Hawaiian Electric

2021 System Stability Study
IGP TAP Review

Transmission Planning Department

December 13, 2021

Agenda

- Study Objectives and Status
- Study Methodology
  - High level description
  - Dispatch scenarios
  - Starting point assumptions
  - Model updates
  - Simulations & Analyses
- Next Steps

Study Objectives and Status

Study Backgrounds, Objectives and Status

- System level stability issues were identified during Stage 2 SIS
  - Instability caused by Centralized IPP project GFL control
  - DER Momentary Cessation (MC) poses high risk to system stability
  - Frequency response resource adequacy review
  - UFLS effectiveness review
  - New mode of oscillation

Study Backgrounds, Objectives and Status

- 2021 System Stability Study Objectives
  - Perform complete system wide study, obtain deeper understanding of the issues identified in the Stage 2 SIS.
  - Identify mitigation solutions for system beyond Stage 2 projects commission dates.

Study Backgrounds, Objectives and Status

- Kick-off study
- Review resource planning scenarios
- Determine study assumptions, scope and study dispatch scenarios

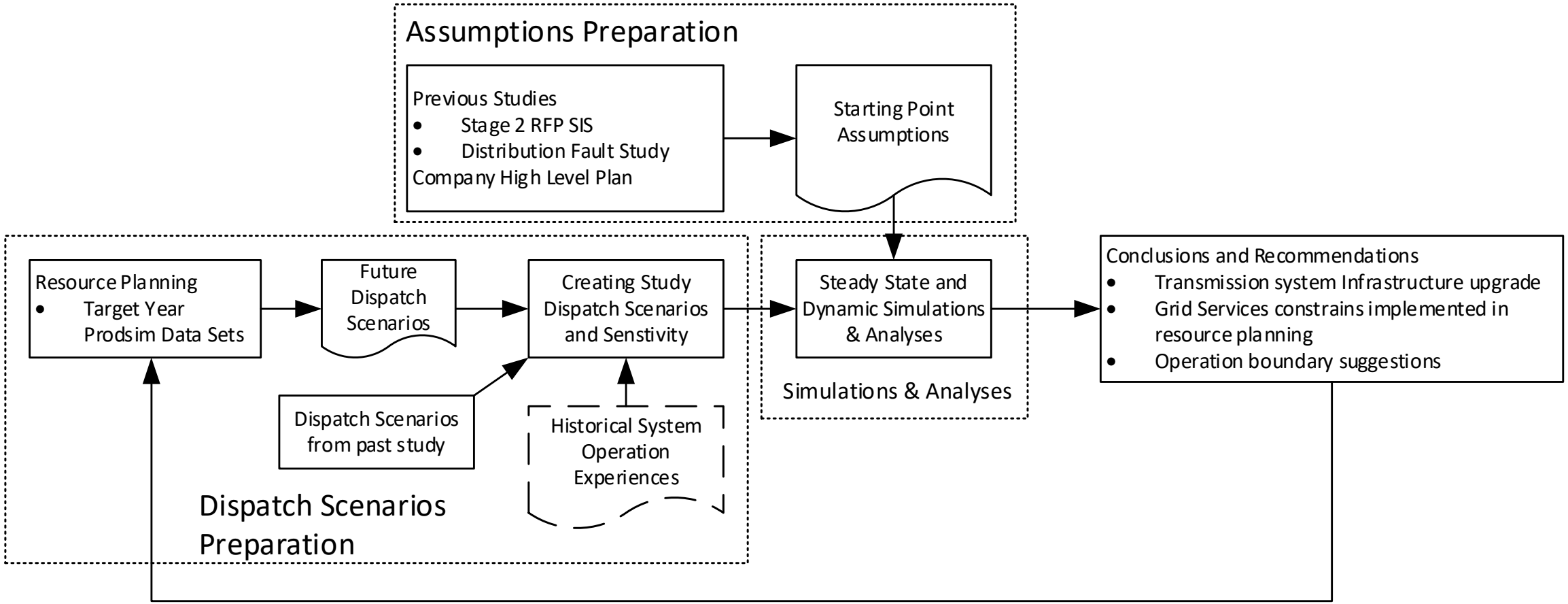
- First milestone review – steady state analysis
- Kickoff dynamic study

- Second milestone review
  - System dynamic study results (with starting point assumptions)
  - Sensitivity study plan
    - Synchronous condenser study
    - DER MC study
    - Frequency response resource review
    - GFM Oscillation study

- Final study review
  - Sensitivity study results
  - Final conclusions and recommendations

Study Methodology

Study Methodology
High Level Description



Study Methodology

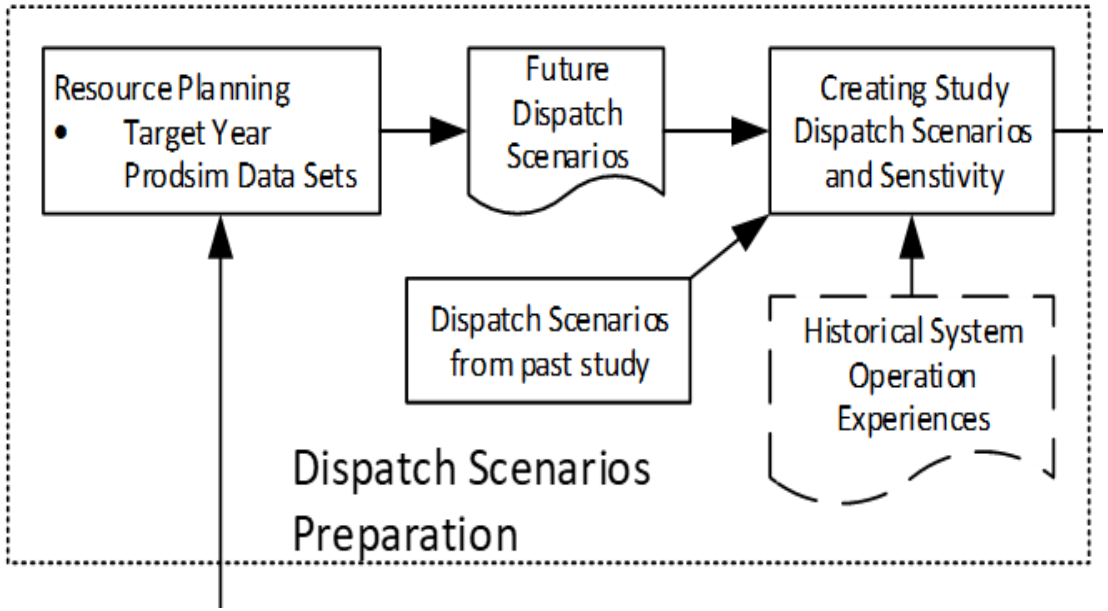
- Inputs
  - Dispatch scenario preparation
  - Assumptions preparation
- Simulations & Analyses
  - Steady state (only major islands) and dynamic analyses
  - PSS/E and PSCAD simulations
  - Observations

Study Methodology
Dispatch Scenario Preparations

- Study year – 2028
  - Near term planning, 5 years since the commissioning of Stage 2 IPP projects
  - No major procurement on major islands (O`ahu, Maui island and Hawai`i)

Study Methodology

Dispatch Scenario Preparations

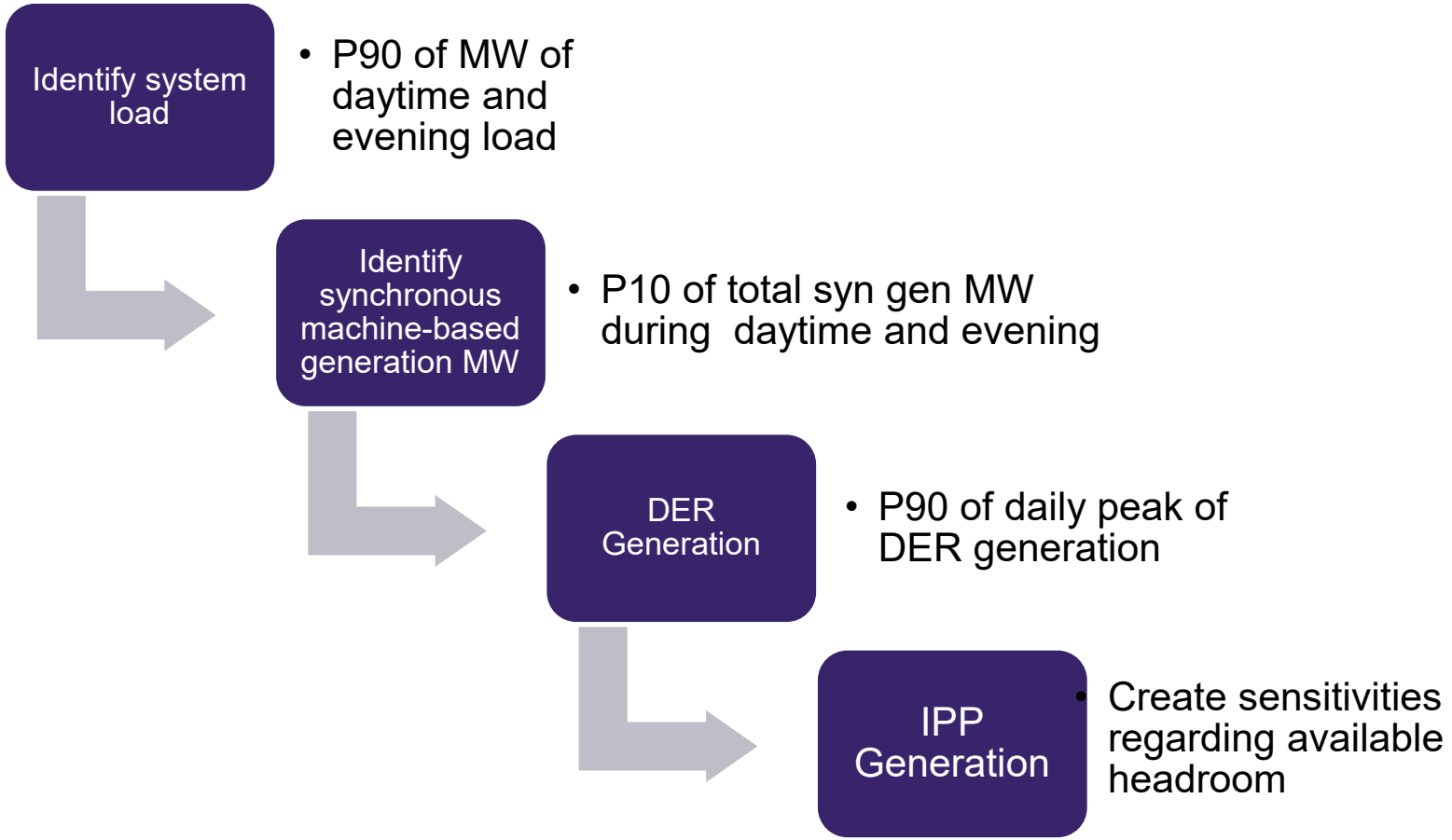


- Study year – 2028
  - Near term planning
  - No major procurement on major islands (O`ahu, Maui island and Hawai`i)
- Study scenarios
  - Low synchronous machine-based generation (P10)
  - Daytime peak load (P90) with high DER generation (P90)
  - Evening peak load
  - Considerations
    - DER is an important factor
    - Peak load scenarios are normally worse than light load scenarios
    - Reduce available headroom in IPP BESS

