System Restoration: Getting Started with Restoration

Restoration Strategies

Student Guide

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State & Member Training
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Objectives

At the end of this module, the Learner will be able to:

- Describe strategies for system restoration
- Define cranking paths, critical loads and priority loads
- Describe the black start generation requirements
- Describe reporting requirements for PJM

Methods of Restoration

Methods of System Restoration

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Bottom-Up Approach

The Bottom-Up approach to restoration:

- Form islands from black-start generation
- Several variations
- Only method available in a full shutdown with no outside assistance available
- Should be the basis for company restoration plans

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Bottom-Up Approach

The bottom-up restoration strategy includes:

1. Select units to black start
2. Start and stabilize black start units
3. Determine restoration transmission path
4. Begin expanding island(s) by restoring transmission and load
5. Synchronize island(s) when appropriate

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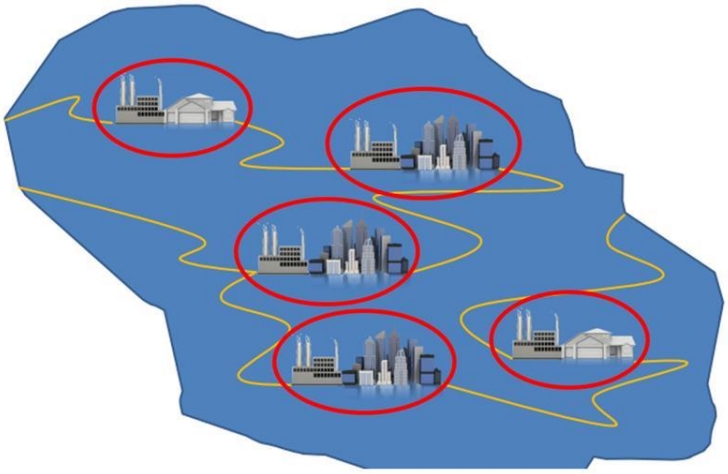
Bottom-Up Approach: Multiple Island Method



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Bottom-up Approach: Multiple Island Method

- **Advantages:**
  - Multiple areas of the system being restored at the same time
  - Faster restart of specific generation
  - If one area blacks out, the other areas are in service
  - Allows for critical load pick-up
  - High series reactance; high voltage drop

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Bottom-up Approach: Multiple Island Method

- **Disadvantages**:
  - More complex
  - Less stability due to smaller islands (larger frequency deviations)
  - Frequency control is area specific (controlled by individual generators)
  - Overall restoration time is longer
  - Reduced fault current for relay operation

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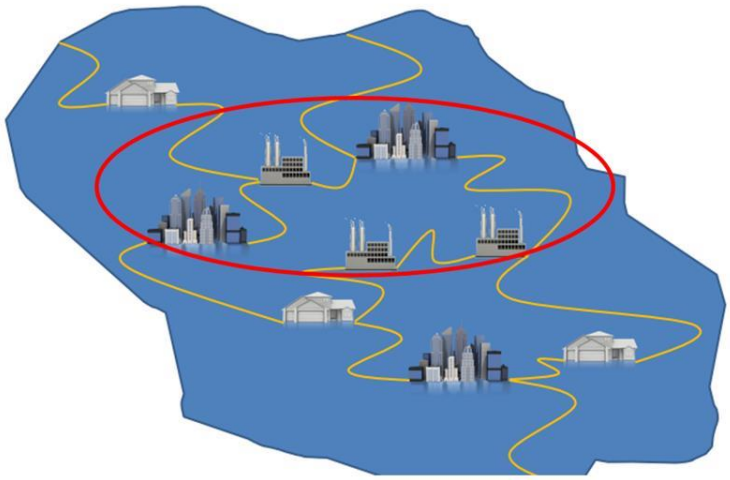
Bottom-up Approach: Core Island Method



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Bottom-up Approach: Core Island Method

- **Advantages:**
  - Larger, more stable island with more generation
  - Focused control and switching
  - Allows for quicker load restoration (based on amount of generation)
  - Quicker interconnection based on stability
  - Overall restoration time is shorter
  - Faster clearing time based on available fault current

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Bottom-up Approach: Core Island Method

- **Disadvantages:**
  - Process starts over if island blacks out
  - Critical load restoration may be delayed if located outside of core island
  - DC power may be expended at stations outside of the core island

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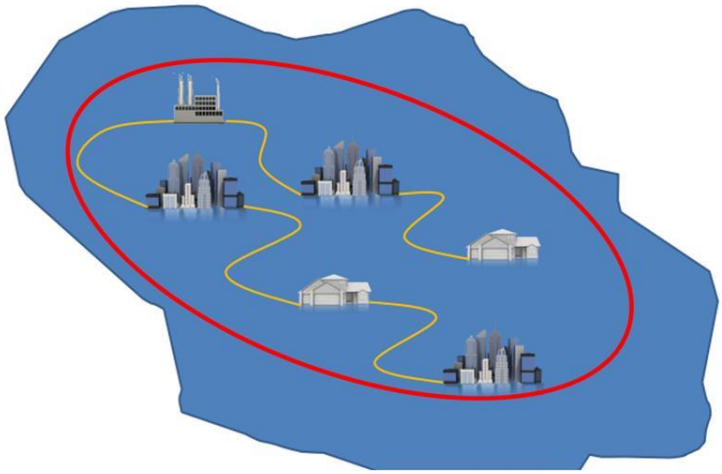
Bottom-up Approach: Backbone Island Method



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Bottom-up Approach: Backbone Island Method

- **Advantages:**
  - Critical load restoration to generating and substation facilities
  - Focused control and switching
  - Allows for outside assistance

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Bottom-up Approach: Backbone Island Method

- **Disadvantages:**
  - Over-voltage conditions due to excess line charging
  - Instability issues due to limited generation and less transmission networking
  - Delay in critical load restoration

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Top-Down Approach

The top-down restoration strategy includes:

1. Restore backbone transmission system, usually from outside assistance
2. Restore critical generating station and substation load
3. Bring on more generation
4. Restore underlying transmission system
5. Continue restoring load

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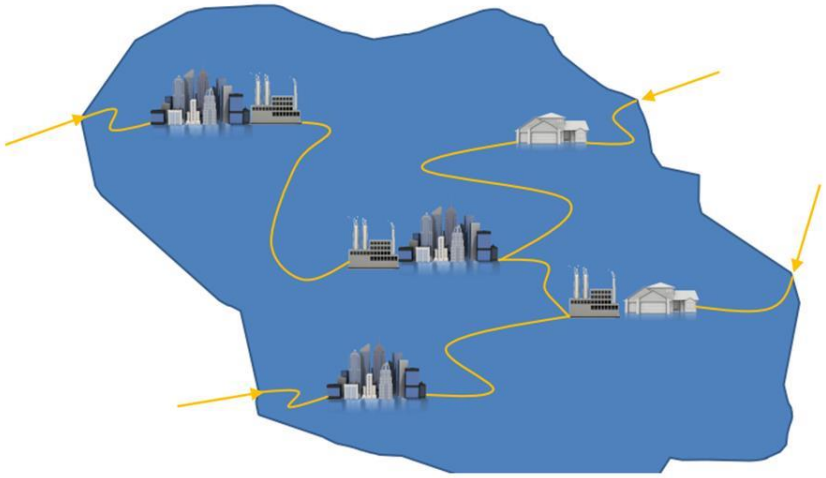
Top-Down Approach



