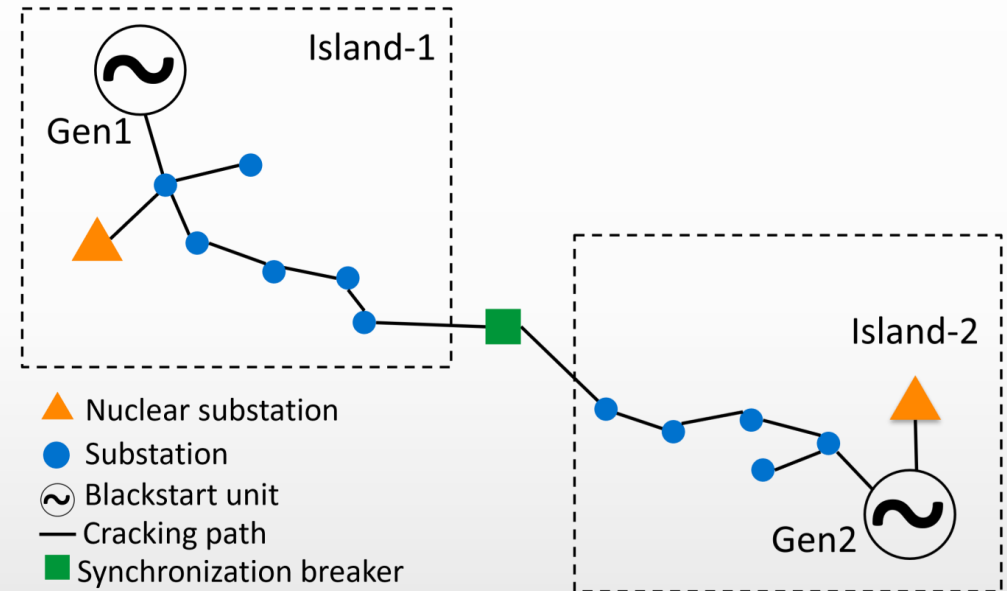
Island Synchronization Requirements

① Secure synchro-check relay settings:

- ✓ Voltage
- ✓ Frequency
- ✓ Phase Rotation
- ✓ Phase Angle

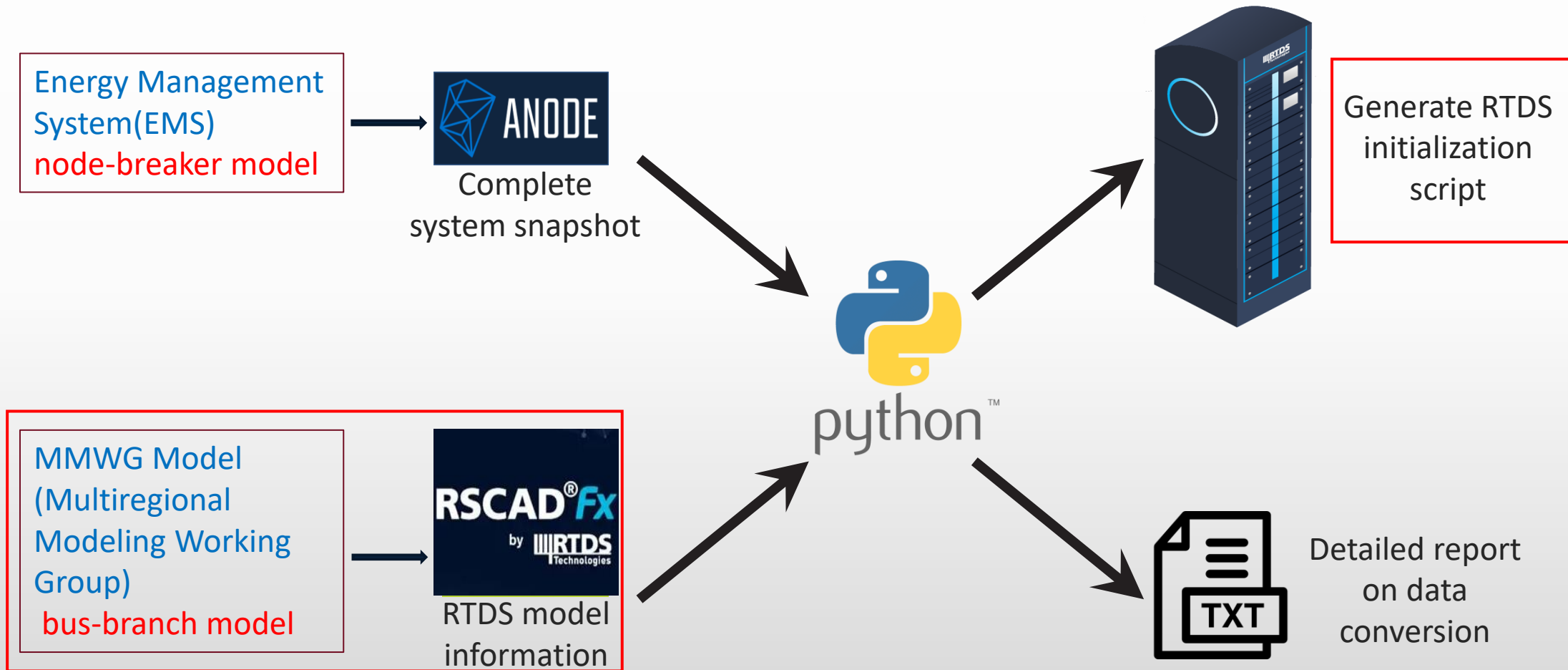
② Control mode switch of black start units

③ Minimum island energization level



Black Start Model in RSCAD

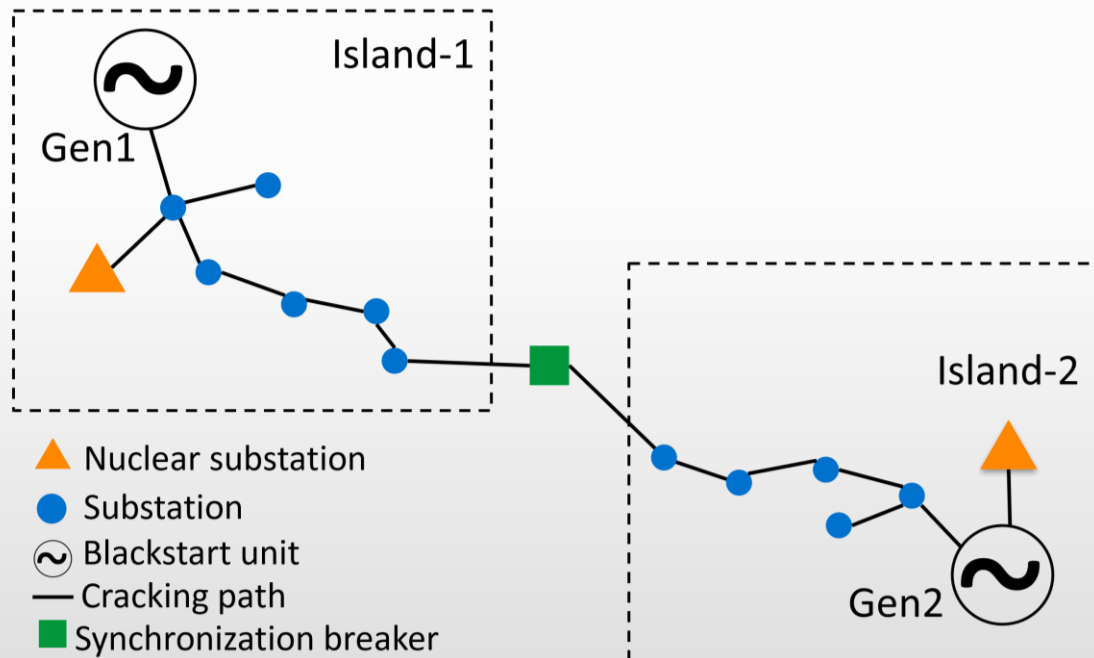
Model Building and Initialization Pipeline