Study Methodology
Dispatch Scenario Preparations

- “Artificial” Dispatch Scenarios
  - No historical system operation experiences for system similar as the studied system
  - Limitations in Prodsim data
  - Low DER, low fossil generation, high IPP outputs

Study Methodology
Dispatch Scenario Preparations



Study Methodology
Dispatch Scenario Preparations

O`ahu System Dispatch Scenario

2028 Cases	Synchronous Machines (MW)	Centralized Renewable IPPs (MW)	DER (MW)	System Demand (MW)
DP-HD-HW				
DP-HD-LW				
DP-MaxD-LW-S				
DP-LD-HW				
DP-LD-LW				
EP-HD-HW				
EP-HD-LW				
EP-LD-LW				

Study Methodology
Dispatch Scenario Preparations

Maui System Dispatch Scenario

2028 Cases	Synchronous Machines (MW)	Centralized Renewable IPPs (MW)	DER (MW)	System Demand (MW)
DP-HD-HW				
DP-HD-LW				
DP-LD-HW				
DP-LD-LW				
EP-HW				
EP-LW				
EP-LD-LW				

Study Methodology
Dispatch Scenario Preparations

Hawai`i System Dispatch Scenario (Base)

2028 Cases	Synchronous Machines (MW)	Centralized Renewable IPPs (MW)	DER (MW)	System Demand (MW)
DP-HD-HW				
DP-HD-LW				
DP-LD-HW				
EP-HD-HW				
EP-HD-LW				
EP-LD-LW				

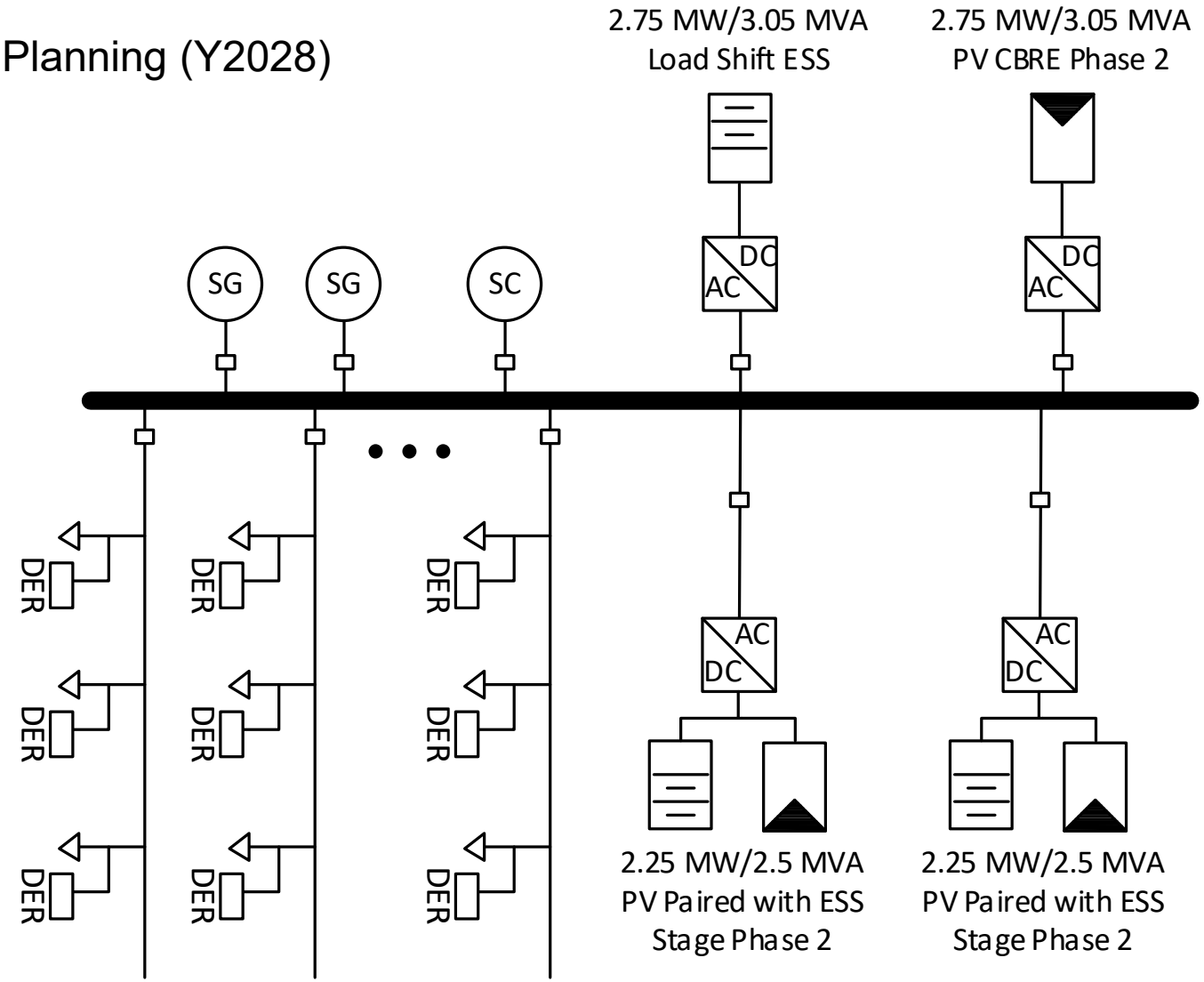
Study Methodology
Dispatch Scenario Preparations

Hawai`i System Dispatch Scenario (Sensitivity)

2028 Cases	Synchronous Machines (MW)	Centralized Renewable IPPs (MW)	DER (MW)	System Demand (MW)
DP-HD-HW				
DP-HD-LW				
DP-LD-HW				
EP-HD-HW				
EP-HD-LW				
EP-LD-LW				

Study Methodology
Dispatch Scenario Preparations

Moloka'i Resource Planning (Y2028)



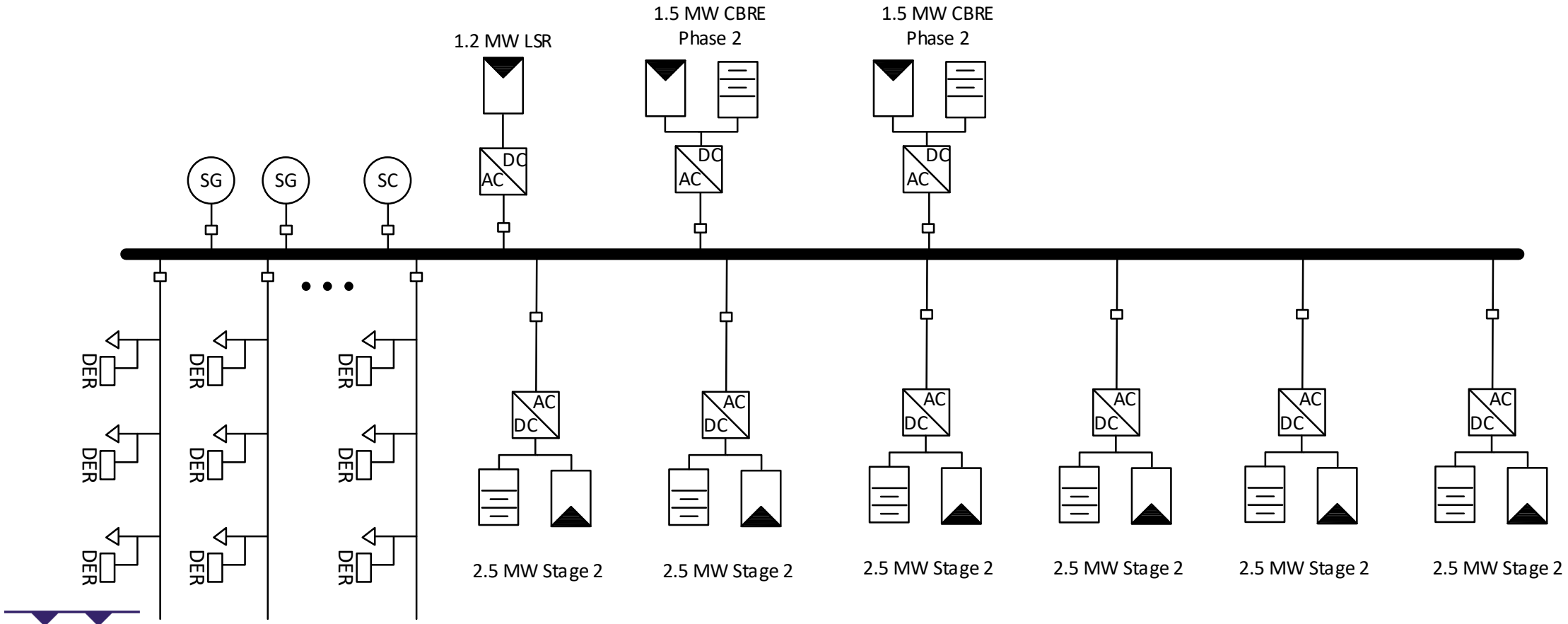
Study Methodology
Dispatch Scenario Preparations