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Top-Down Approach

- **Advantages:**
  - Quicker critical load restoration
  - Parallel restoration of areas within the system
  - Stability
  - Synchronization not required

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Top-Down Approach

- **Disadvantages:**
  - Over-voltage conditions due to excess line charging
  - Reliant on neighboring entities
  - Transmission constraints

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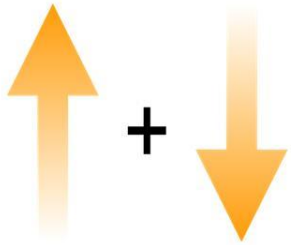
Combination Approach

Combines the **Bottom-up** and **Top-down** Approach

- Includes:
  - Restoring transmission from an outside source, at the same time as building "islands" of generation
  - Interconnecting "islands" with each other or outside source when able



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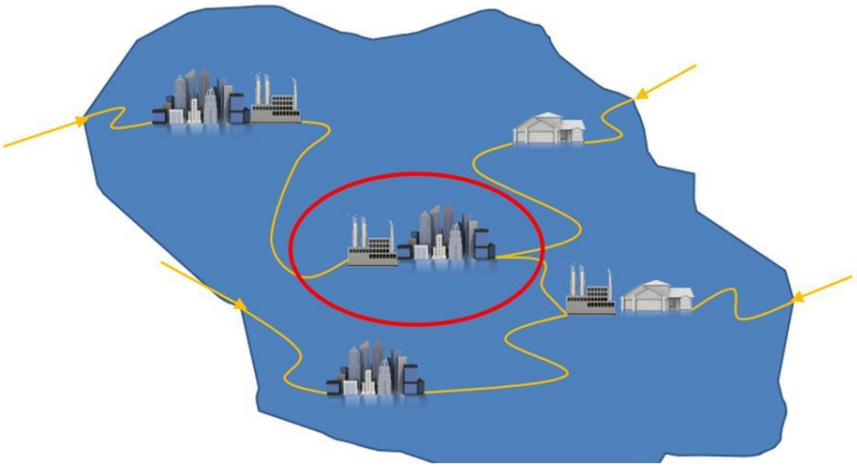
Combination Approach



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Combination Approach

- **Advantages:**
  - Quickest timeframe for restoring power to critical loads
  - Parallel restoration of areas within the system
  - Stability based on load connected outside of area

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Combination Approach

- **Disadvantages:**
  - Over-voltages due to excess line charging
  - Reliant on neighboring entities
  - Requires synchronization of multiple areas
  - Complex control and switching

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Selection of a Restoration Method

- Restoration method chosen depends on:
  - Extent of blackout
  - Availability of outside assistance
  - Availability of internal black-start generation
- Company restoration plans are based on worst case scenario and must be approved by PJM

When *deviating* from approved restoration plan, **communication must occur** between the TO and PJM

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Choosing a Restoration Method Exercise

1. **Your system has suffered a disturbance involving multiple transmission trippings. The disturbance has left several blacked out "pockets" or "holes" in your system. Each pocket contains a large steam generation unit, but no CTs or hydro units. Though your system suffered a loss of load during this event, the portion of the system remaining is very stable.**

   Which is the best restoration strategy to be applied? _____

2. **Your system has suffered a complete blackout. You receive information that your neighboring systems are also blacked out. Your system consists of several large load centers with black-start capable CTs available in each load center. These load centers are connected to each other by very long transmission lines.**

   Which is the best restoration strategy to be applied? _____

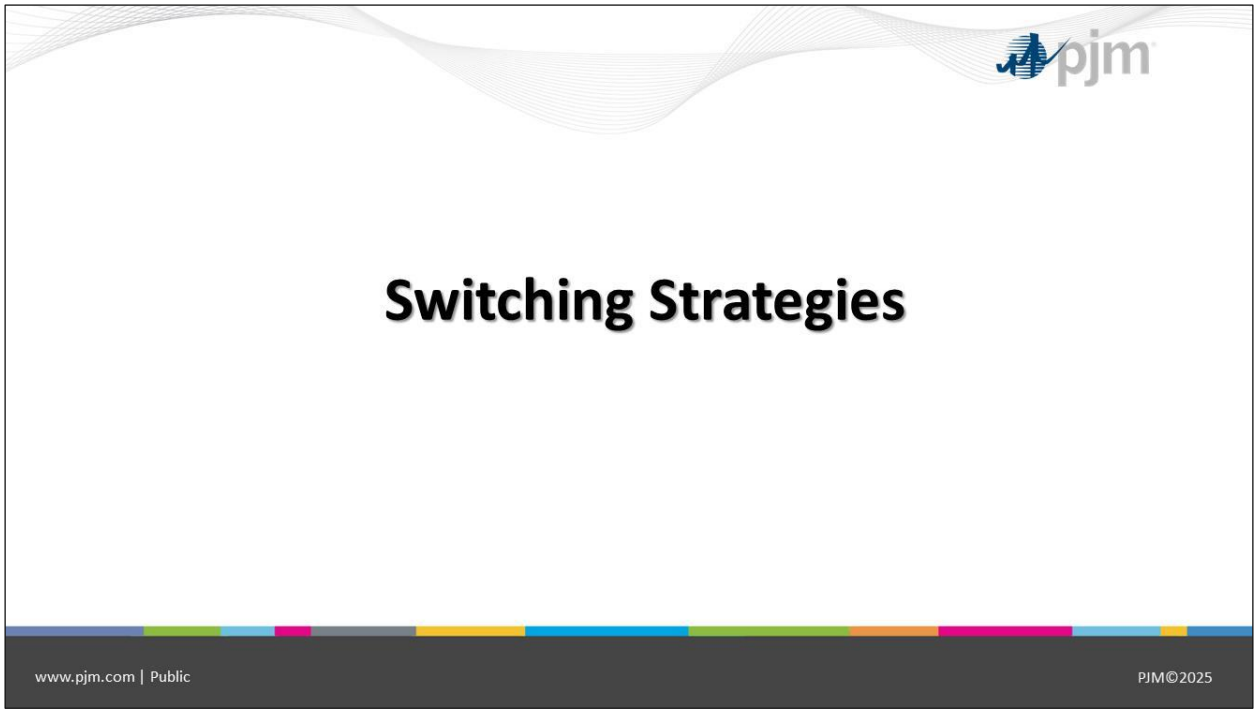
3. **Your system has suffered a complete blackout. You receive information that your neighboring systems are unaffected and still connected to the Eastern Interconnection. You have a very large system with a critical load center including a nuclear plant in the electrical center of your system. You have black-start capable generation strategically placed throughout your system.**