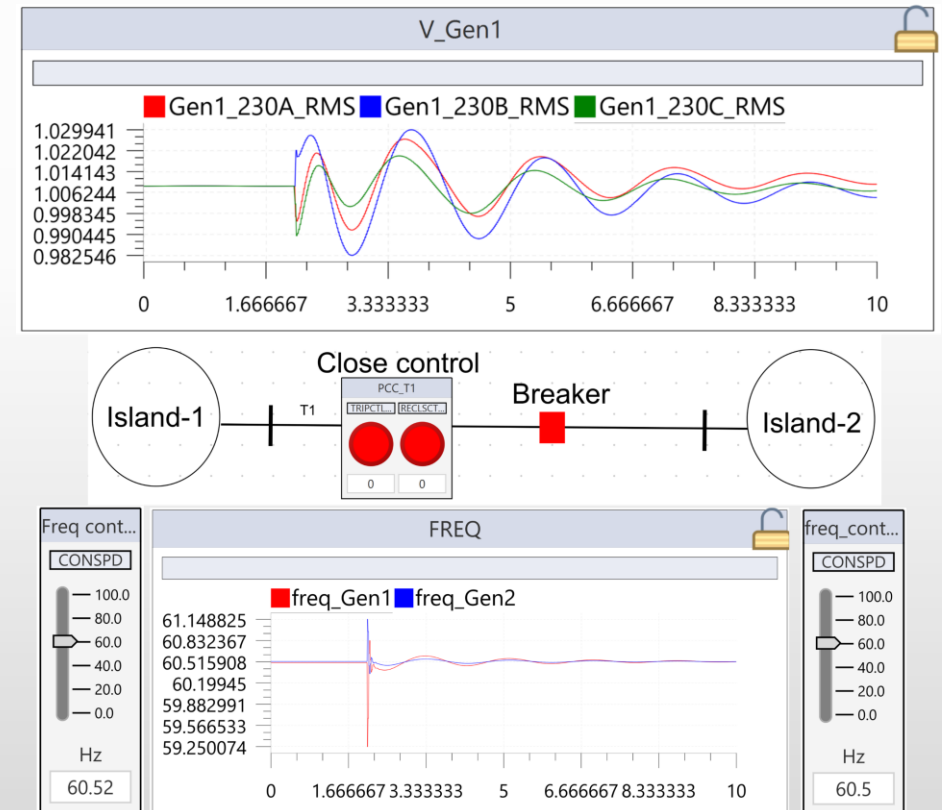
Black Start Model in RSCAD

Model Overview

Draft Model



Runtime

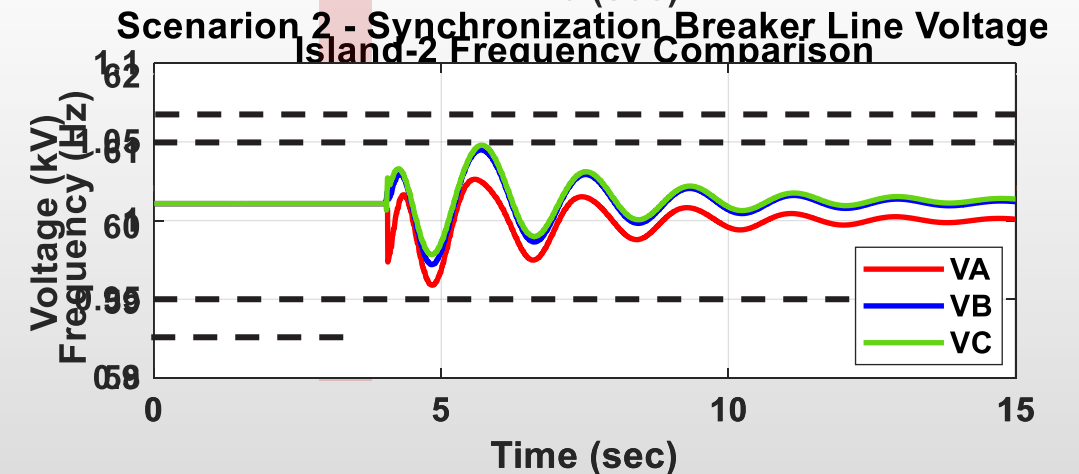
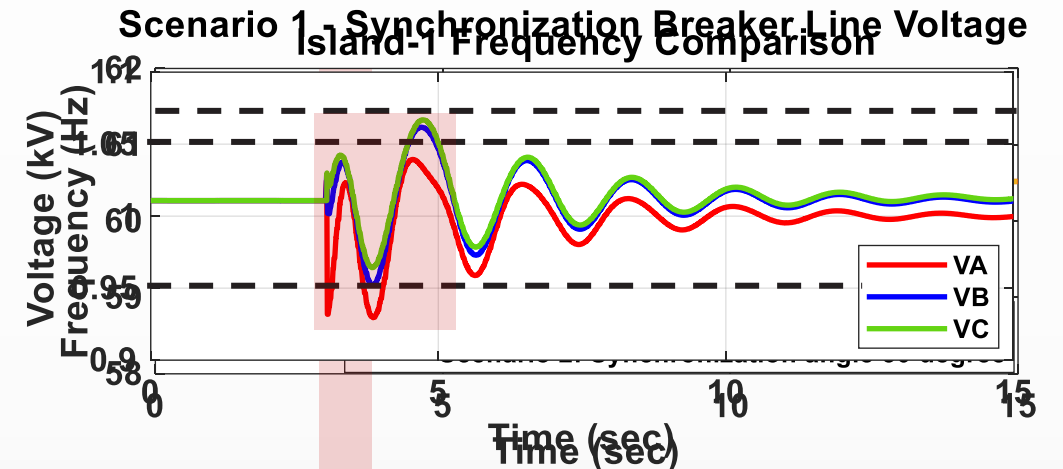


Synchro-Check Relay Settings

Maximum Angle Difference Effect

Parameters		Scenario 1	Scenario 2
Applied thresholds	$min f$ (Hz)	58.5	58.5
	$max f$ (Hz)	61.5	61.5
	$min V$ (pu)	0.95	0.95
	$max V$ (pu)	1.05	1.05
Synchro-check relay settings	$max \Delta \delta$ (deg)	50	30
	$max \Delta f$ (Hz)	0.1	0.1
	$max \Delta V$ (kV)	3	3

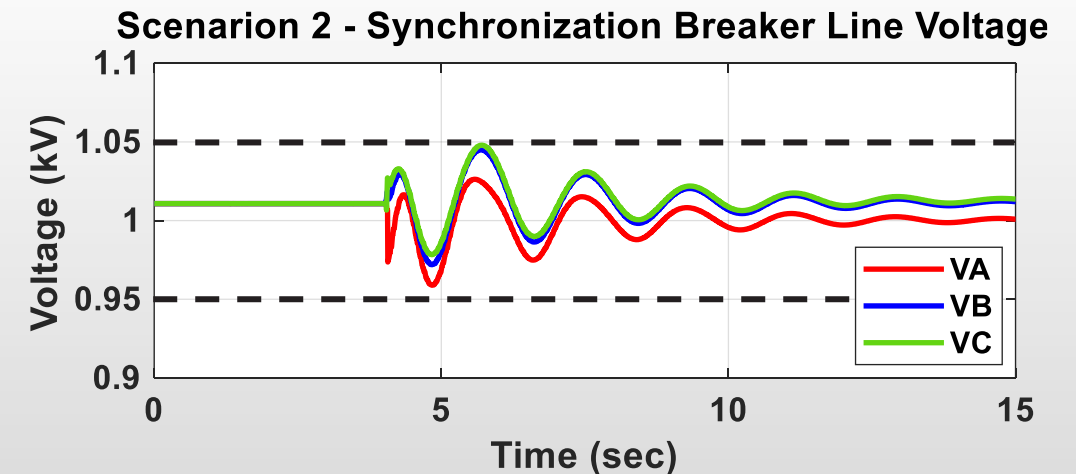
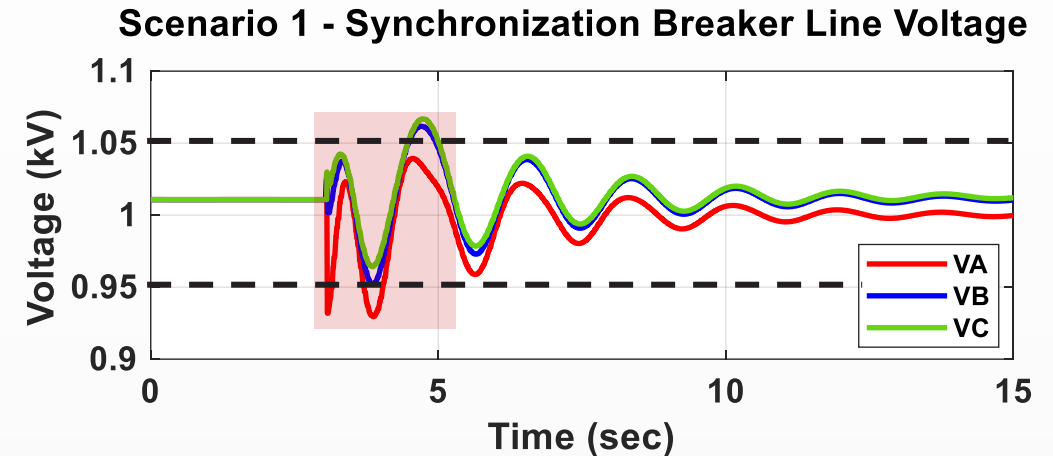
✓ The thresholds applied in this work are:
 $0.95 \leq V \leq 1.05$, $58.5 \text{ Hz} < f \leq 61.5 \text{ Hz}$.



Synchro-Check Relay Settings

Maximum Angle Difference Effect

Simulation results emphasize the critical need to synchronize under correct parameters to prevent violations of system limits and ensure smooth and reliable restoration process.