Moloka`i System Dispatch Scenario

2028 Cases	Synchronous Machines (MW)	Centralized Renewable IPPs (MW)	DER (MW)	System Demand (MW)
DM-HD-NF				
DP-HD-NF				
DP-LD-LF				
DP-LD-HF				
EP-NF				
EP-HF				

Study Methodology
Dispatch Scenario Preparations

Lana`i Resource Planning (Y2028)



Study Methodology
Dispatch Scenario Preparation

Lana`i System Dispatch Scenario

2028 Cases	Synchronous Machines (MW)	Centralized Renewable IPPs (MW)	DER (MW)	System Demand (MW)
DM-HD-NF				
DP-HD-NF				
DP-LD-LF				
DP-LD-HF				
EP-NF				
EP-HF				

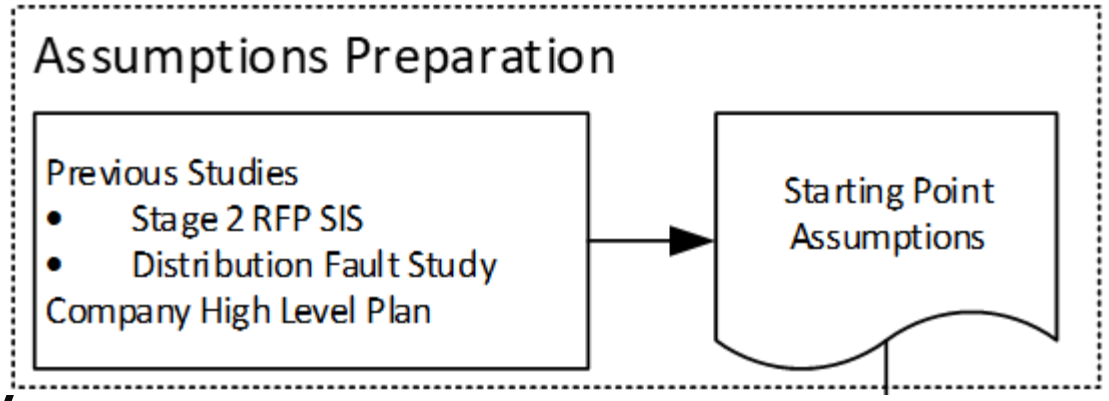
System Stability Study

Dispatch Scenario Preparations

Island	Min. Synchronous Machine based generation	Max. DER based Generation	IPP Projects
O`ahu			
Maui			
Hawai`i			
Moloka`i			
Lana`i			

*From Stage 2 island wide study

Study Methodology
Assumptions Preparation



- Stage 2 SIS
  - IPP projects control settings
  - DER MC
- Distribution Fault Dynamic Study
  - Location and MVA size of synchronous Condenser
- Company High Level Plan
  - DER FFR (MW size, control settings)
  - Fossil unit retirement

Study Methodology Assumptions Preparation

DER Momentary Cessation (MC)

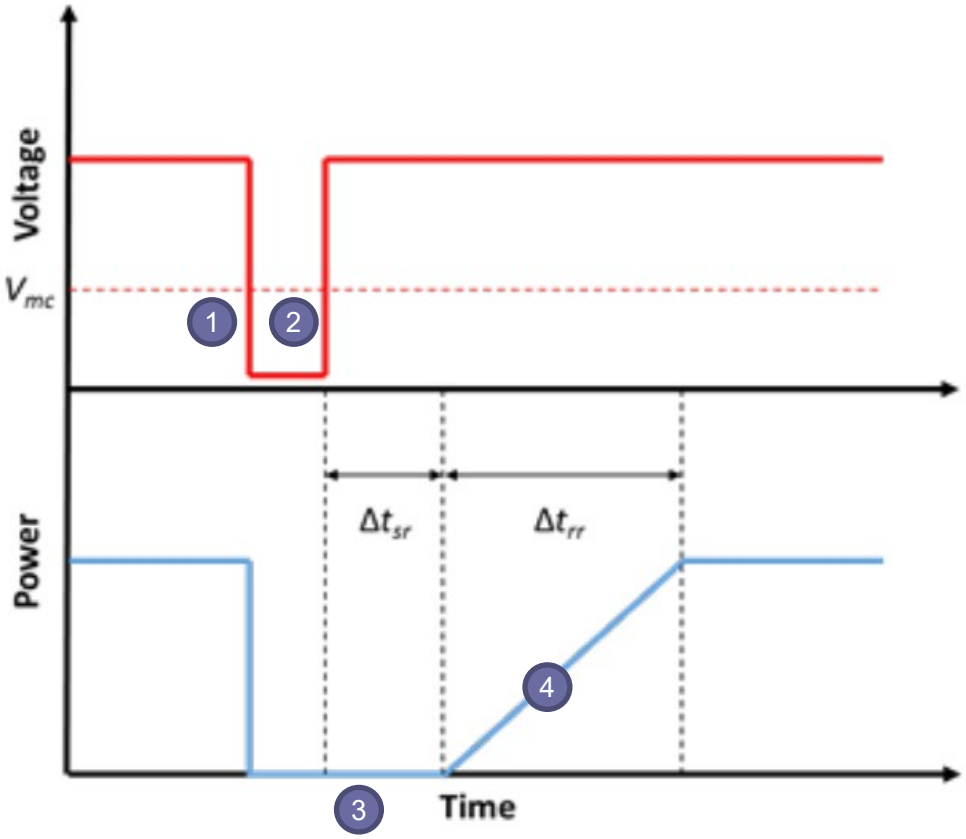


Figure 1: Illustration of Momentary Cessation

Credit: NERC

DER Type	1 UV Block Limit (Vmc, PU)	2 UV Unblock Limit (Vmc, PU)	3 Recovery Delay* (Δtsr, s)	4 Recovery Ramp Rate (during Δtrr, pu/s)
P1				
P2				
P3				

*"Recovery Delay" means from the point voltage recovers above the UV unblock limit to when DER inverter active current starts to recover.

Study Methodology
Assumptions Preparation

- DER Ride-Through settings
  - P1 – Legacy DER (IEEE 1547-2003)
  - P2 – Re-programmed Legacy DER (extended UF ride-through settings based on IEEE 1547-2003)
  - P3 – Rule 14h ride-through requirements since 2016
  - Rule 14h TrOV-2 trip settings are not modeled.
  - ROCOF ride-through (IEEE 1547-2018) is not modeled.

Study Methodology
Model Updates

- Changes since Stage 2 SIS
  - Updating DER MC modeling
  - In PSCAD
    - Using single phase inverter model to represent DER
    - Modeling under-voltage blocking for UFLS frequency measurement
    - Using Tesla OEM model to represent future centralized IBR projects

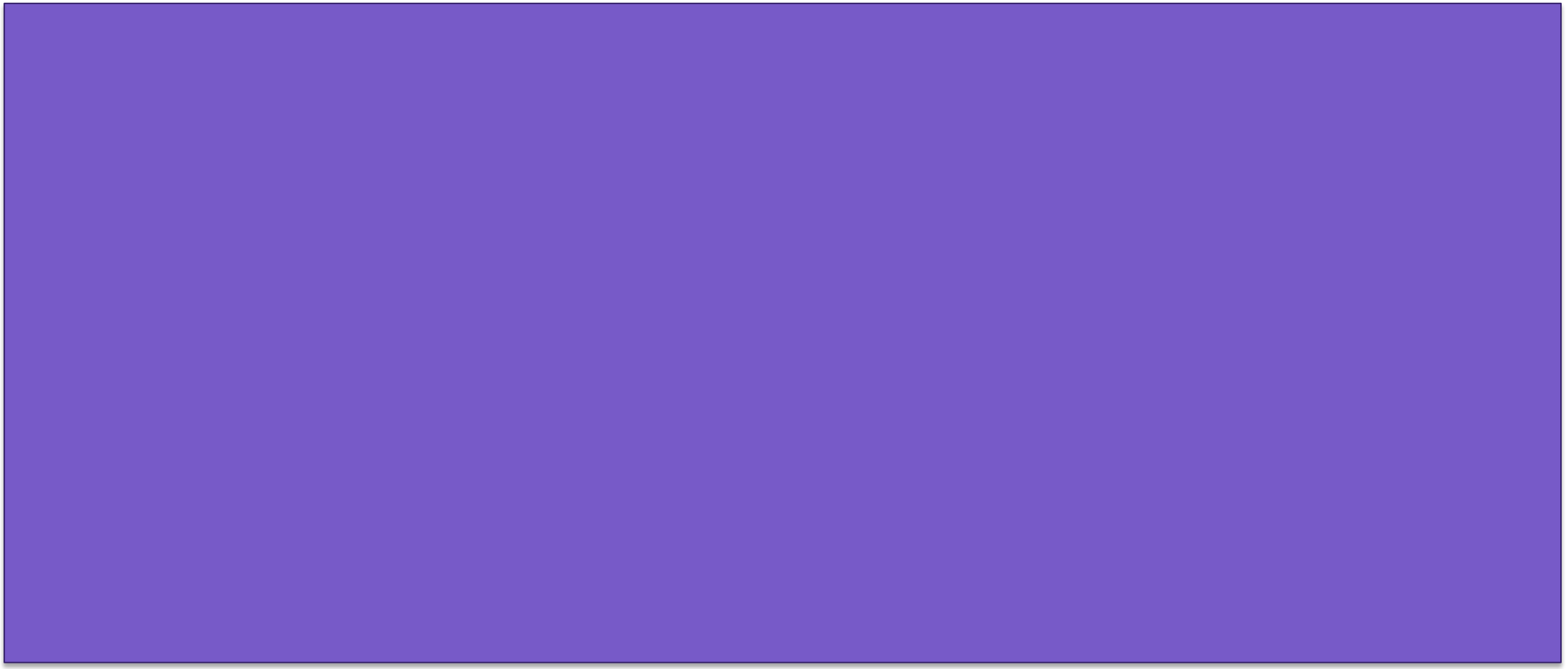
Study Methodology
Simulations & Analyses