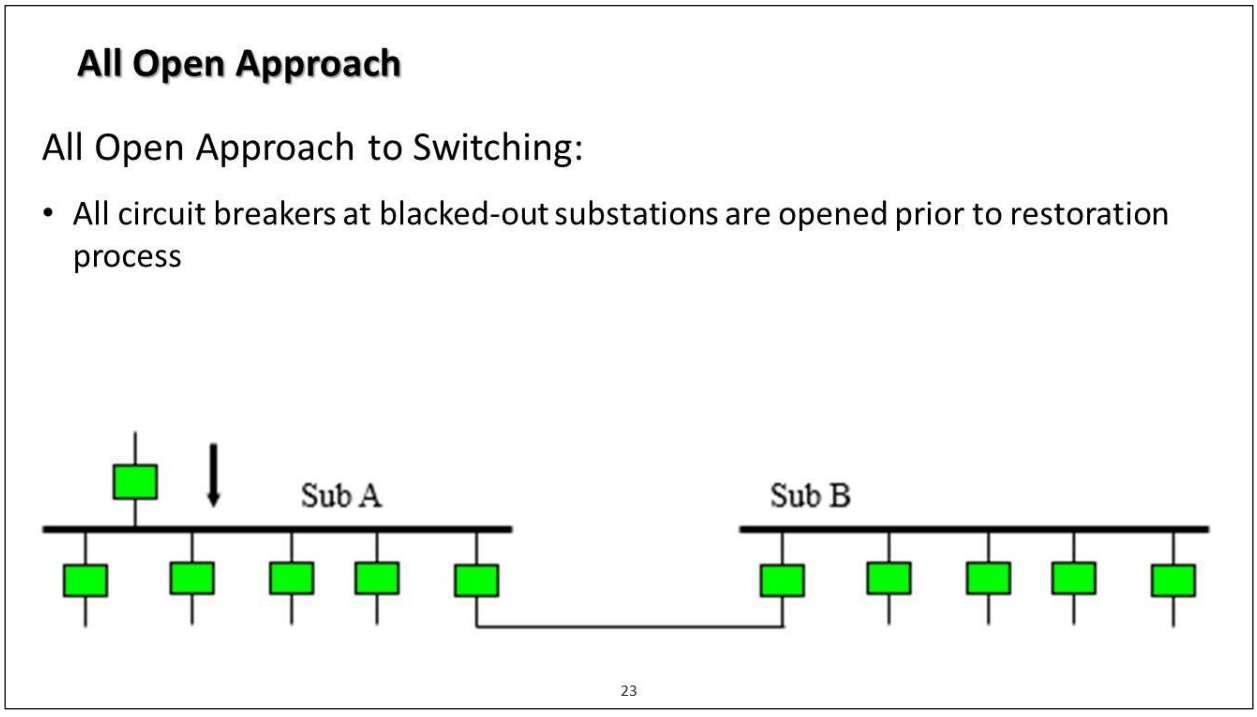
   Which is the best restoration strategy to be applied? _____

4. **Your system has suffered a complete blackout. You receive information that your neighboring systems are also blacked out. Your system consists of a large load center in the electrical center of the system with small pockets of rural load covering a large physical area. Most of your generating resources are located in the large load center.**

   Which is the best restoration strategy to be applied? _____

Switching Strategies





All Open Approach

- **Advantages**:
  - Simpler and safer configuration to re-energize
    - Inadvertent load pick-up less likely
    - Only breakers involved in restoration process need to be closed

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All Open Approach

- **Disadvantages**:
  - Longer restoration time
  - More stored energy required for greater number of breaker operations
    - Compressed air or gas, springs, station battery
    - Breakers should be capable of one open-close-open operation without AC station service

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Controlled Open Approach

Controlled Operation Approach to Switching:

- Only those circuit breakers necessary to allow system restoration to proceed are opened

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Controlled Open Approach

- **Advantages**:
  - Less stored energy requirements
    - Breakers not involved in the initial sectionalization and restoration remain closed
    - Some breaker operations may not be needed until after station service is re-established

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Controlled Open Approach

- **Disadvantages**:
  - Dispatcher must be continually aware of boundary between restored and de-energized systems
    - Switching process becomes more complex
    - Possibility of system shutdown due to inadvertent load pickup is increased

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System Sectionalizing

- **System Sectionalizing**
  - Disconnect load and capacitors from system prior to energization
  - Use reactors to prevent high voltage
  - Review transformer tap positions prior to energization
  - Generator voltage regulators should be in service
  - Protective relaying on all equipment should be in service