Synchro-Check Relay Settings

Study Scenarios

Scenarios	f_1 (Hz)	f_2 (Hz)	ΔV (kV)	δ (Deg.)	Variable
A	60.52	60.50	< 3	10~50	δ
B	60.50	60.52	< 3	10~50	δ
C	60.52	60.50	3~17	30	ΔV

✓ The thresholds applied in this work are:
 $0.95 \leq V \leq 1.05$, $58.5 \text{ Hz} < f < 61.5 \text{ Hz}$.

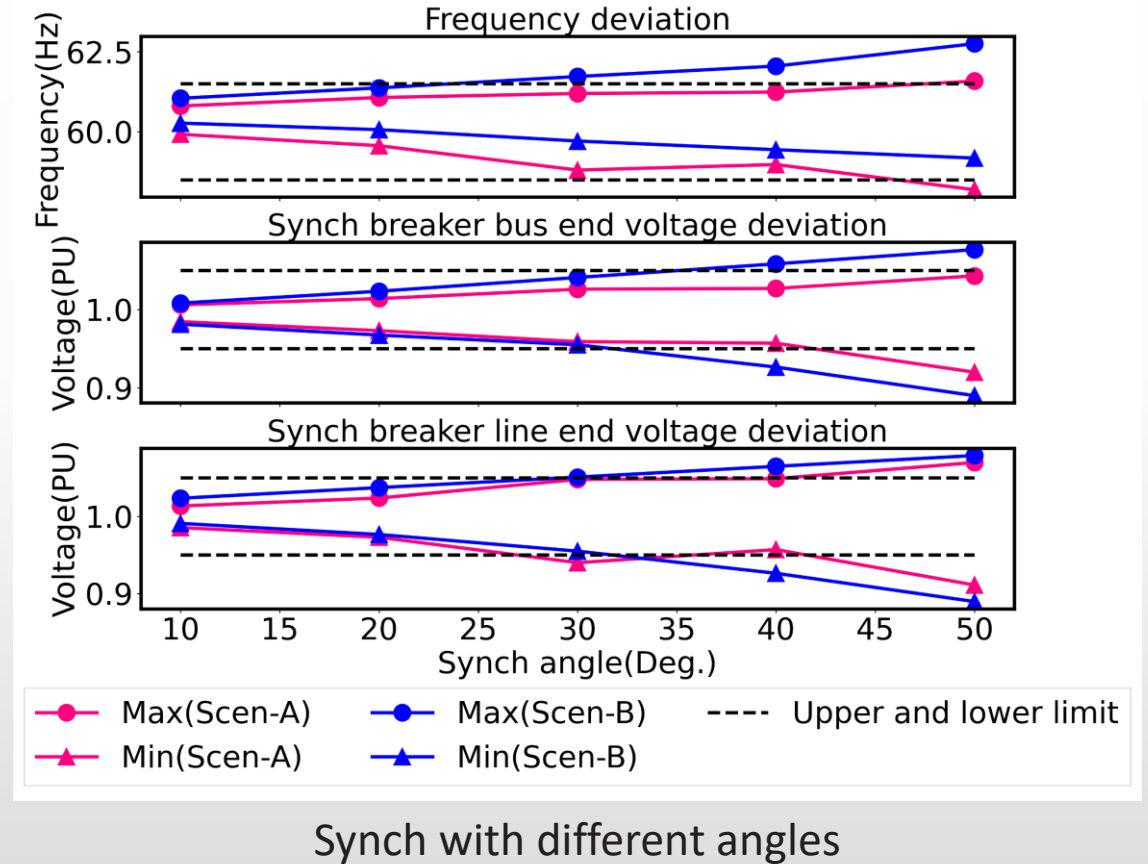
Synchro-Check Relay Settings

Maximum Angle Difference Effect – Scenarios A and B

- Synch angle changes from 10° to 50° .
- Minimum and maximum frequency plotted
- Voltage deviations check on both ends of the synchronization breaker

Scenario-A maximum synch angle is around 40° .

Scenario-B maximum synch angle is around 30° .

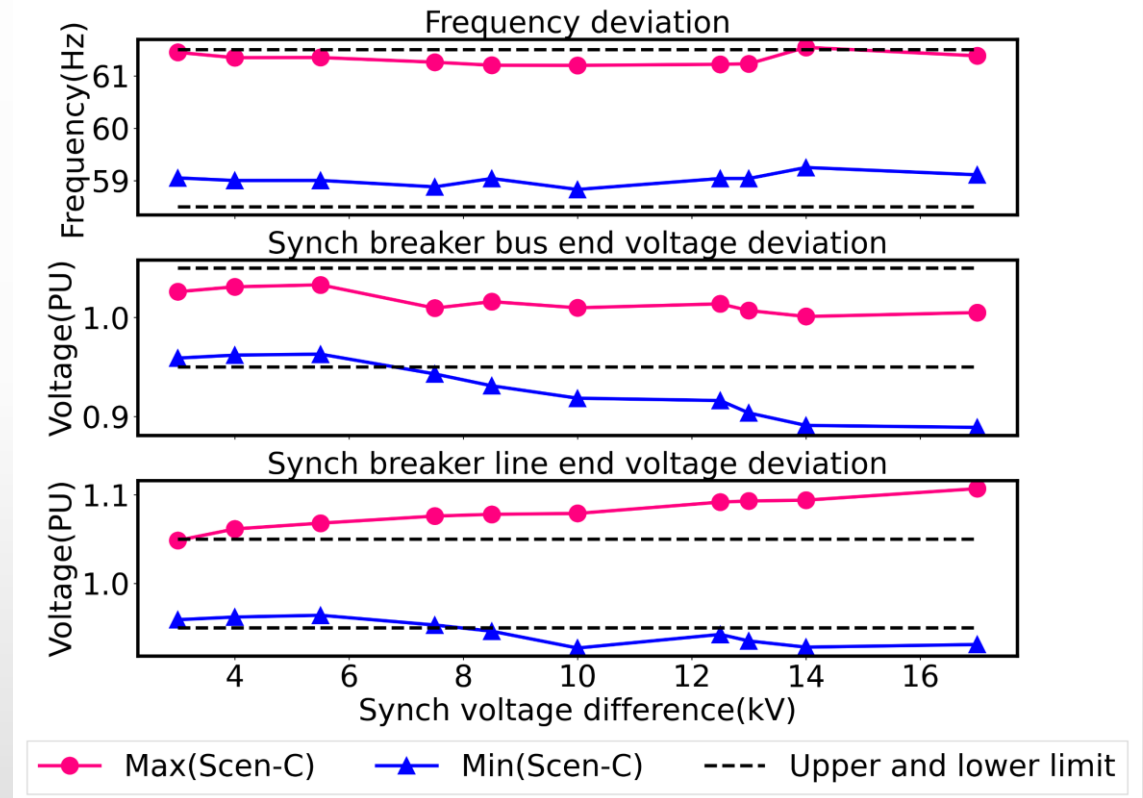


Synchro-Check Relay Settings

Voltage Difference Effect – Scenario C

- Frequency and voltage deviations check when increasing ΔV .
- Synch angle is fixed at 30° .
- Maximum and minimum frequency plotted.
- Voltage deviations check on both ends of the synchronization breaker.

A safe voltage difference should be under 3 kV.



Synch with different voltage difference

Synchro-Check Relay Settings

Study Scenarios Summary

The recommended settings based on the simulation scenarios:

- Frequency set point:
 - Island 1: 60.52 Hz
 - Island 2: 60.5 Hz
- Maximum synchronization angle: 30°
- Maximum voltage difference: 3 kV
- Acceptable frequency slip: 0.1 Hz

Control mode switch of black start units

Study Scenarios Overview

Scenario 1

Switch control mode of black start unit in island 2 to droop control **before** island synchronization.