- Steady State Analyses
  - Running power flow analysis for all identified dispatch scenarios (N-0, N-1, and N-2 for O`ahu system)
  - Identify any voltage and thermal loading planning criteria violation.
  - Running PV, QV study to determine power transfer limit and var resource adequacy

Study Methodology

Simulations & Analyses

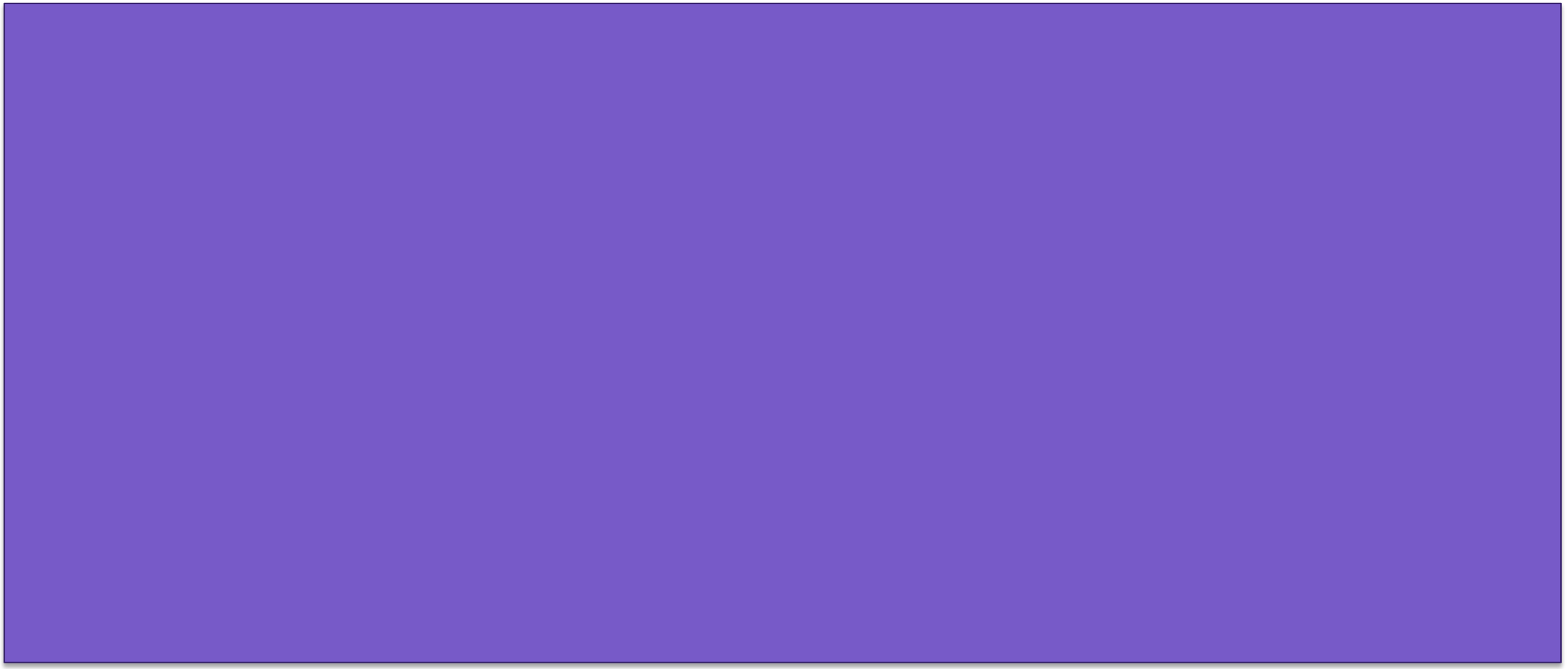
O`ahu Steady State Analyses Results



Study Methodology

Simulations & Analyses

Maui Island Steady State Analyses Results



Study Methodology

Simulations & Analyses

Hawai`i Steady State Analyses Results

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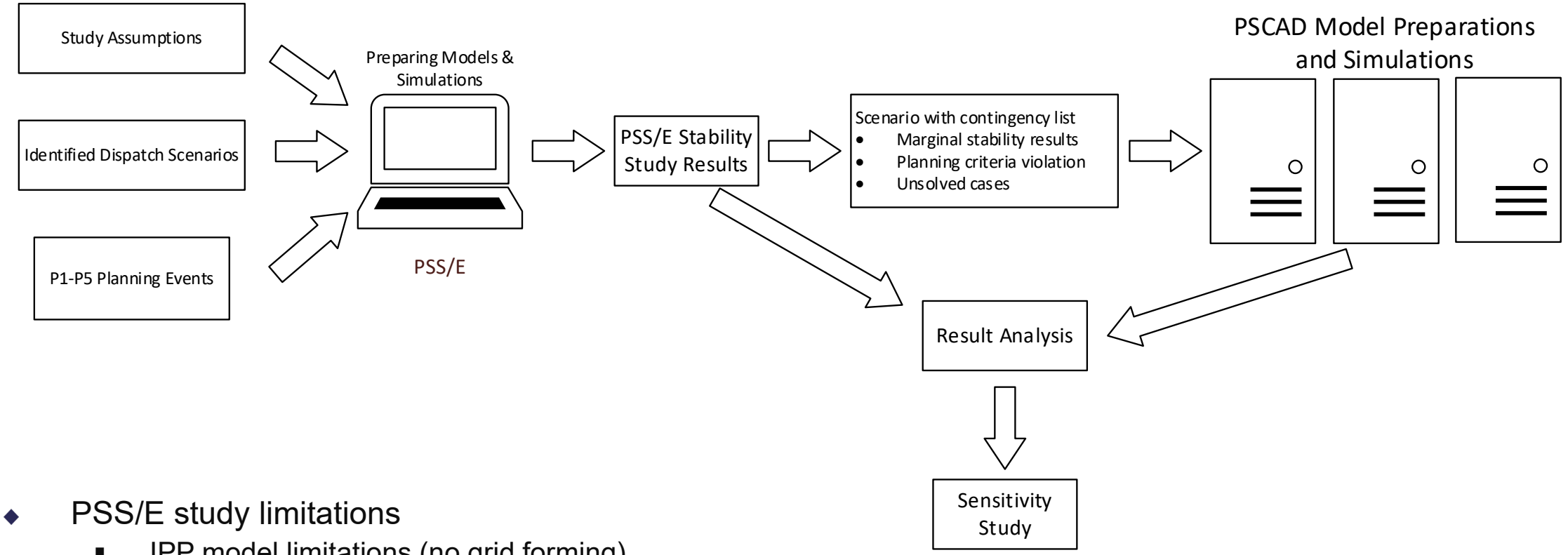
Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)



- PSS/E study limitations
  - IPP model limitations (no grid forming)
  - General limitations positive sequency simulation for high IBR/DER penetration scenario dynamic study.
- PSCAD study limitations – Very slow
- PSS/E Study inform PSCAD study

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study) – O`ahu

Planning Event	Description	Allowable UFLS	# of PSSE Studied Contingency	# of PSSE Simulation Cases	# of PSCAD Simulation Cases*
P1	3PH Fault w/ Loss of Transmission Line (w/ Reclosing)	None	54	432	2
	3PH Fault w/ Loss of Generator	None	2	13	N/A
	Loss of Generator (No Fault)	None	2	13	N/A
P2	3PH Bus Fault	None	30	240	N/A
P3	Select Cases (Loss of generator with system adjustments) - P1 Analysis	None	54/1/1	168	N/A
P4	SLG Fault with Breaker Failure (Loss of Multiple Elements)	None	56	448	2
P5	3PH Fault w/ Delayed Clearing (Loss of Non-Redundant Component of Protection System)	None	54	432	6

*28 PSCAD cases are still under simulations.

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study) – O`ahu

PSS/E Study Results Summary

Planning Event	Description	DP-HD-HW			DP-HD-LW			DP-MaxD-LW-S			DP-LD-HW			DP-LD-LW			EP-HD-HW			EP-HD-LW			EP-LD-LW		
		U	V	C	U	V	C	U	V	C	U	V	C	U	V	C	U	V	C	U	V	C	U	V	C
P1	3PH Fault w/ Loss of Transmission line (w/ Reclosing)																								
	3PH Fault w/ Loss of Generation																								
	Loss of Geneartion (No Fault)																								
P2	3PH Bus Fault																								
P3	3PH Fault w/ Loss of Transmission line (w/ Reclosing)																								
	3PH Fault w/ Loss of Generation																								
	Loss of Geneartion (No Fault)																								
P4	SLG Fault w/ Breaker Failure (Loss of Multipule Elements)																								
P5	3PH Fault w/ Delayed Clearing Loss of Transmission line (Loss of non-redundant component of Protection system)																								

U=Unsolved; V=Planning criteria violation; C=Complying with planning criteria

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study) – Maui Island

Planning Event	Description	Allowable UFLS	# of PSSE Studied Contingency	# of PSSE Simulation Cases	# of PSCAD Simulation Cases
P1	Loss of Generator (w/ Fault)	Up to 15%	0	0	0
	3PH Fault w/ Loss of Transmission Line (w/ Reclosing)	None	62	428	2
	Loss of Generator (No Fault)	Up to 15%			
P2	3PH Bus Fault	Up to 15%	23	161	0
P3	Loss of generator with system adjustments w/ P1 Line Faults	Up to 20%	120	480	0
P4	SLG Fault with Breaker Failure (Loss of Multiple Elements)	Up to 40%	60	420	3
P5	3PH Fault w/ Delayed Clearing (Loss of Non-Redundant Component of Protection System)	Up to 15%	60	420	7

*32 PSCAD cases are still under simulations.