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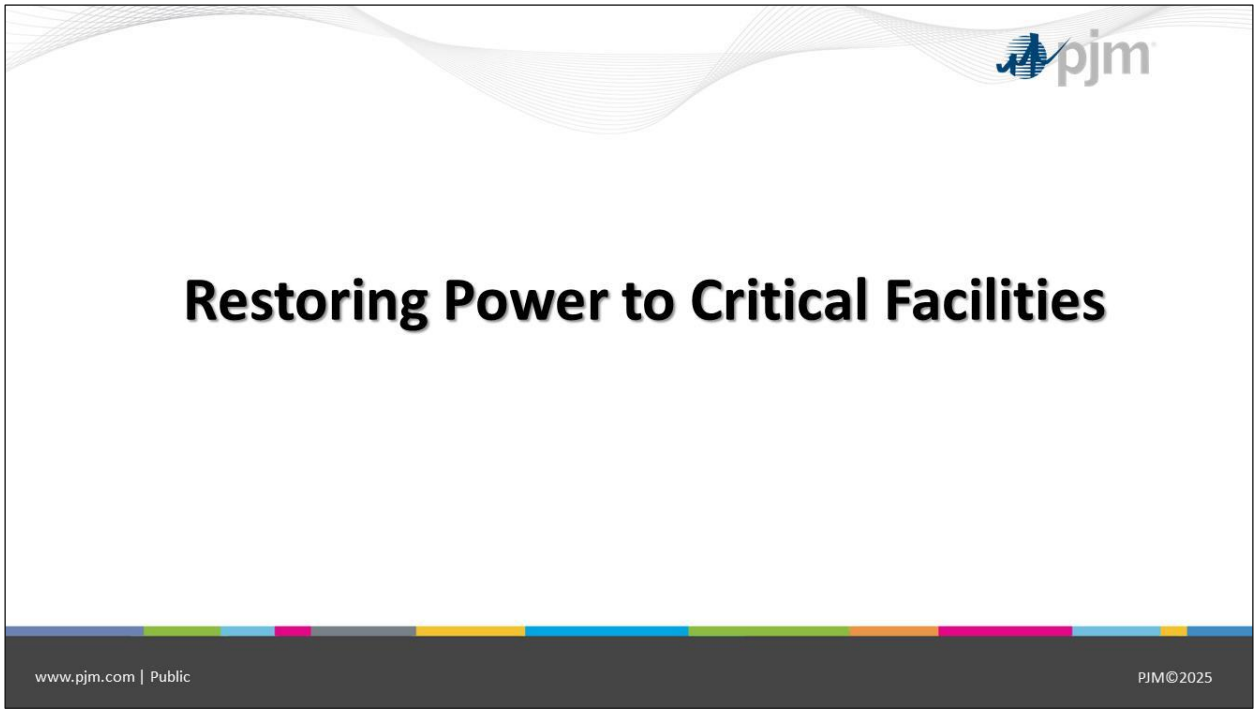
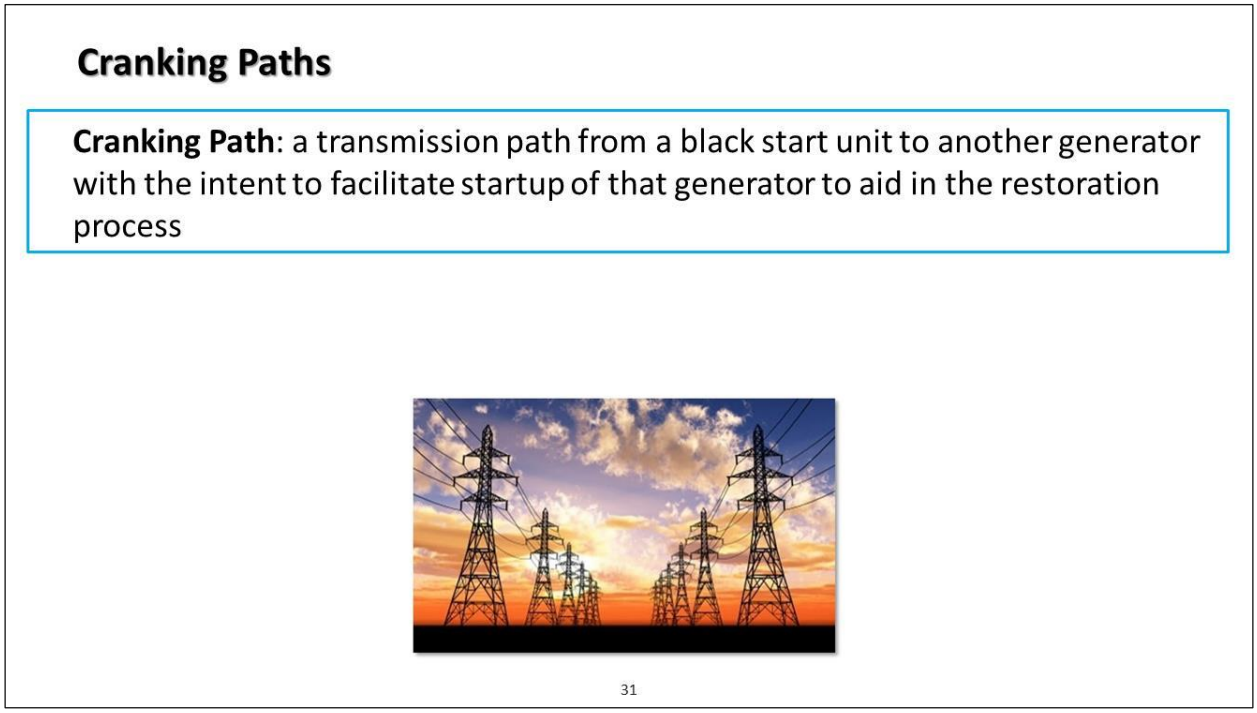
Restoring Power to Critical Facilities





Cranking Paths

- Types of cranking paths:
  - Critical Restoration Paths
    - *Nuclear*: provides off-site power to a nuclear plant's auxiliary equipment to allow the nuclear plant to maintain a safe shutdown
    - *Load*: restores load that is identified as critical
  - Non-Critical Restoration Paths
    - Restores non-critical, or priority loads or facilities, as identified within the restoration plan

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Critical Load Restoration

- Critical loads are defined by PJM
- Minimum Critical Load Requirements for each transmission zone consists of:
  - Cranking power load to units with a **"hot" start-up time of 4 hours or less**
  - Off-site nuclear station light and power
    - Including units off-line prior to disturbance to maintain a safe shutdown
    - One feed into each facility
  - Critical gas infrastructure
    - Key in quick restoration of critical steam units

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Priority Load Restoration

- Priority load provided by black start or other generation
  - Nuclear Station Auxiliary Power (2nd feed)
  - Cranking power to generation with a start time greater than 4 hours
  - Power to electric infrastructure
    - Light and power to substations
    - Pumping plants for underground cable systems
  - Communication equipment
  - Command and control facilities
  - Under-frequency load shed circuits

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Load Restoration

Nuclear Station Auxiliary Power (Priority Load)

- Emergency on-site generators provide for safe shutdown, only
- To facilitate a restart:
  - Two independent off-site power sources
  - Stable voltages and frequency
  - No damage to unit

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Load Restoration

Substation light & power required for:

SF6 Circuit Breakers (heaters & compressor)	*Battery Chargers*
	

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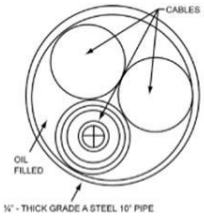
Load Restoration

Pipe-Type Cable Installations

- With no power at pumping plants, there is risk of immediate electrical failure or damage to cable upon re-energization
- Locations of pipe-type cable installations and pumping plants should be known by dispatchers
- Pressures should be verified prior to re-energization if cable and pumping plants have been off



Cross-Sectional View of 345kV Pipe-Type Cable

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Load Restoration

Priority Customer Load

- Circuits with load identified by company
  - Governmental, military facilities
  - Medical facilities
  - Public health (water, sewage pumping stations)
  - Public communications (TV, radio)
  - Communication facilities (phone)
  - Law enforcement (police, fire)