100% energization level

Scenario 2

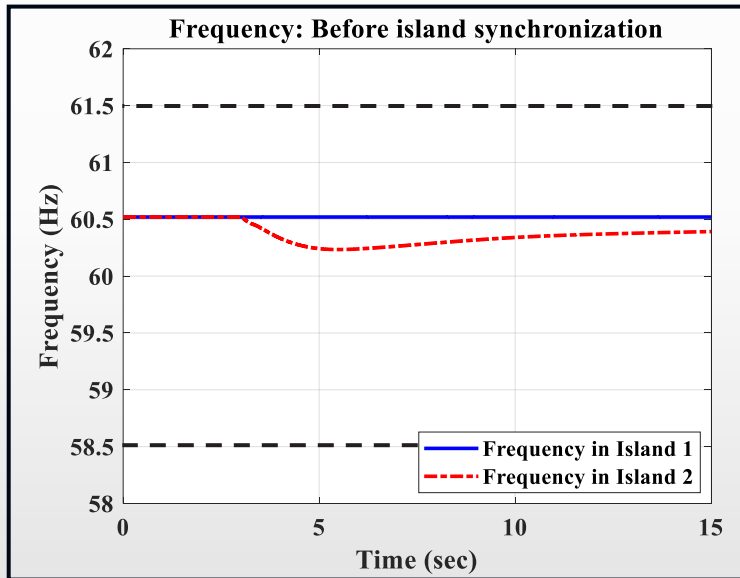
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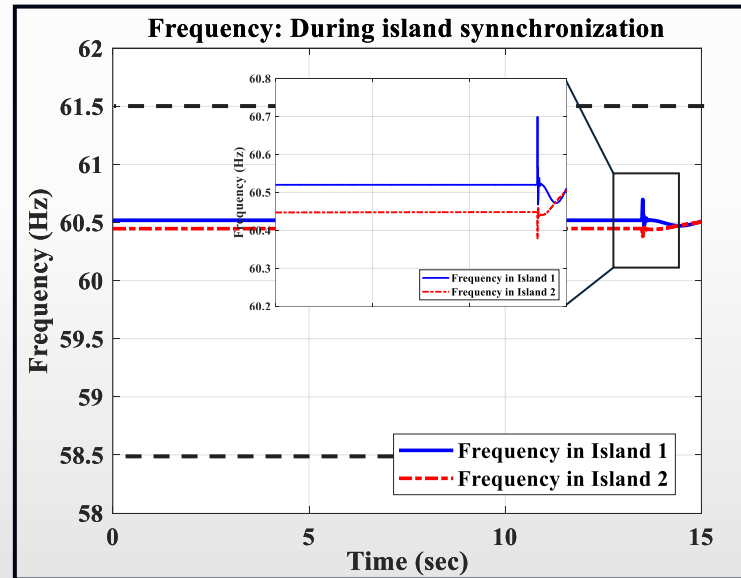
Control mode switch of black start units

Study Scenario 1 – Frequency Response

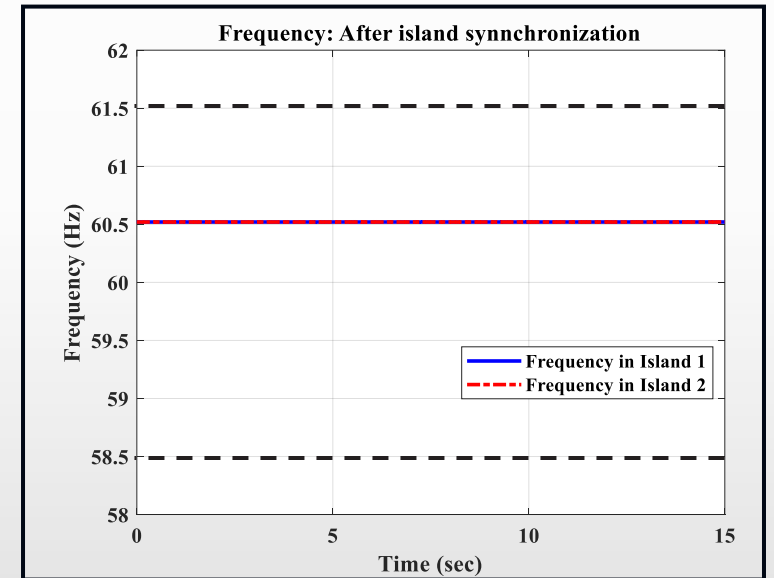
Before island synchronization
Gen2 switch to droop control



During island synchronization
 $\max \delta = 10^\circ, \max \Delta V = 3 \text{ kV}, \max \Delta f = 0.1$