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study) – Maui Island

PSS/E Study Results Summary

Planning Event	Description	DayPeak, HWHD			DayPeak, HWLD			DayPeak, LWHD			DayPeak, LWLD			EvePeak, HW			EvePeak, LW			EvePeak, LWLC		
		U	V	C	U	V	C	U	V	C	U	V	C	U	V	C	U	V	C	U	V	C
P1	3PH Fault w/ Loss of Transmission line (w/ Reclosing)																					
	3PH Fault w/ Loss of Generation																					
	Loss of Geneartion (No Fault)																					
P2	3PH Bus Fault																					
P3	Select Cases (Loss of generation with system adjustments) and P1 Fault Analysis																					
P4	SLG Fault w/ Breaker Failure (Loss of Multipule Elements)																					
P5	3PH Fault w/ Delayed Clearing Loss of Transmission line (Loss of non-redundant component of Protection system)																					

U=Unsolved; V=Planning criteria violation; C=Complying with planning criteria; NC=Not completed

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study) – Hawai`i

Planning Event	Description	Allowable UFLS	# of PSSE Studied Contingency	# of PSSE Simulation Cases	# of PSCAD Simulation Cases
P1	Loss of Generator (w/ Fault)	Up to 15%	62	0	0
	3PH Fault w/ Loss of Transmission Line (w/ Reclosing)	None	5	428	2
	Loss of Generator (No Fault)	Up to 15%			
P2	3PH Bus Fault	Up to 15%	35	161	0
P3	Loss of generator with system adjustments w/ P1 Line Faults	Up to 20%	62/5	480	0
P4	SLG Fault with Breaker Failure (Loss of Multiple Elements)	Up to 40%	62	420	3
P5	3PH Fault w/ Delayed Clearing (Loss of Non-Redundant Component of Protection System)	Up to 15%	62	420	7

*32 PSCAD cases are still under simulations.

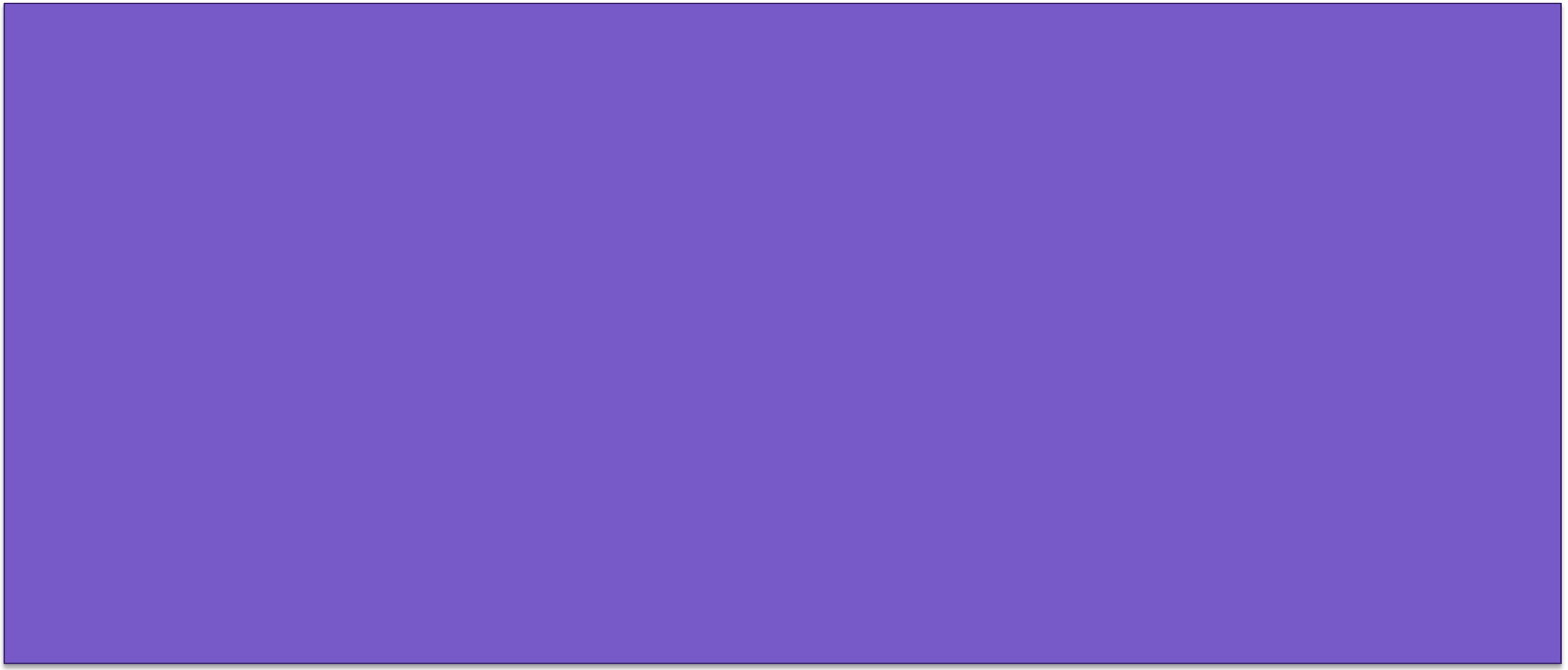
Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study) – Hawaii Island

PSS/E Study Results Summary

Planning Event	Description	DP High Wind High DER			DP High Wind Low DER			DP Low Wind High DER			EP High Wind High DER			EP Low Wind High DER			EP Low Wind Low DER		
		U	V	C	U	V	C	U	V	C	U	V	C	U	V	C	U	V	C
P1	3PH Fault w/ Loss of Transmission line (w/ Reclosing)																		
	3PH Fault w/ Loss of Generation																		
	Loss of Generation (No Fault)																		
P2	3PH Bus Fault																		
P3	3PH Fault w/ Loss of Transmission line (w/ Reclosing)																		
	3PH Fault w/ Loss of Generation																		
	Loss of Generation (No Fault)																		
P4	SLG Fault w/ Breaker Failure (Loss of Multipule Elements)																		
P5	3PH Fault w/ Delayed Clearing Loss of Transmission line (Loss of non-redundant component of Protection system)																		

U=Unsolved; V=Planning criteria violation; C=Complying with planning criteria; NC=Not completed

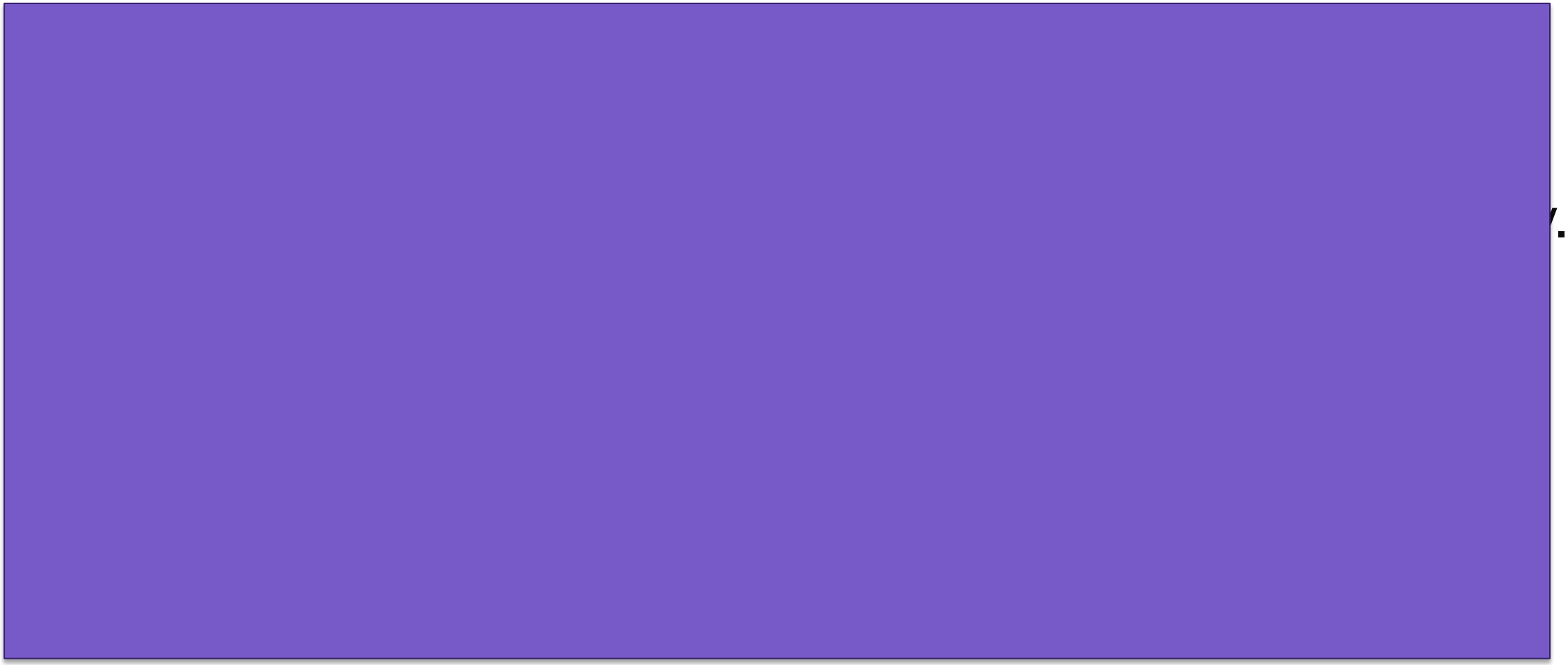
Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)