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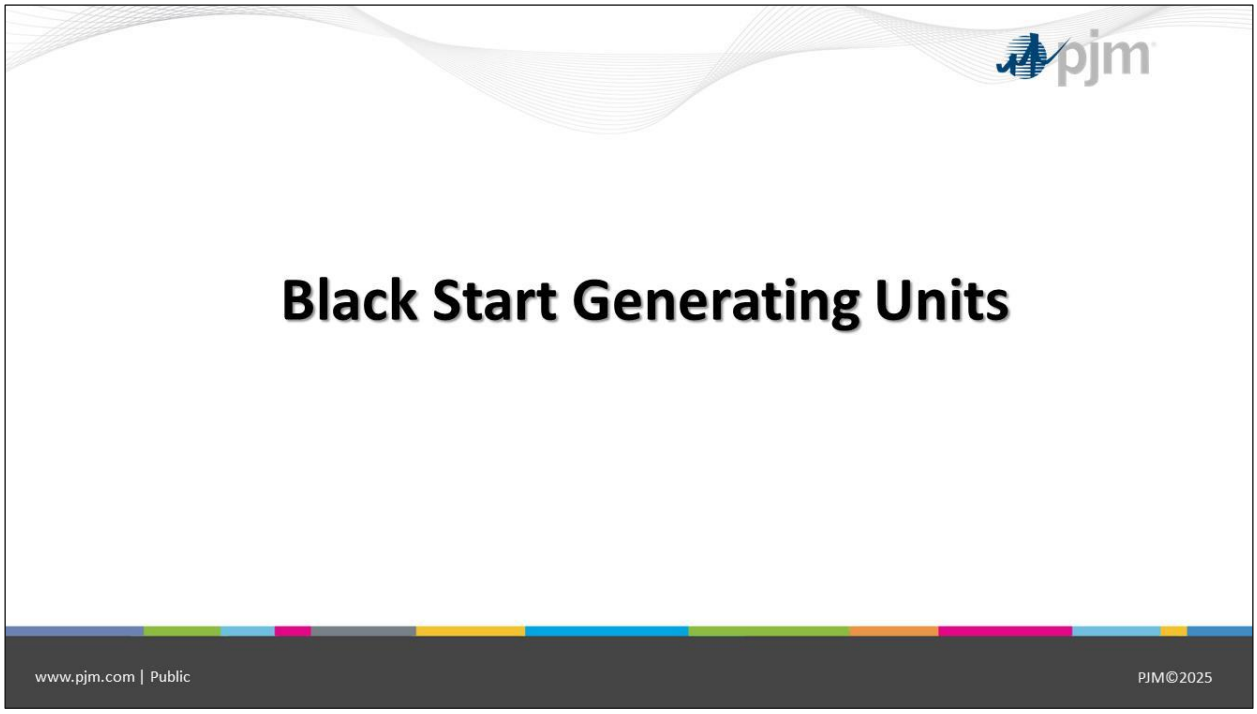
Black Start Generating Units



Black Start Generating Units

Black Start Unit: a generating unit that has equipment enabling it to start without an outside electrical supply or a unit with the demonstrated ability to automatically remain operating, at reduced levels, when disconnected from the grid

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NERC Requirements for Critical Black Start (EOP-005)

- Each GOP:
  - Shall participate in the RC's restoration drills, exercises, or simulations as requested by the Reliability Coordinator
  - With a black start resource shall:
    - Have documented procedures for starting each one and energizing a bus
    - Notify its TOP of any known changes to the capabilities of that black start resource affecting the ability to meet the TOP's restoration plan within 24 hours following such change
    - Provide a minimum of two hours of training every two calendar years to each of its operating personnel responsible for the startup of its black start resource
      - Training shall include a review of the applicable restoration plan and coordination with the TOP
    - Test the capability of the resource to perform

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NERC Requirements for Critical Black Start (EOP-005)

- Each TOP:
  - Shall have a restoration plan, approved by its RC, that identifies each black start resource, their characteristics, and associated cranking paths/switching requirements
  - Shall have black start resource testing requirements to verify that each black start resource is capable of meeting the requirements of its restoration plan

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PJM Requirements for Black Start

- Must be tested annually
  - Unit can self-start when requested from a "blackout" state without any outside source of power
  - Personnel are familiar with up-to-date procedures
  - Close unit onto a dead bus within 3 hours of the request
  - Run for 16 hours, or as defined by TO restoration plan
    - GOs must notify PJM and the TO if a critical black start fuel resource at max output falls below 10 hours
  - Maintain frequency and voltage under varying load

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PJM Requirements for Black Start

- Exceptions or additions to the PJM black start requirements will be allowed, with PJM approval:
  - Coping power needs for steam units that cannot be supplied by resources other than black start
  - Exceptions to critical cranking power are made for intermittent generation (i.e., wind, solar)
  - Exception to critical cranking power will be considered on a case by case basis for:
    - Complex cranking paths for minimum ICAP gain
    - Non-dispatchable unit or units with very high minimum limits

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Amount of Black Start Required

Required Black Start = 110% (Critical Load requirement) on a locational basis

- At least 2 black start resources per transmission zone
  - PJM allocated
  - Cross zonal coordination is possible

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Fuel Assured Black Start Units

Fuel Assured Black Start Units
Fuel Storage of 16+ hours
Multiple interstate pipeline connections
Gas supply basin / Gathering system ahead of interstate pipeline

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Fuel Assured Black Start Units

Hydro/Intermittent/Hybrid Resources

16 hours at a 90% confidence MW output	• Calculate the MWh for each hour of the day • Sum the hours with MWh ≥ assumed black start MW for each day • Each day with the sum ≥ 16 is a 1; less than 16 is a 0 • Yearly confidence level is: – A simple average – Calculated using ELCC weather-weighted average to find unit specific confidence levels

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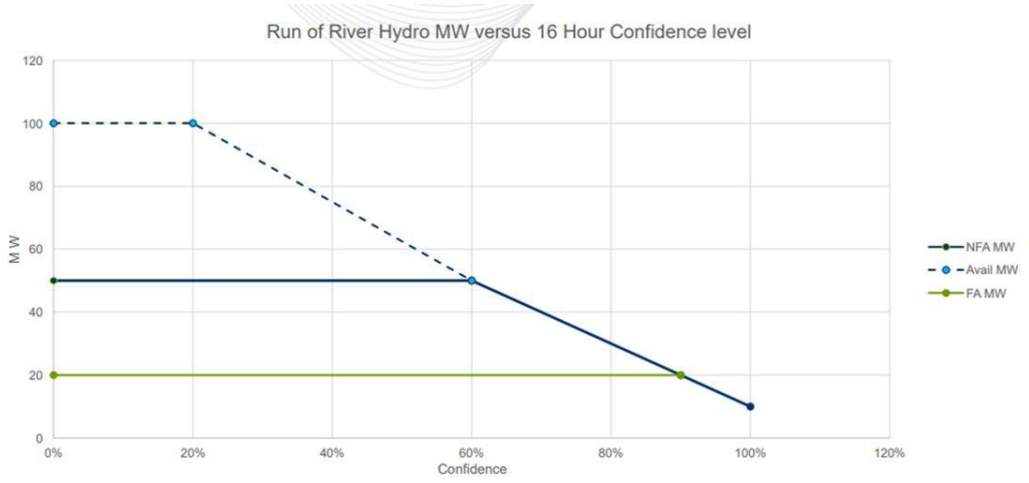
Fuel Assured Black Start Units