After island synchronization
Islands frequency = 60.52 Hz

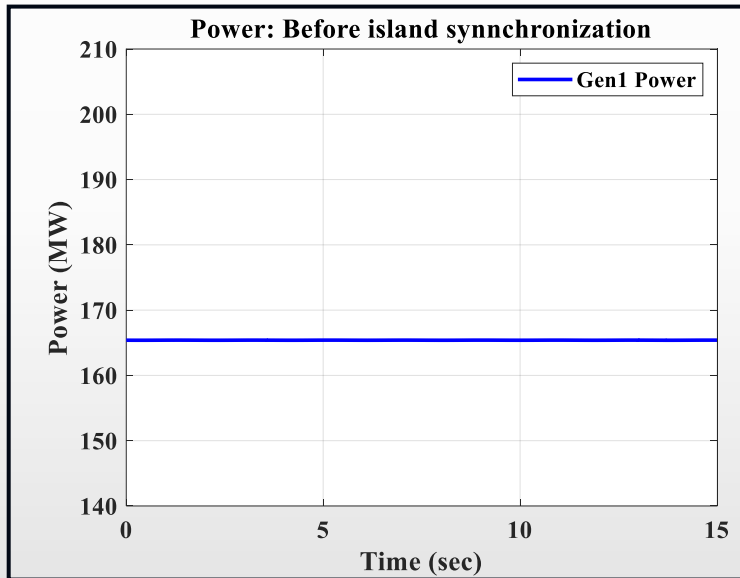


Control mode switch of black start units

Study Scenario 1 – Black Start Unit Active Power

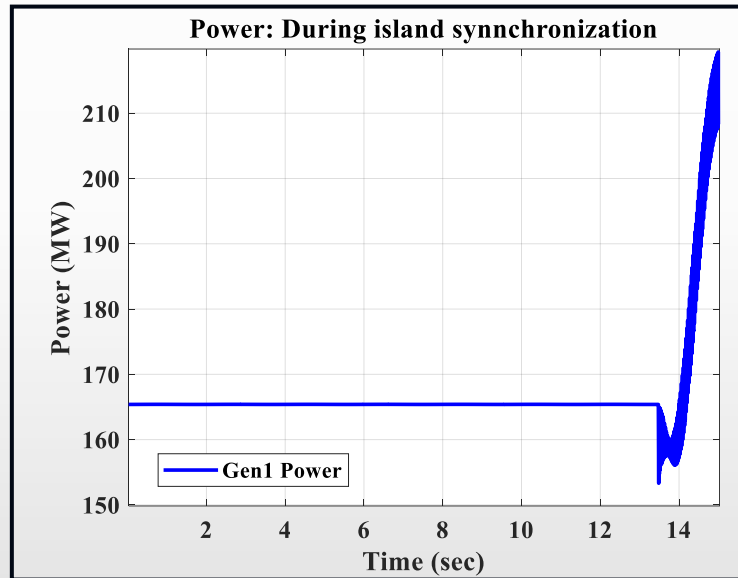
Before island synchronization

Gen2 switch to droop control



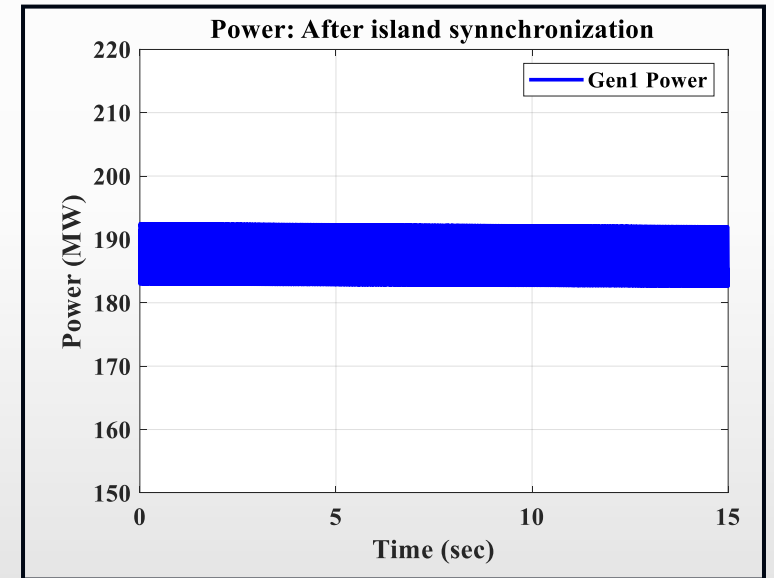
During island synchronization

max $\delta = 10^\circ$, max $\Delta V = 3$ kV, max $\Delta f = 0.1$



After island synchronization

Islands frequency = 60.52 Hz

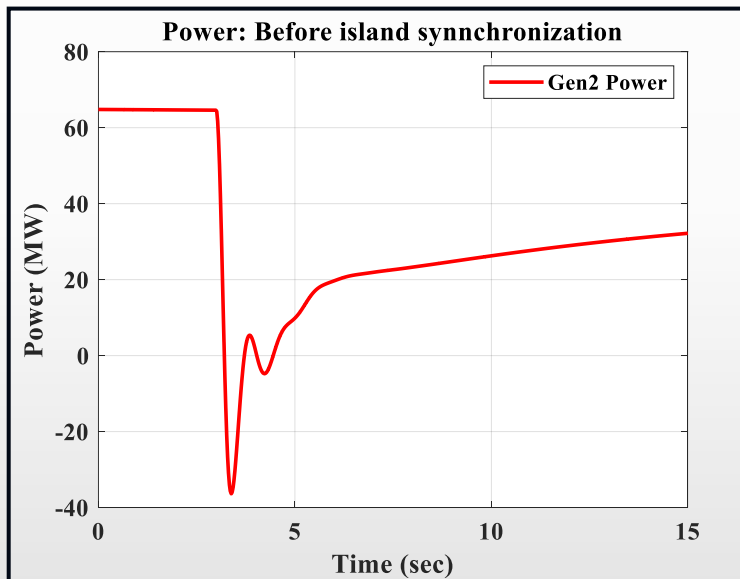


Control mode switch of black start units

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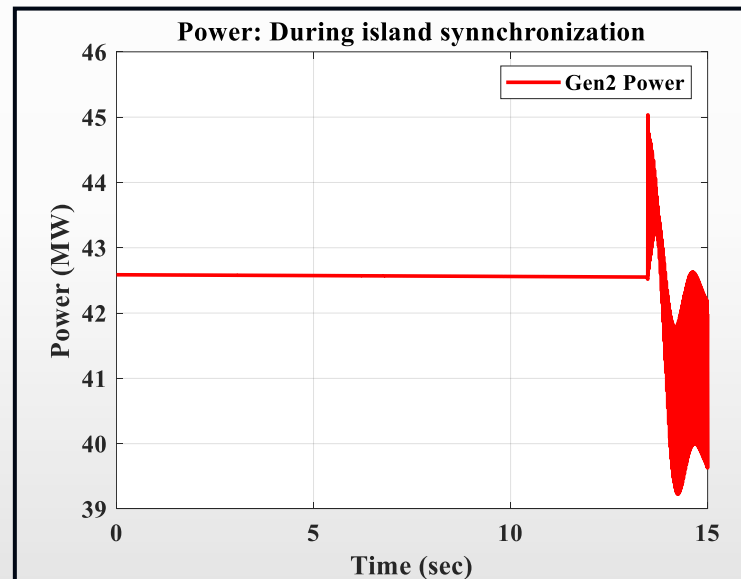
Before island synchronization

Gen2 switch to droop control



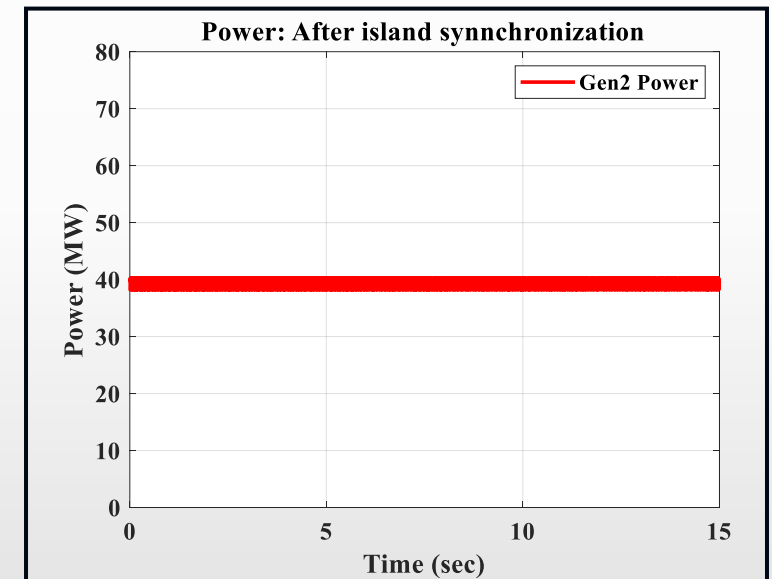
During island synchronization

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Islands frequency = 60.52 Hz