- 

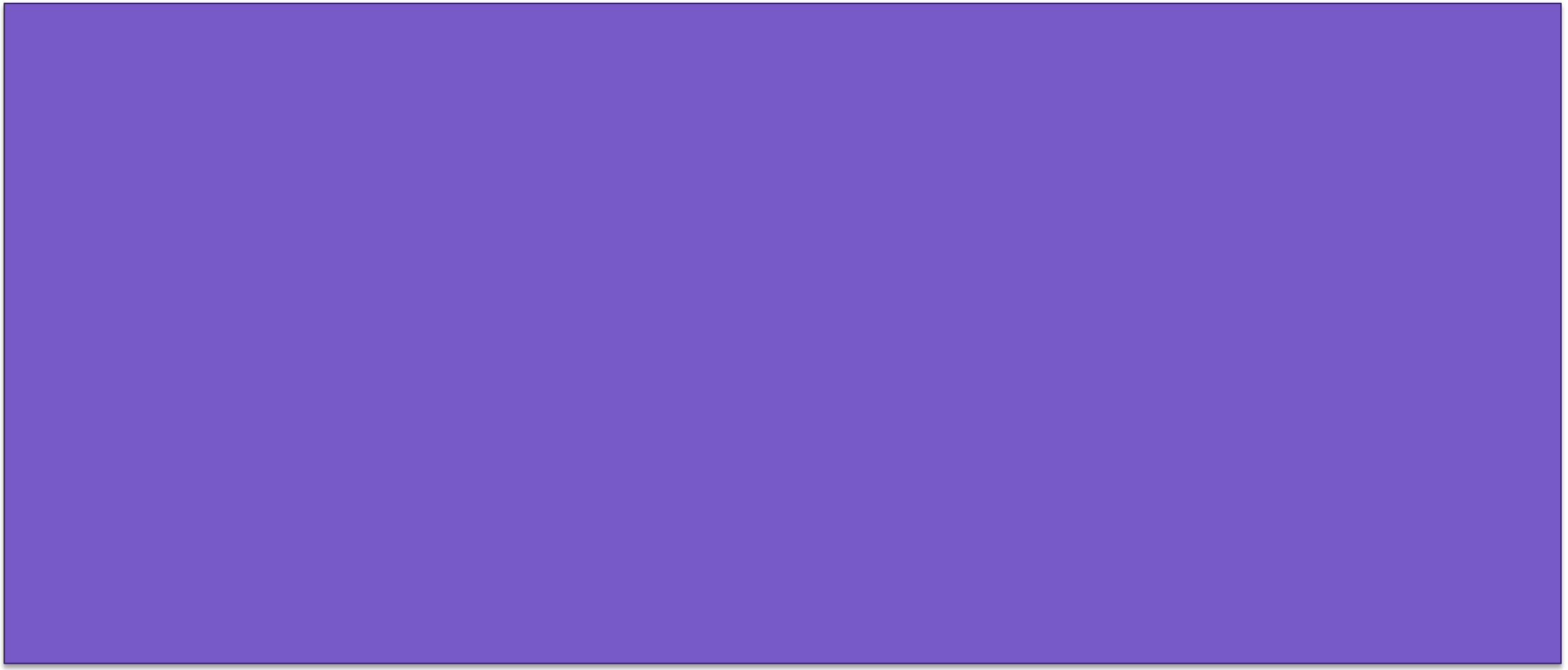
Study Methodology

Simulations & Analyses

Dynamic Study (Stability Study)

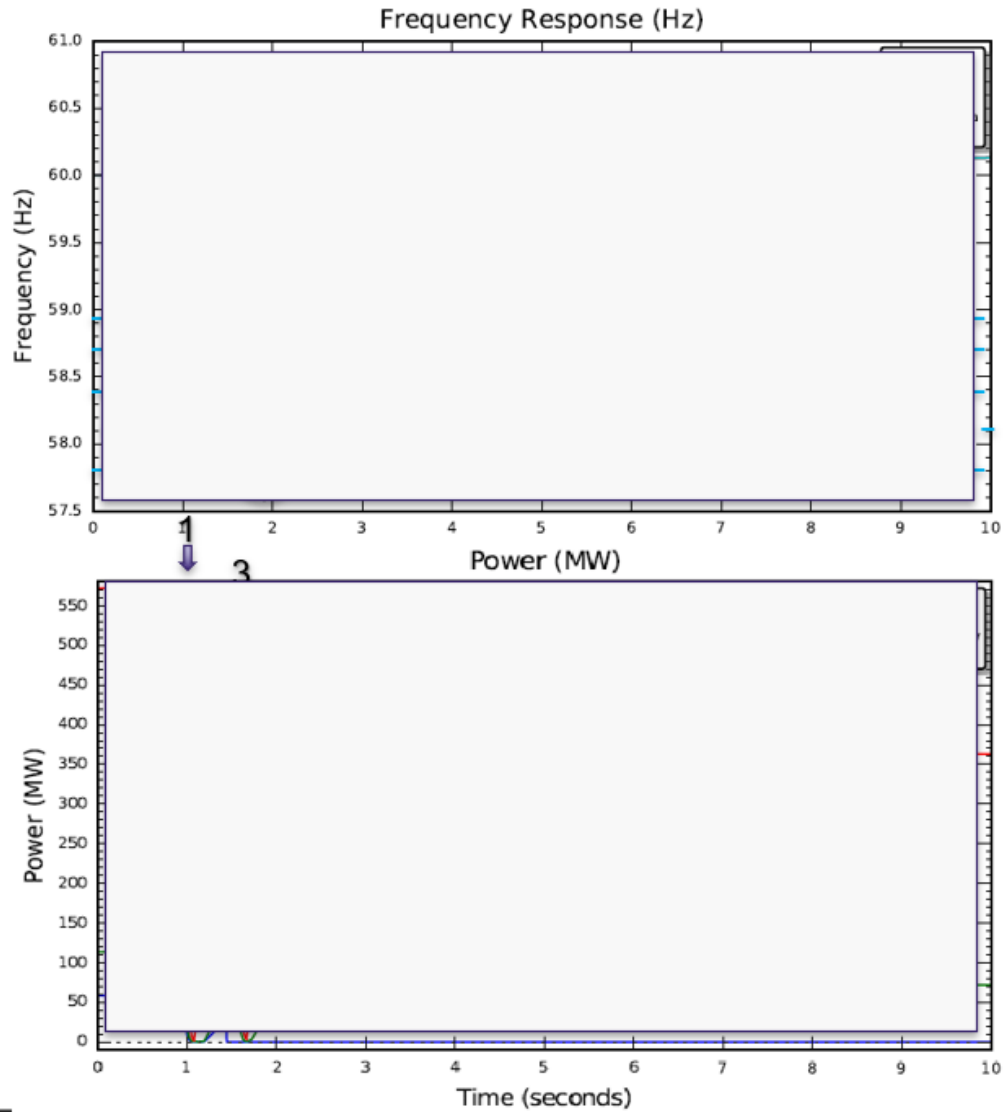
- 

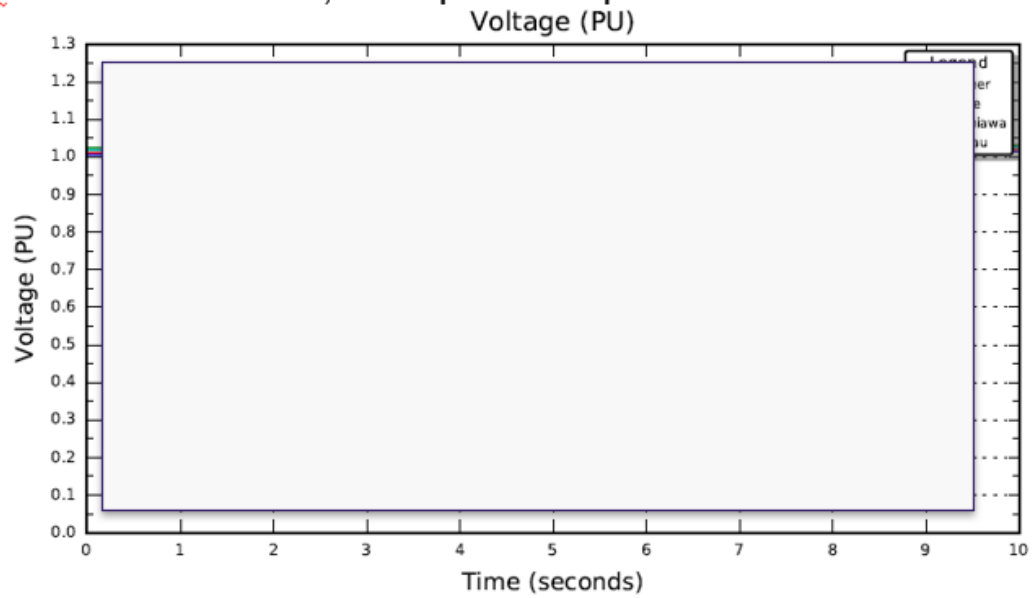
Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)

- 

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)

Example: 3PH Fault w/ Reclose Con 08 DP-MaxD-LW-S case: 5 Block UFLS, No unexpected IPP trips





1. Fault Applied
2. Fault Cleared after 5 cycles on both ends of line
3. Reclose into Fault at 1.583s (leader)
4. Fault Cleared after 5 cycles
5. UFLS Block 5 triggered and DER ramped up

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)

Observed Rate of Change of Frequency (ROCOF) in PSS/E Simulations

1: Fault inception
2: Fault cleared
3: Frequency reach nadir
4: DER recovery from MC, frequency reach peak