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Black Start Unit Procurement - PJM Responsibilities

- In its roles as Transmission Operator (TOP), PJM is responsible for selecting the black start resources for a system restoration plan
- Would work closely with the TOs to identify these units based on:
  - Critical Load requirements
  - Available black start resources
  - Minimum number of black start resources allocated to a zone
  - Possible cross zonal opportunities

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Black Start Unit Procurement - PJM Responsibilities

- Utilize the start time parameters and test data to evaluate the black start resources and whether these resources will meet the requirements of the restoration plans
  - May require some black start resources to adhere to less than a 3-hour start time given critical load restoration timing requirements
    - These units will be notified of this timing requirement and tests to it during annual black start testing
  - Recognizes that black start resources with 3-hour start times may not be appropriate to meet nuclear power off-site safe-shutdown load restoration requirements
    - The target restoration time for off-site power to nuclear stations is 4 hours

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Black Start Unit Procurement - PJM Responsibilities

- In collaboration with the TOs, will select black start units to meet critical load requirements during the 5-year black start selection process described in PJM Manual 14D: Generator Operational Requirements
- Will utilize the black start replacement process, as described in M-14D, for changes to black start availability or critical load requirements that occur within the 5-year period

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Black Start Unit Procurement - Member Responsibilities

- Adjust their system restoration plan based on the black start units allocated to it from this selection process
- Has the option of procuring additional black start resources
  - Cost will be on the TO
- Under frequency islanding schemes and load rejection schemes
  - Can be used in conjunction with black start
- Disputes or disagreements
  - SOS-T consultation → Dispute Resolution Process

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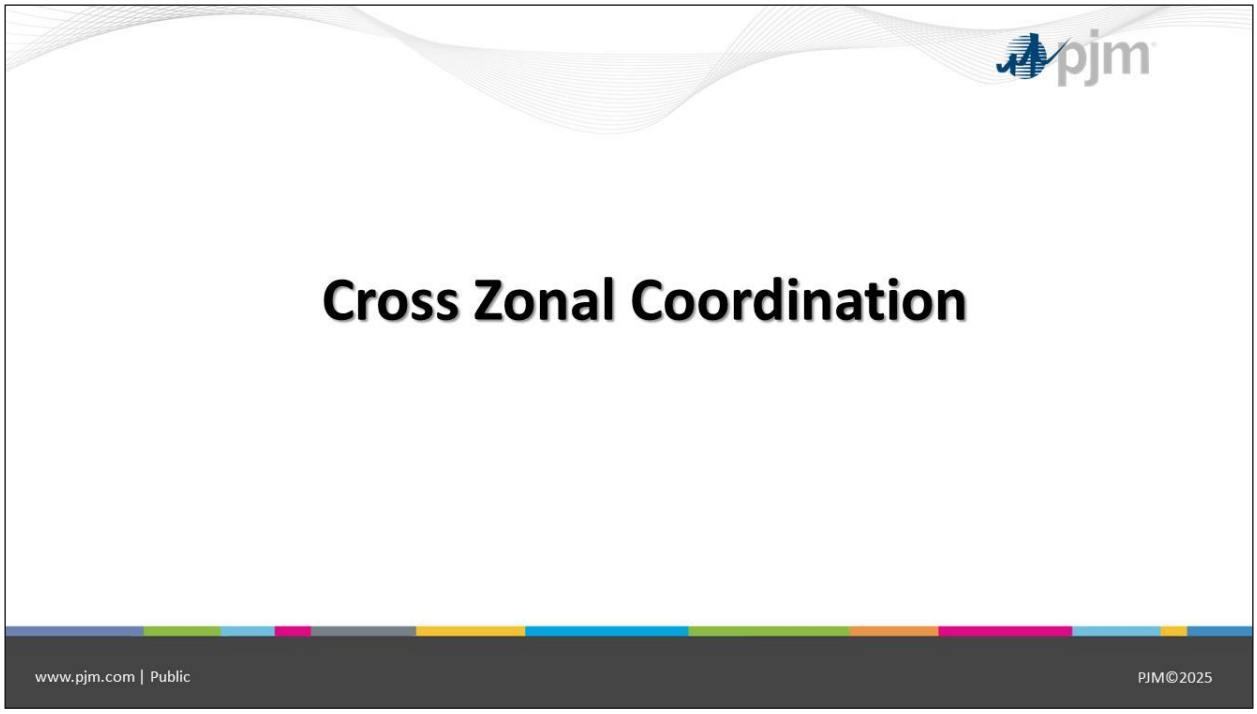
Cross Zonal Coordination



Cross Zonal Coordination

Cross Zonal Coordination is a process where PJM and the member company Transmission Owners identify areas within the RTO where it would be beneficial to coordinate individual TO restoration plans.

- Reliability Requirements:
  - Critical load
  - Restoration timing
  - Redundancy
- Efficiency Opportunities:
  - Speed of restoration
  - Cost savings