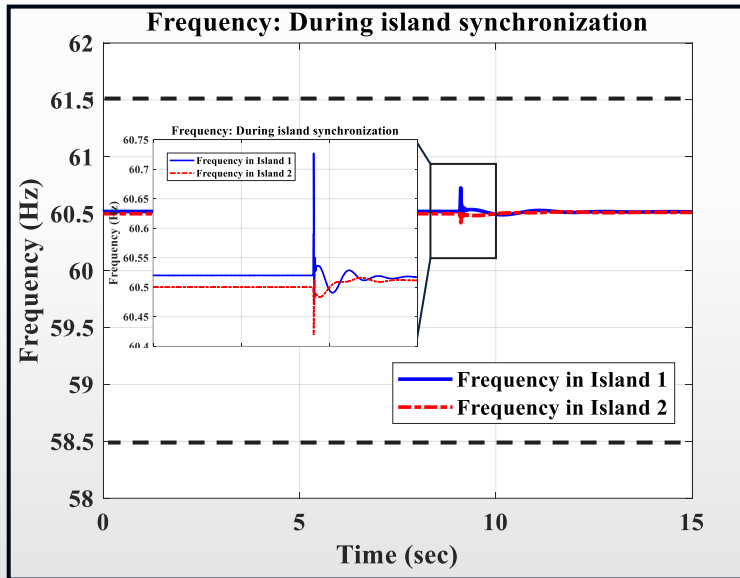


Control mode switch of black start units

Study Scenario 2 – Frequency Response

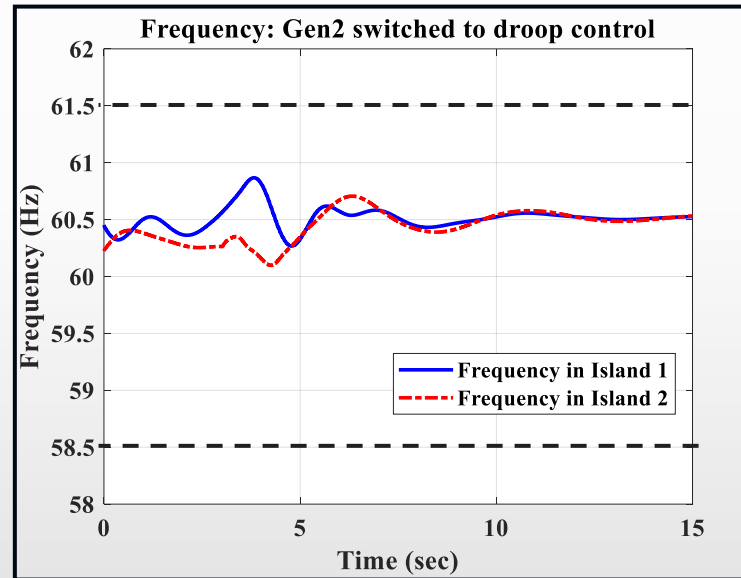
During island synchronization

max $\delta = 10^\circ$, max $\Delta V = 3$ kV, max $\Delta f = 0.1$



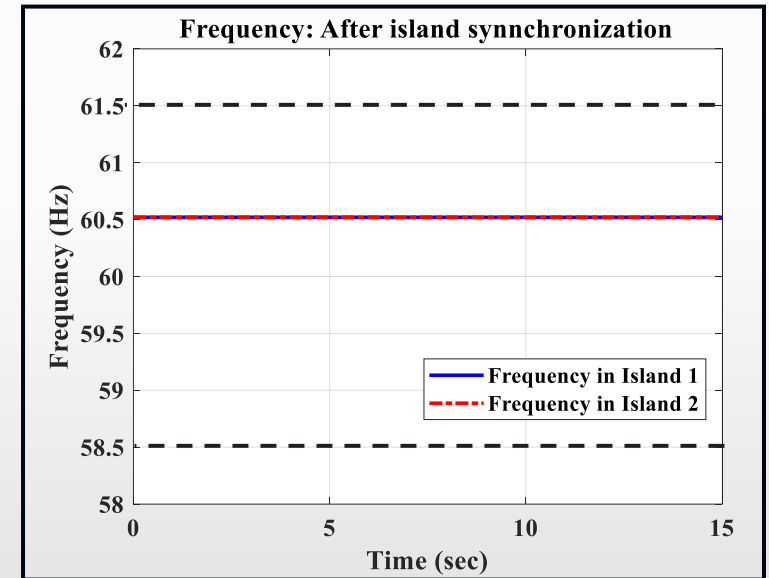
After island synchronization

Gen2 switch to droop control



After island synchronization

Islands frequency = 60.52 Hz

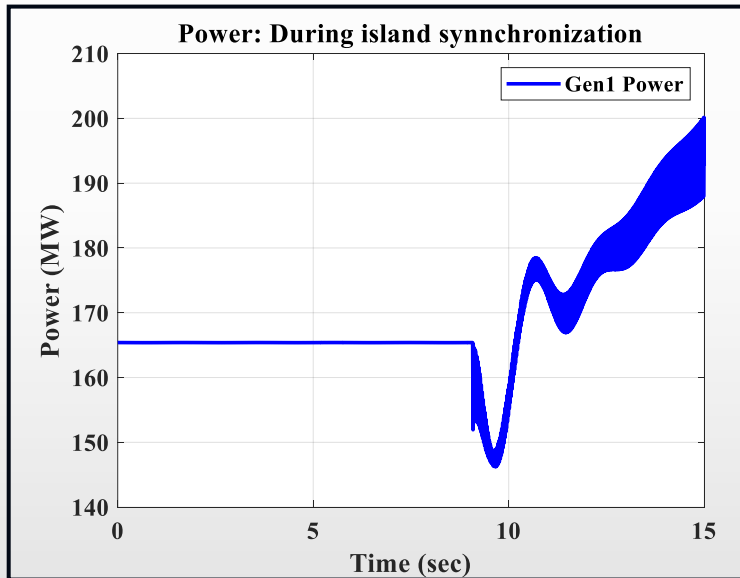


Control mode switch of black start units

Study Scenario 2 – Black Start Unit Active Power

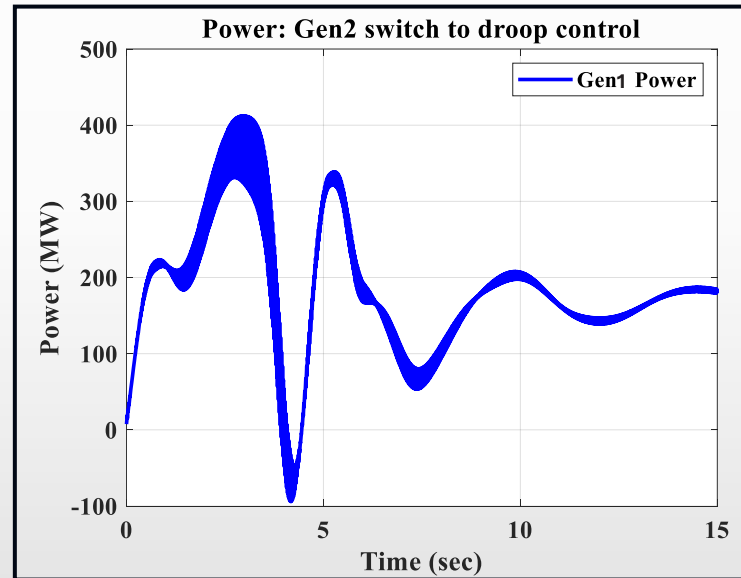
During island synchronization

$\max \delta = 10^\circ$, $\max \Delta V = 3 \text{ kV}$, $\max \Delta f = 0.1$



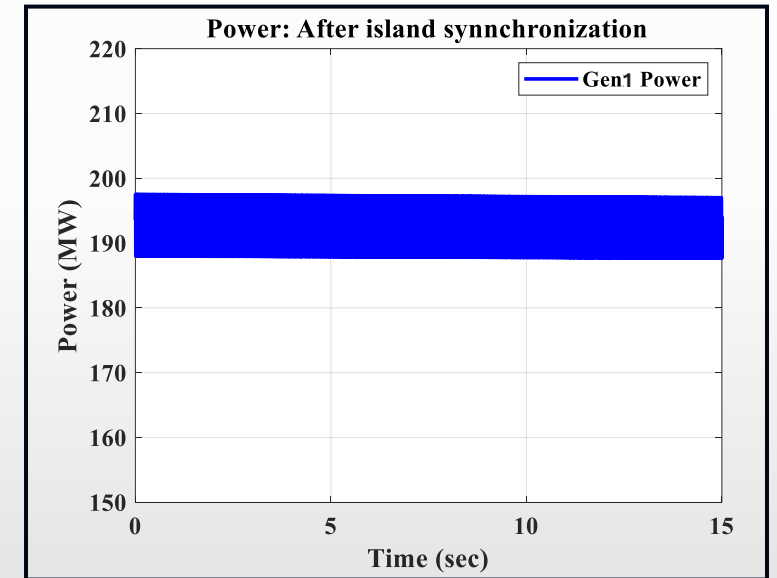
After island synchronization

Gen2 switch to droop control



After island synchronization

Islands frequency = 60.52 Hz

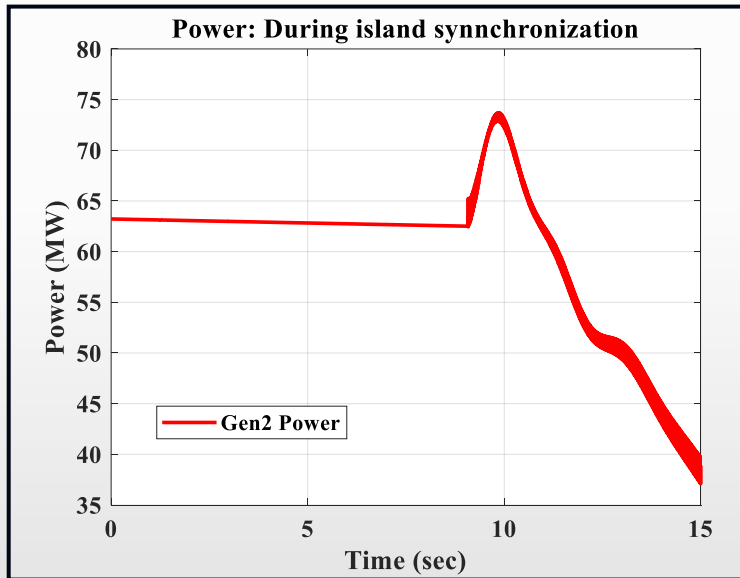


Control mode switch of black start units

Study Scenario 2 – Black Start Unit Active Power

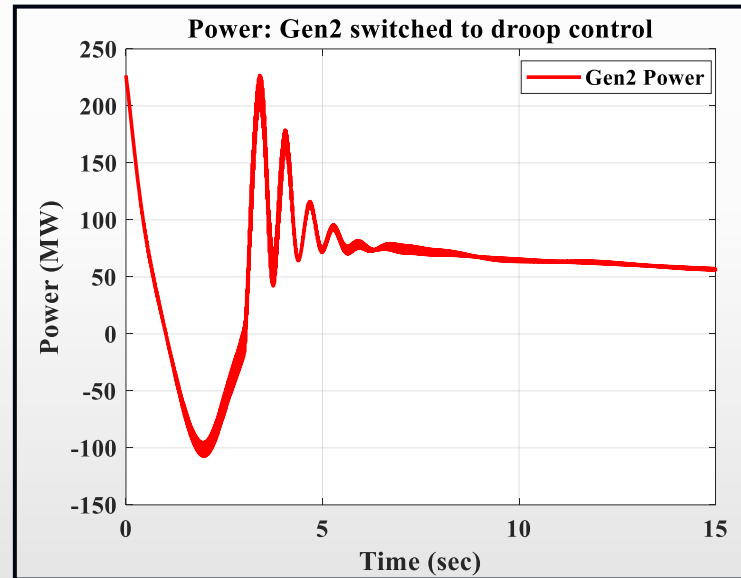
During island synchronization

$\max \delta = 10^\circ$, $\max \Delta V = 20V$, $\max \Delta f = 0.1$



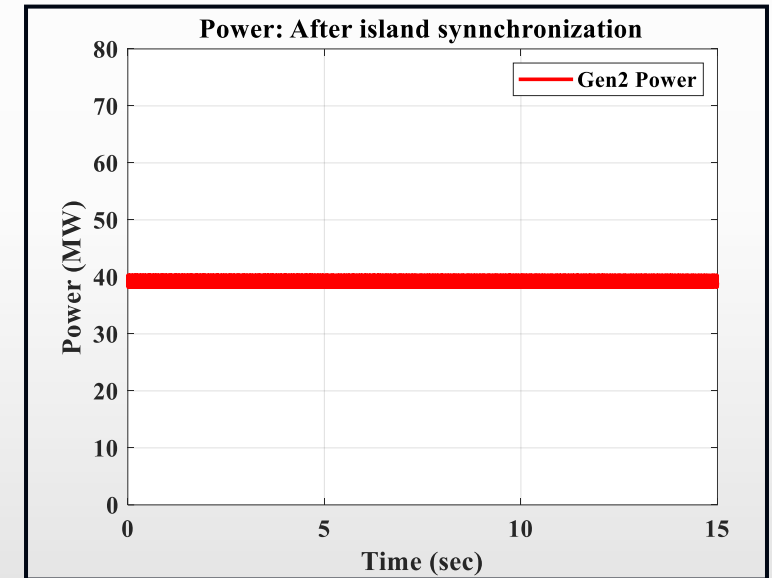
After island synchronization

Gen2 switch to droop control



After island synchronization

Islands frequency = 60.52 Hz



Control mode switch of black start units

Study Scenarios Summary

Scenario 1

- Stable and fast frequency recovery.
- No frequency limits violation.
- Well-damped active power response → no excessive stress on generators

Scenario 2

- Slower frequency recovery.
- No frequency limits violation.
- Large active power oscillations, high ramp rates, with significant overshoot and undershoot → **excessive stress on generators**

Minimum island energization level

Synchronization at 50% and 100% Island Energization

Scenario 1

Switch control mode of black start unit in island 2 to droop control **before** island synchronization.