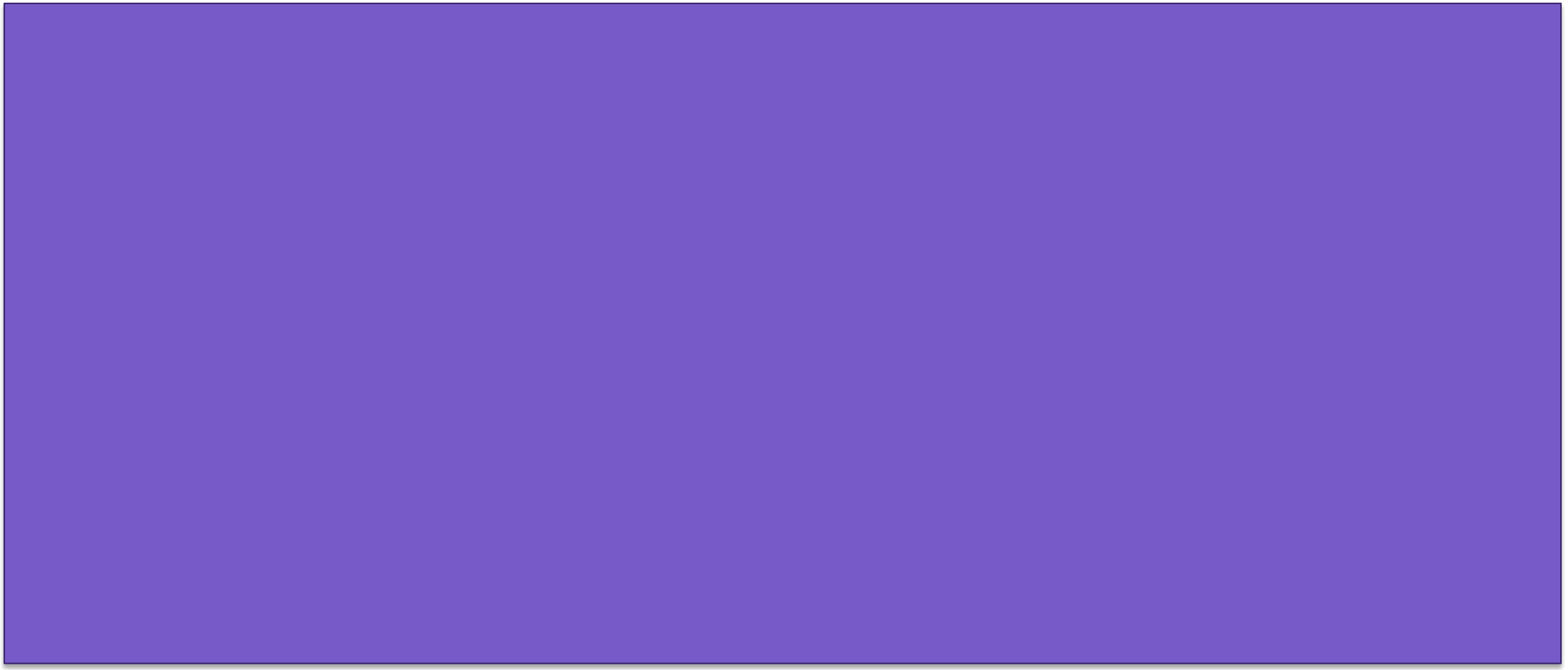
Estimate ROCOF between 1 and 3, and 3 and 4.

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)

Observed Rate of Change of Frequency (ROCOF, in Hz/s) in PSS/E Simulations

Planning Event	Description	O`ahu	Maui Island	Hawai`i
P1	3PH Fault w/ Loss of Transmission Line (w/ Reclosing)			
	3PH Fault w/ Loss of Generator			
	Loss of Generator (No Fault)			
P2	3PH Bus Fault			
P3	Select Cases (Loss of generator with system adjustments) - P1 Analysis			
P4	SLG Fault with Breaker Failure (Loss of Multiple Elements)			
P5	3PH Fault w/ Delayed Clearing (Loss of Non-Redundant Component of Protection System)			

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)

- 

Study Methodology

Simulations & Analyses

Dynamic Study (Stability Study)