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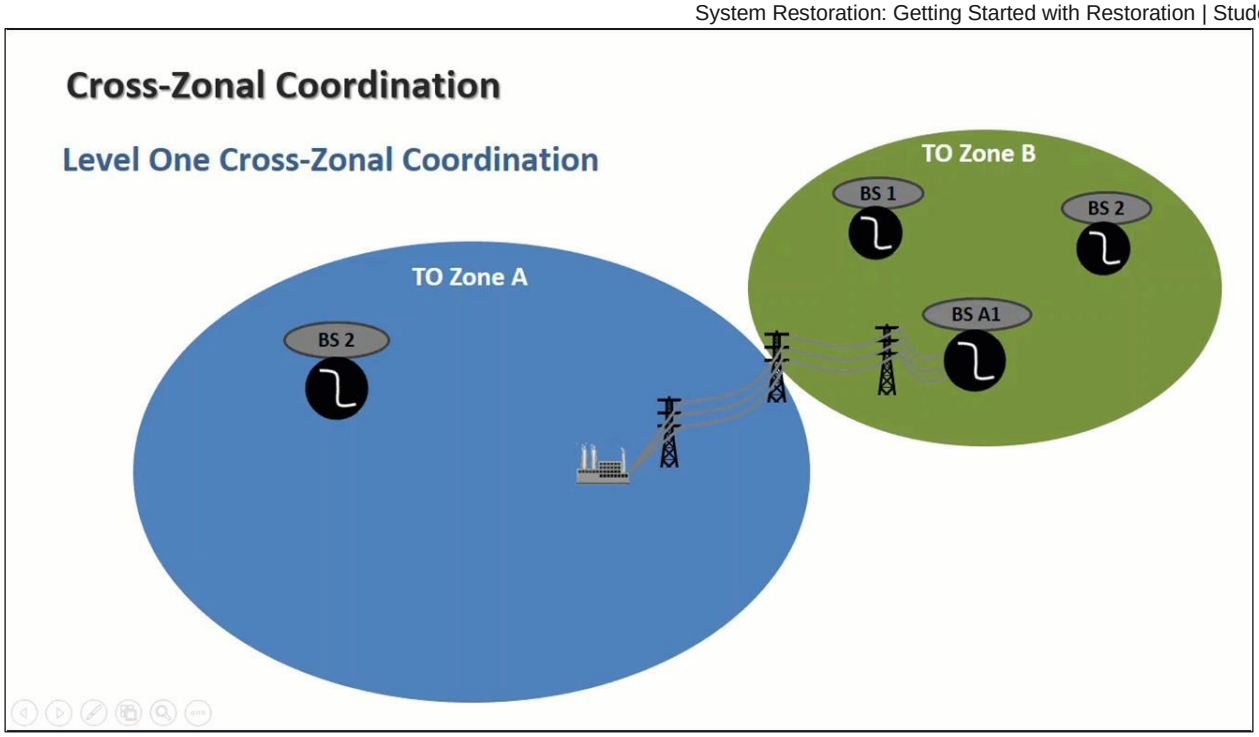
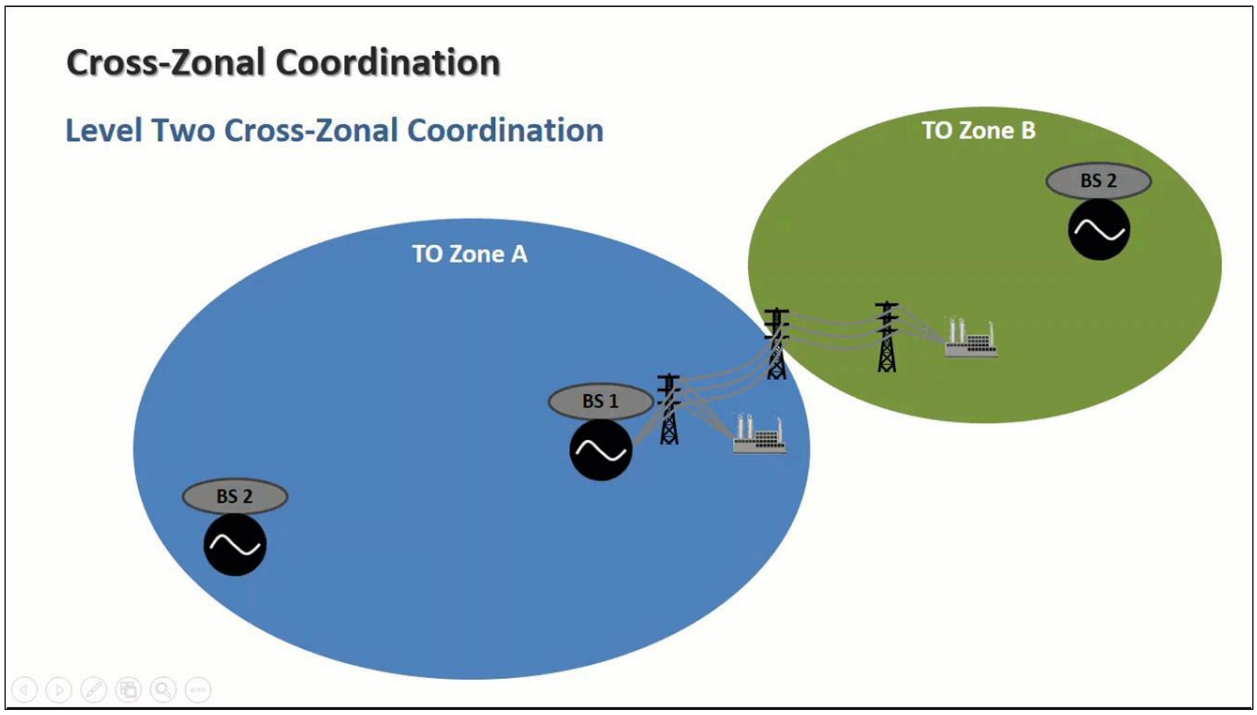
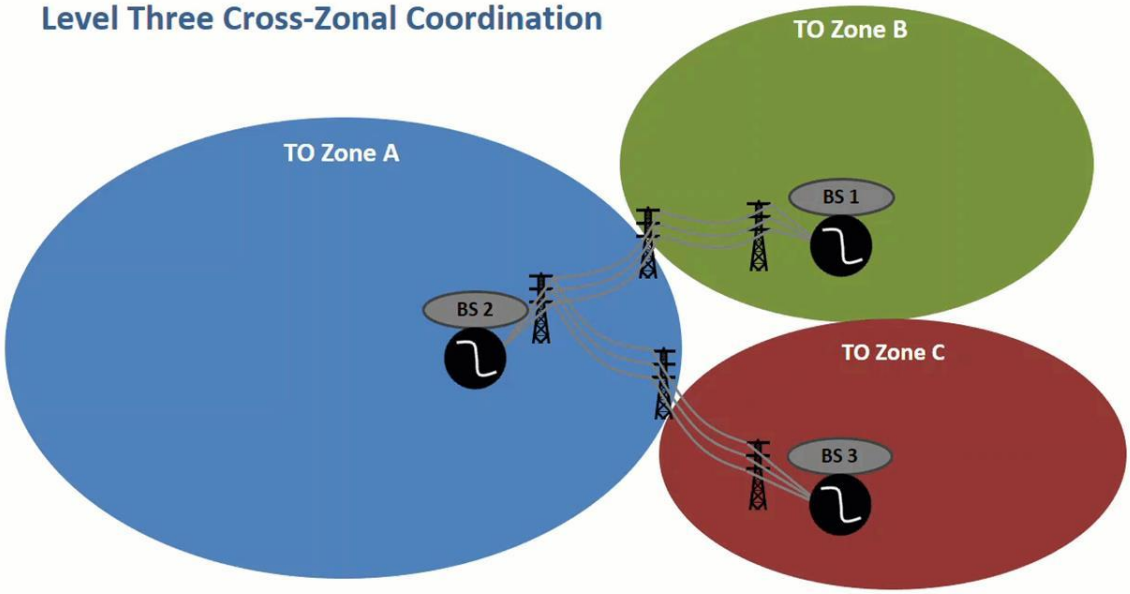

Cross-Zonal Coordination
Level One Cross-Zonal Coordination
TO Zone B
BS 1
BS 2
BS A1
TO Zone A
BS 2


Cross-Zonal Coordination
Level Two Cross-Zonal Coordination
TO Zone B
BS 2
TO Zone A
BS 1
BS 2

Cross-Zonal Coordination

Level Three Cross-Zonal Coordination



Cross Zonal Coordination

- Technical Feasibility Requirements:
  - Maintaining voltages within limits
  - Maintaining MW flows within thermal limits
  - Maintaining dynamic stability of generation
  - Timing requirements of serving critical load
  - Test history and performance history of each black start resource