*50% energization level
(half of generator, load and transmission lines are energized)*

Scenario 2

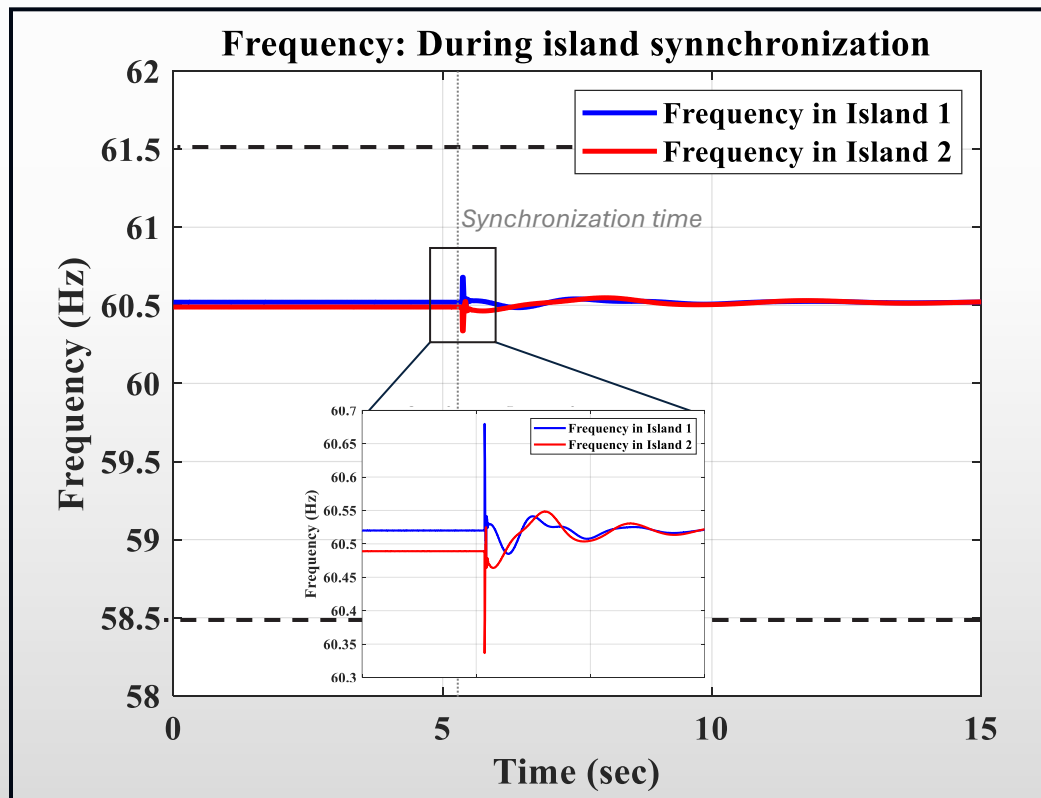
Switch control mode of black start unit in island 2 to droop control **before** island synchronization.

*100% energization level
(all generator, load and transmission lines are energized)*