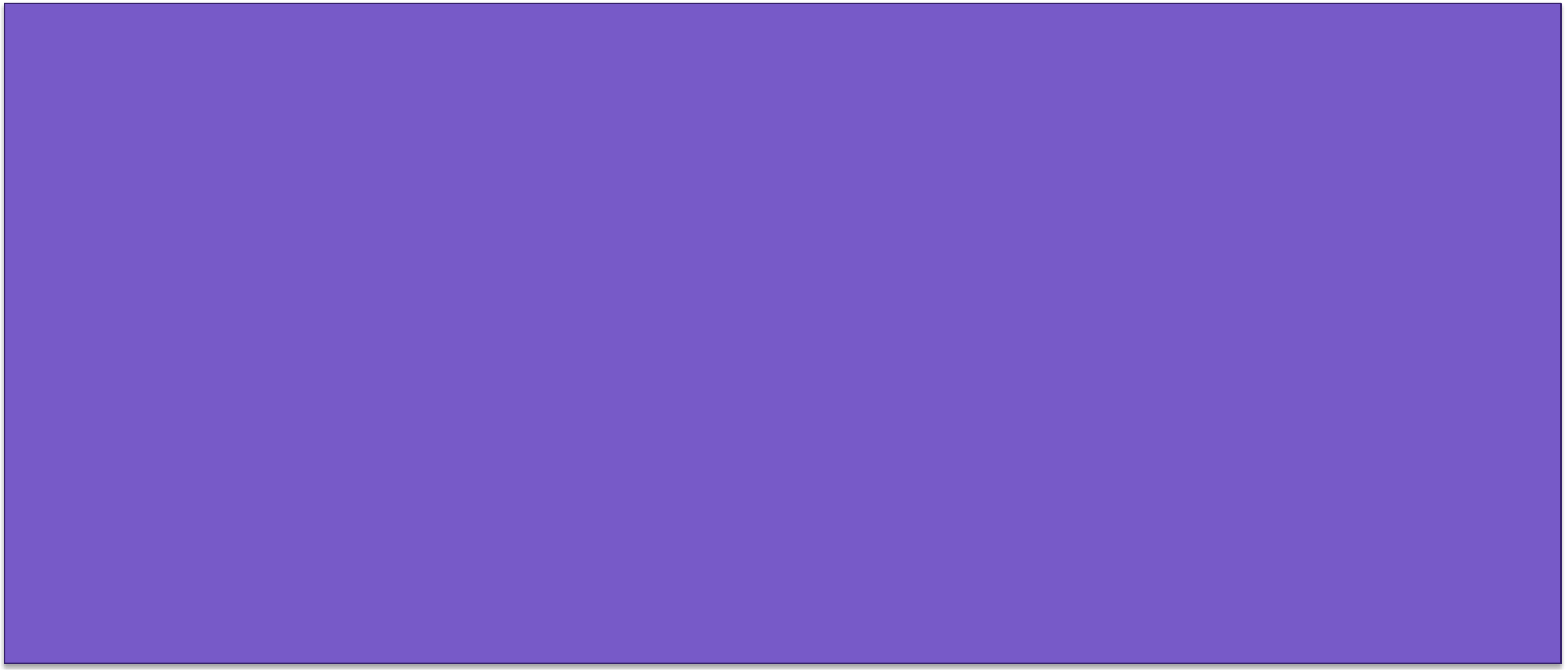
PSSE Simulation Results

PSCAD Simulation Results

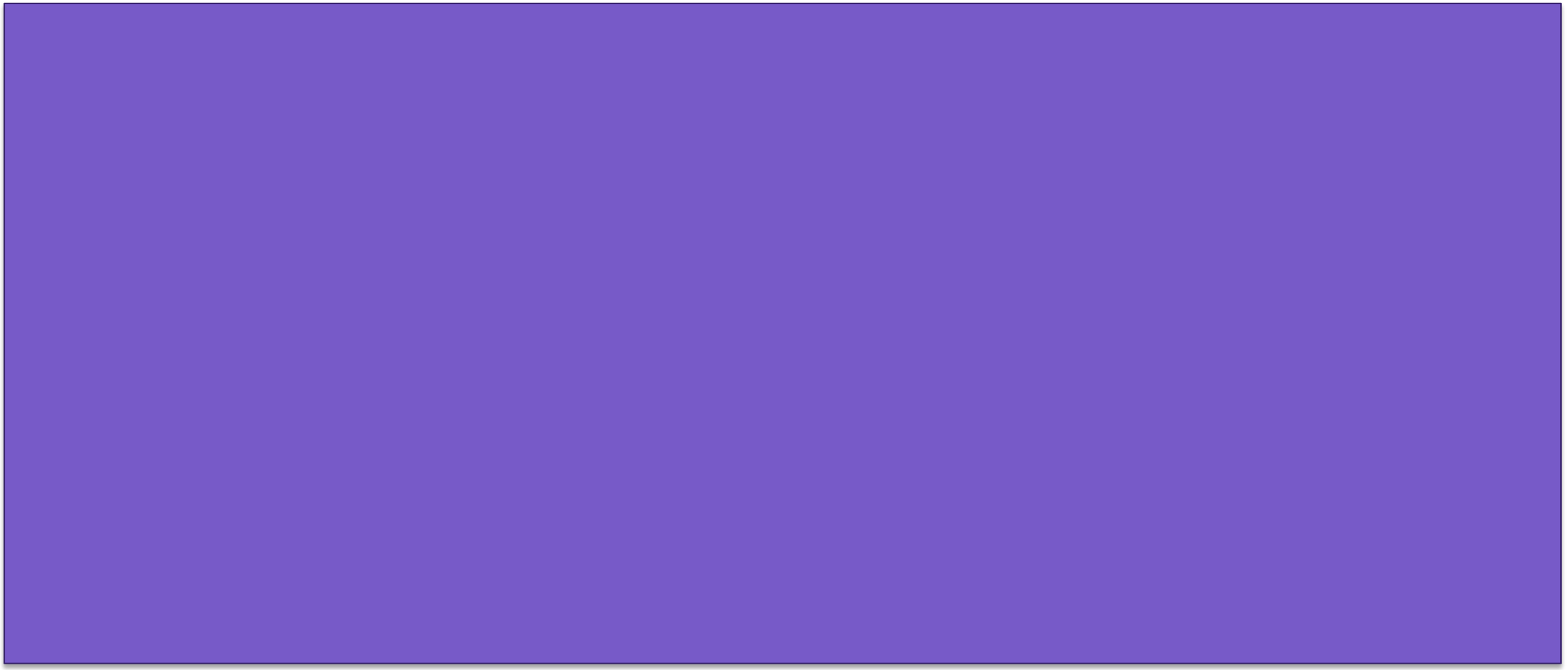
Study Methodology

Simulations & Analyses

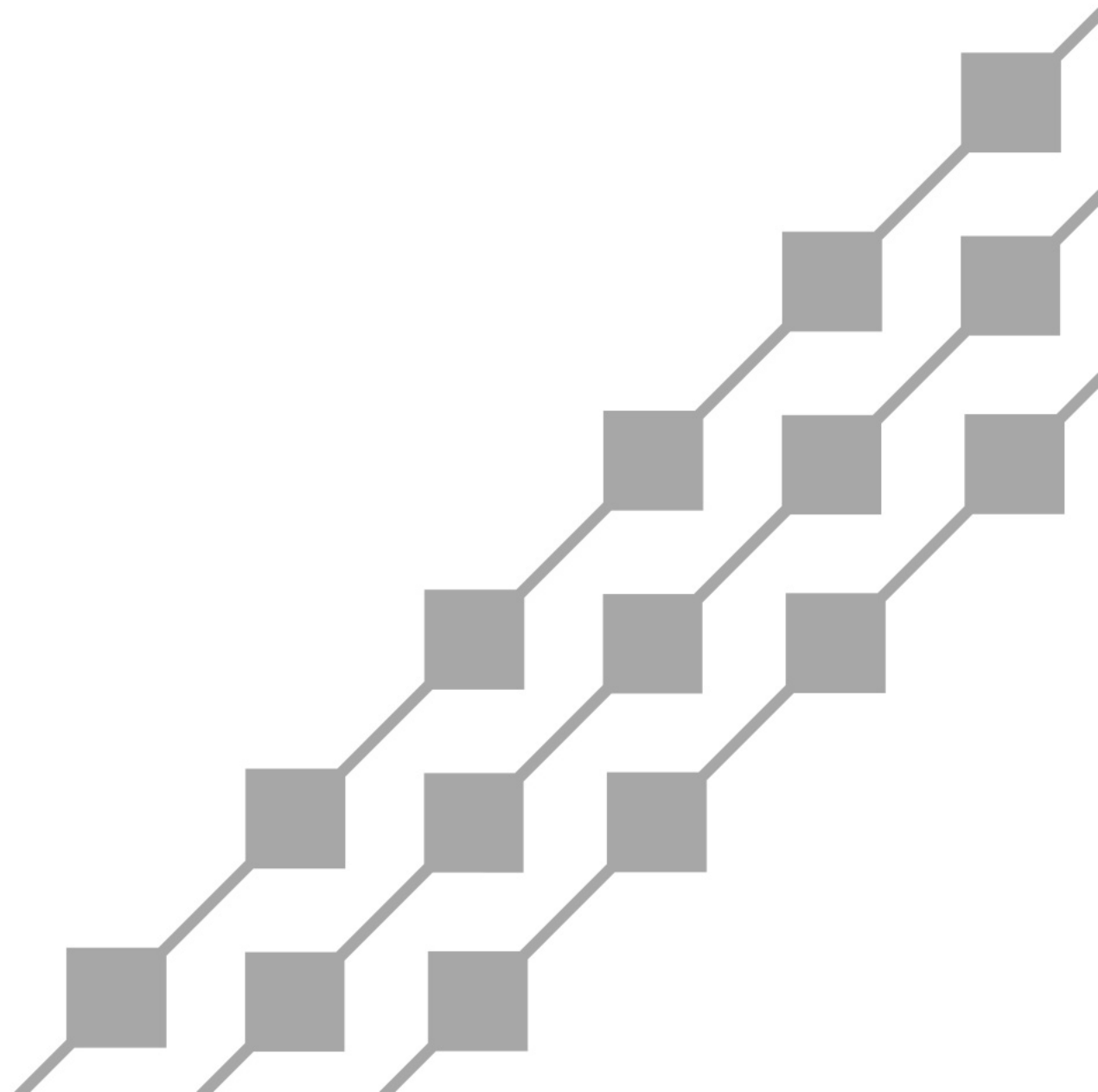
Dynamic Study (Stability Study)

- 

Study Methodology
Simulations & Analyses
Dynamic Study (Stability Study)

- 

Next Steps



Next Steps
Sensitivity Study

- Synchronous Condenser Study
- DER Momentary Cessation Study
- Frequency Response Resource Study
- GFM Oscillation Study (Performed by Electranix)

Next Steps
Sensitivity Study

Study with Starting Point Assumptions

- Whole system scan with PSS/E
- Confirm results with PSCAD
- Identify study objectives

List of worst contingency

- Use PSCAD simulations in sensitivity study

Design Sensitivities

- Obtaining inputs from other departments, align with Company's plan

Perform analyses and confirming Results

- Use longer list of contingency to confirm study results

Next Steps

Sensitivity Study – Synchronous Condenser Study

Study with Starting Point Assumptions

- Whole system scan with PSS/E
- Confirm results with PSCAD
- **Study objectives – identify size requirement to maintain system voltage during fault, avoid DER MC; maintain system stability during distribution fault; identify required delivery time**

List of worst contingency

- Use PSCAD simulations in sensitivity study

Design Sensitivities

- Obtaining inputs from other departments, align with Company's plan **(Locations, unit retirement plan, feasibility of converting retired units or adding SC capability onto machines)**

Perform analyses and confirming Results

- Use longer list of contingency to confirm study results

Next Steps

Sensitivity Study – DER MC Study

Study with Starting Point Assumptions

- Whole system scan with PSS/E
- Confirm results with PSCAD
- **Study objectives – identify DER MC requirement to minimize DER impacts on system stability**

List of worst contingency

- Use PSCAD simulations in sensitivity study

Design Sensitivities

- Obtaining inputs from other departments, align with Company's plan (P1, P2, P3, P4)

Perform analyses and confirming Results

- Use longer list of contingency to confirm study results

Next Steps

Sensitivity Study – Frequency Response Resource Study

Study with Starting Point Assumptions

- Whole system scan with PSS/E
- Confirm results with PSCAD
- **Study objectives – identify frequency response resource adequacy**

List of worst contingency

- Use PSCAD simulations in sensitivity study

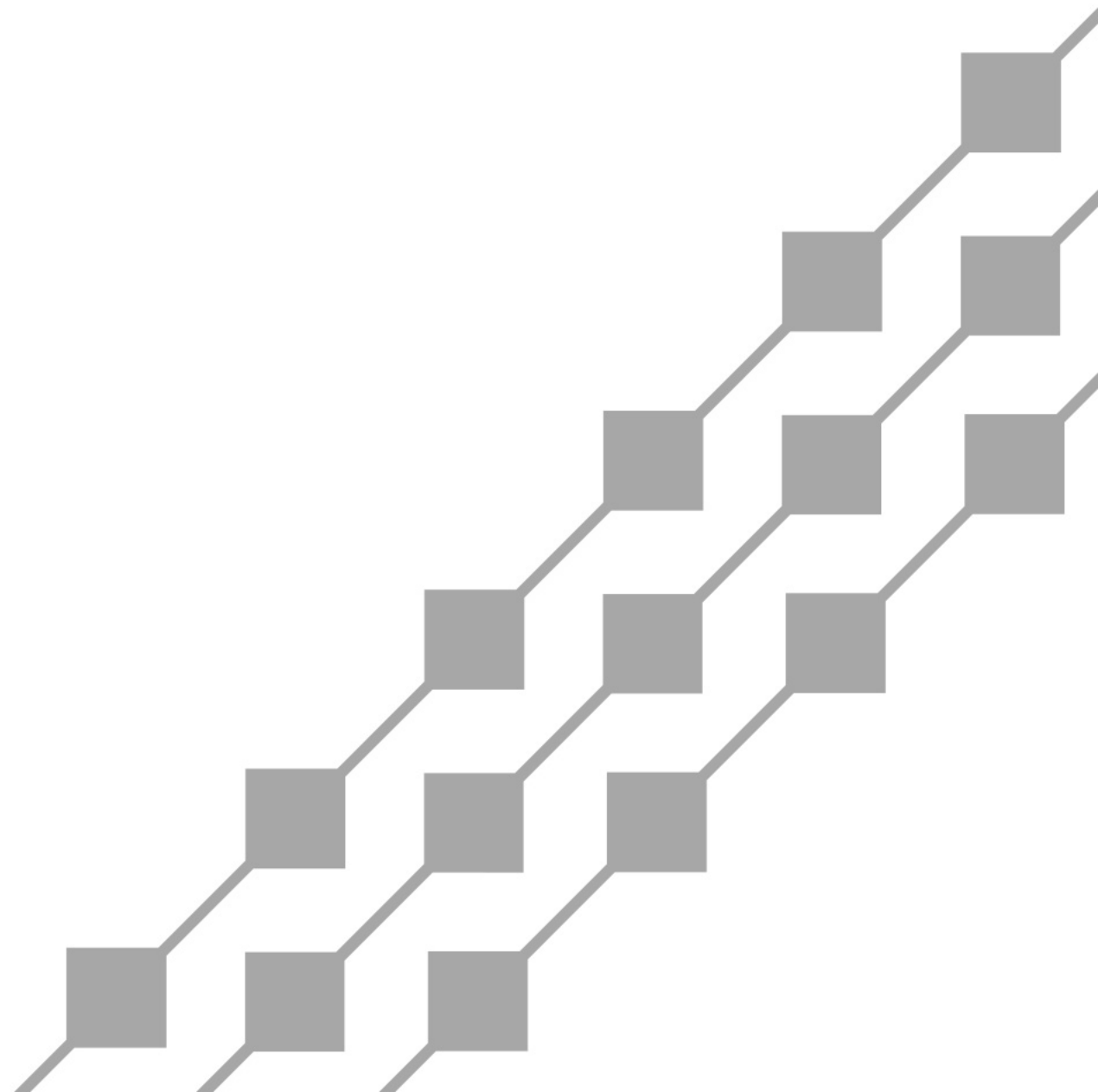
Design Sensitivities

- Obtaining inputs from other departments, align with Company's plan
- **Creating sensitivity about different availability scenarios of FFR and PFR resources**

Perform analyses and confirming Results

- Use longer list of contingency to confirm study results

Questions for TAP



TAP Discussion

- Is the process reasonable? Current system stability study findings reasonable?
- How to consider ROCOF in the study?
- 2022 IGP System Security Study will use the 2021 System Stability Study analyses and results as an inputs. Also plan to use prodsim data based time series analysis (in TARA) to look into system dispatch limitations in steady state analysis. Any comments/advices?
- Will revisit final results with TAP (Target: March 2022).

Mahalo

Questions?