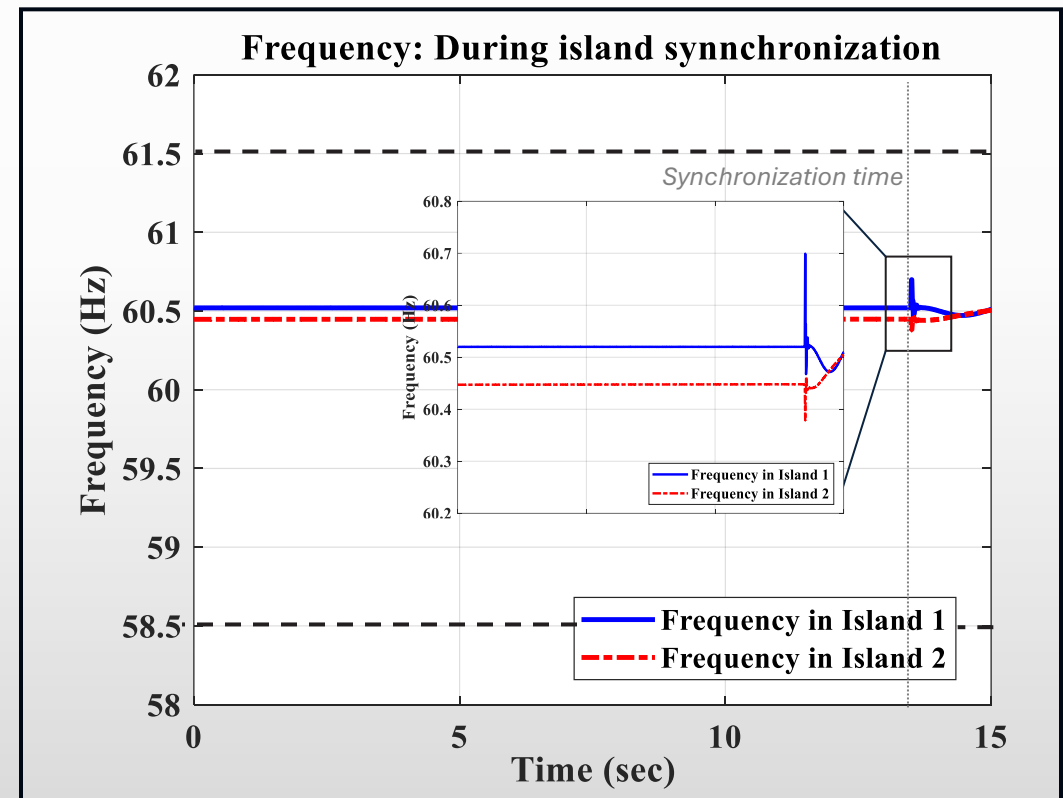
Minimum island energization level

Synchronization at 50% and 100% Island Energization

50% island energization level



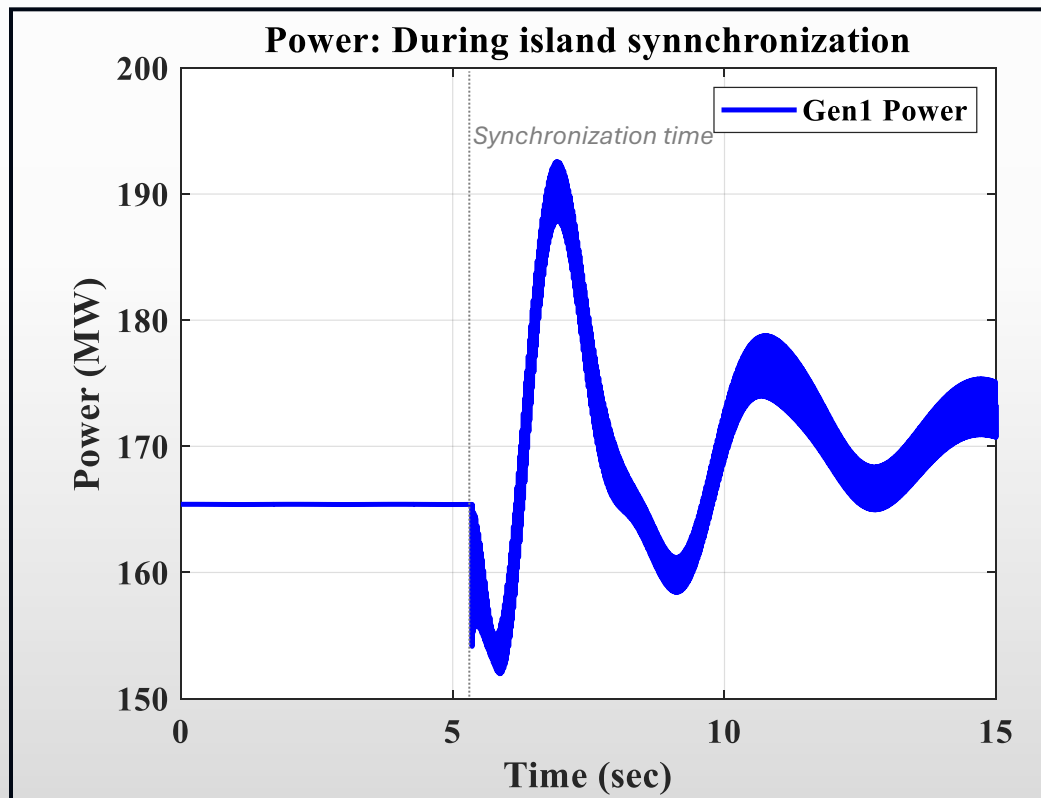
100% island energization level



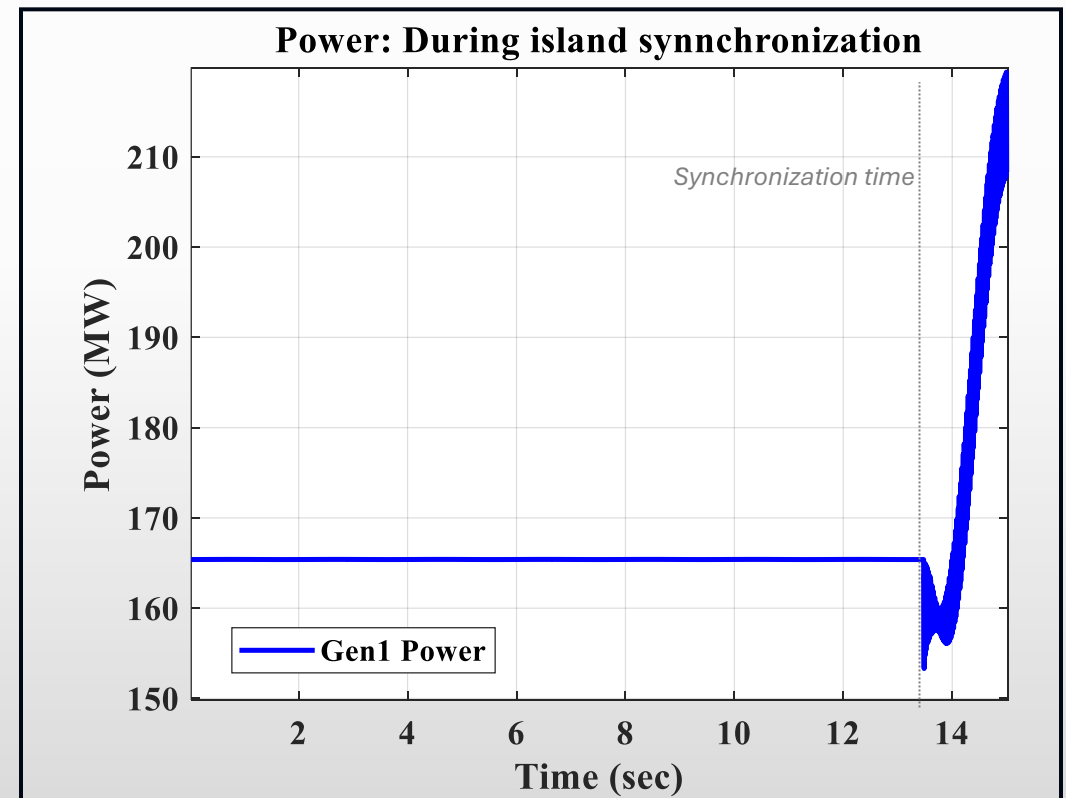
Minimum island energization level

Synchronization at 50% and 100% Island Energization

50% island energization level



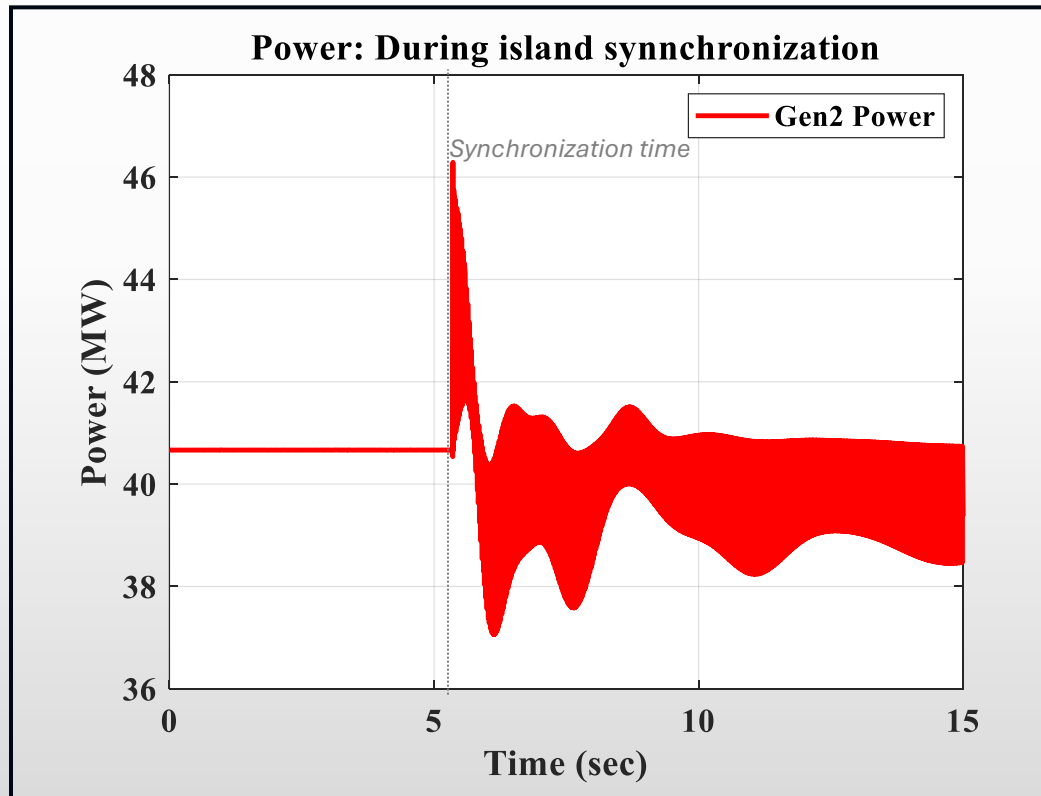
100% island energization level



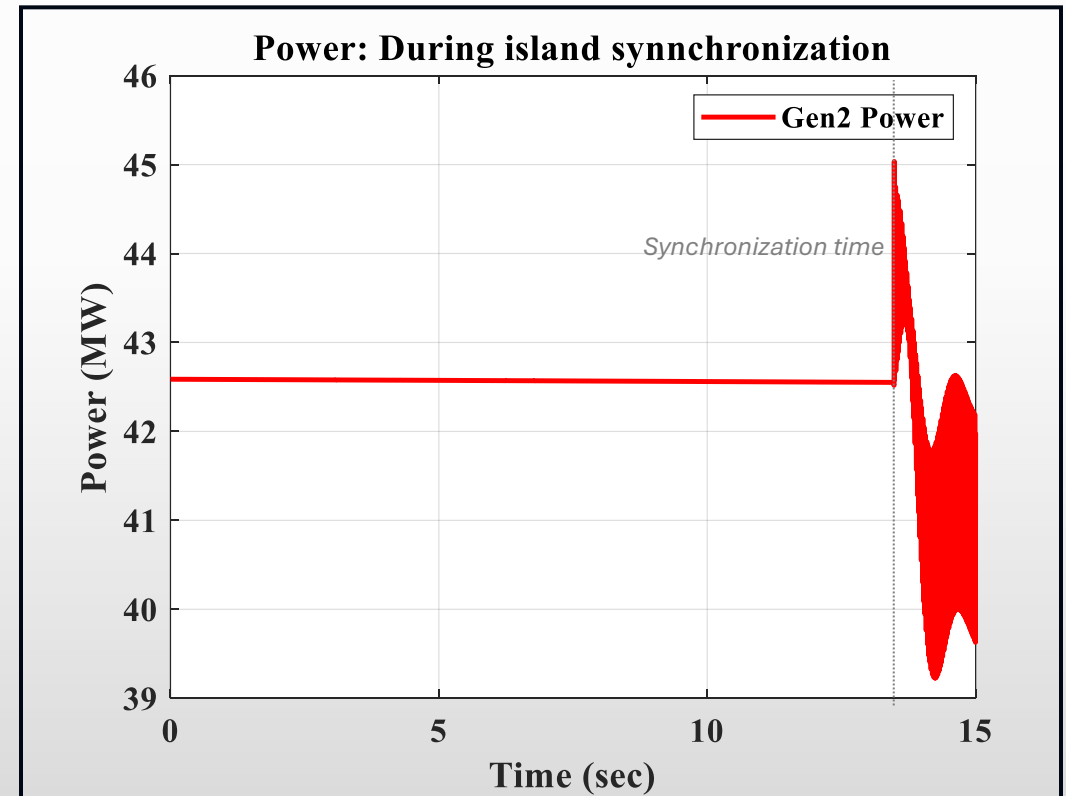
Minimum island energization level

Synchronization at 50% and 100% Island Energization

50% island energization level



100% island energization level



Minimum island energization level

Study Scenarios Summary

Both scenarios showed:

- Stable and fast frequency recovery.
- No frequency limits violation.
- Well-damped active power response → no excessive stress on generators

Synchronizing at full island energization enhances system strength and stability → more resilient operation and improved disturbance tolerance. However, this performance improvement does not justify synchronization delay.

Conclusion

- A detailed modular modeling and real-time data initialization procedure is developed.
- Using the two-island black start test case of Dominion Energy, critical parameters for synchronization, control mode switch of black start units and minimum island energization level, are explored.
- This work provides operators with an interactive training environment, could significantly enhance the preparedness.



Thank you!

Leila Chebbo

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