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Cross Zonal Coordination

- Complexity Considerations:
  - Amount of switching to establish each cranking path
    - Characteristics of cranking path (length, geography, travel time, number of substations, voltage level)
    - Staffing availability (field/control room) to support building cranking path to neighboring area

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Cross Zonal Coordination

- SCADA versus Manual control:
  - Logistical coordination
    - Adjacent TO zones only (do not cross 3 or more zones)
    - Type of load restored in each TO zone
    - Potential additional TO costs incurred to enable cross zonal coordination
    - Number of TO zones in coordination with a single TO zone
- TO/State relationship considerations
  - Restoration priority to remain local

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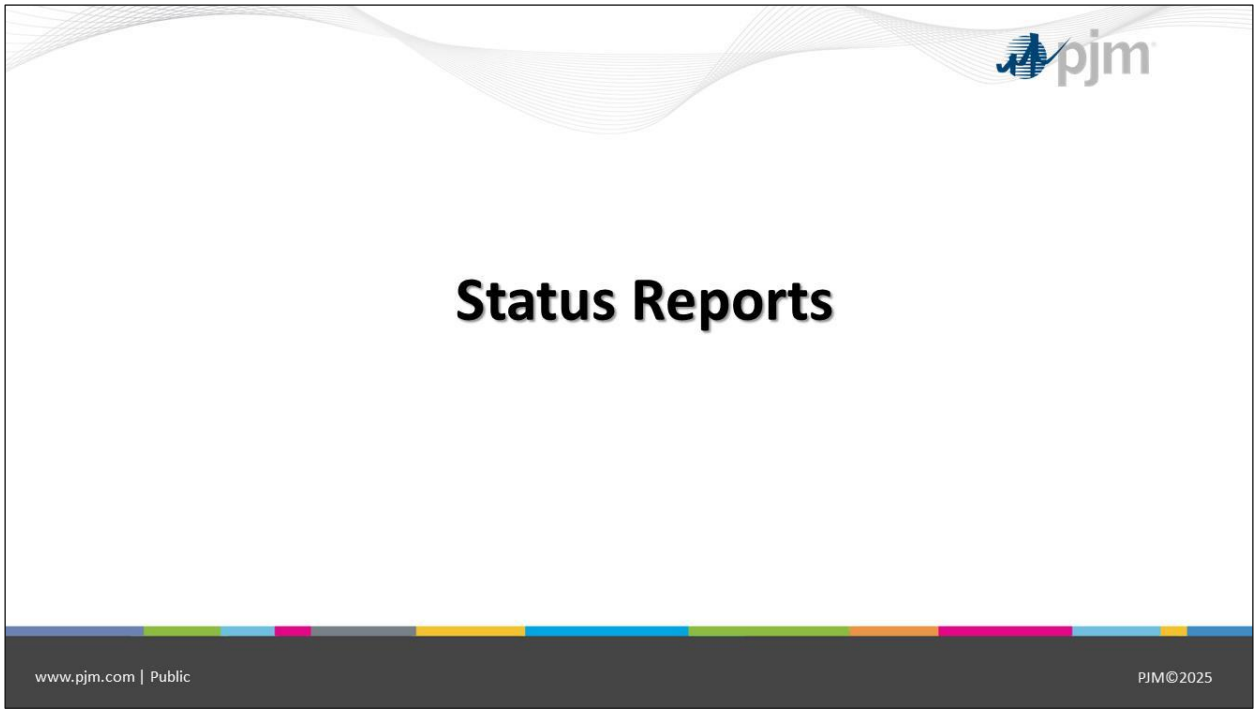
Status Reports



Company Hourly Restoration Report *

Date:			Time:		
Reporting Company:					
Transmission Zone:					
Company Contact:			Estimated Time to Complete Total Restoration: Date: Time:		
During drills, submit forms to RestorationDrillGeneration@pjm.com. If no changes since last report submitted, report is not required					
GENERATION REPORT:	**MW**		**LOAD RESTORATION REPORT:**		**MW**
Generation: Capacity on Line			Total Customer Load Restored		
Generation: Energy on Line			# Of Customers Restored (000)		
# Of Generators on Line			% Customers Restored		
# Of Subsystems (Islands)			% Customers Restored Last Hour		
CAPACITY DUE IN:					
Generation in One Hour (1)					
Generation in Three Hours (3)					
Generation in six Hours (6)					

UNITS ON LINE SINCE LAST REPORT					
Station	**Unit**	**MW**	**Station**	**Unit**	**MW**

UNITS EXPECTED DURING NEXT HOUR					
Station	**Unit**	**MW**	**Station**	**Unit**	**MW**

Damage detected since last report / comments:

CRANKING POWER					
From Company to Station	**kV**	**Time**	**From Company to Station**	**kV**	**Time**

Company Transmission Restoration Report

	Date:		Time:			
	Reporting Company:					
	Company Contact:					
	This report should be submitted every 10 lines restored or 30 minutes. During drills, reports may be emailed to RestorationDrillTransmission@pjm.com If no changes since the last report, no report is required.					
	EXAMPLE DATA					
ID	**Facility Identification**	**Voltage Level**	**Date Restored**	**Time Restored**	**Energized since Last Report (?)**	**Expected in Next Hour (?)**
5003	Keystone – Conemaugh		01/01/00	0800	X	
5004	Key stone – Juniata					X
ID	**Facility Identification**	**Voltage Level**	**Date Restored**	**Time Restored**	**Energized since Last Report (?)**	**Expected in Next Hour (?)**

PJM Composite Hourly Restoration Report

PJM COMPOSITE HOURLY RESTORATION REPORT

Operator: [redacted] Date: Time: HRs [redacted]

Generation Data by transmission Zone

Company Report Time:																								PJM
Company:	RECO	PS	PE	AE	DPL	PL	UGI	JC	ME	PN	BC	PEP	SMECO	DOM	PLS	DLCO	DAY	AEP	Rockville	COM	PEW	CPP	BROK	BKPC	Total
Generation Lost Capacity (MW)																									
Generation still Operating Capacity (MW)																									
Generation still Operating Energy (MW)																									
# of Generators on Line																									
# of Subsystems																									

Load Data by Transmission Zone

Company Report Time:																								PJM
Company:	RECO	PS	PE	AE	DPL	PL	UGI	JC	ME	PN	BC	PEP	SMECO	DOM	PLS	DLCO	DAY	AEP	Rockville	COM	PEW	CPP	BROK	BKPC	Total
Customer Restored MW																									
% of Customer Restored																									
# of Customer Restored																									
% of BES Restored																									
Estimate for Total Restoration (Date/Time)																									

PJM Damage Summary Since Last Report:

Comments:

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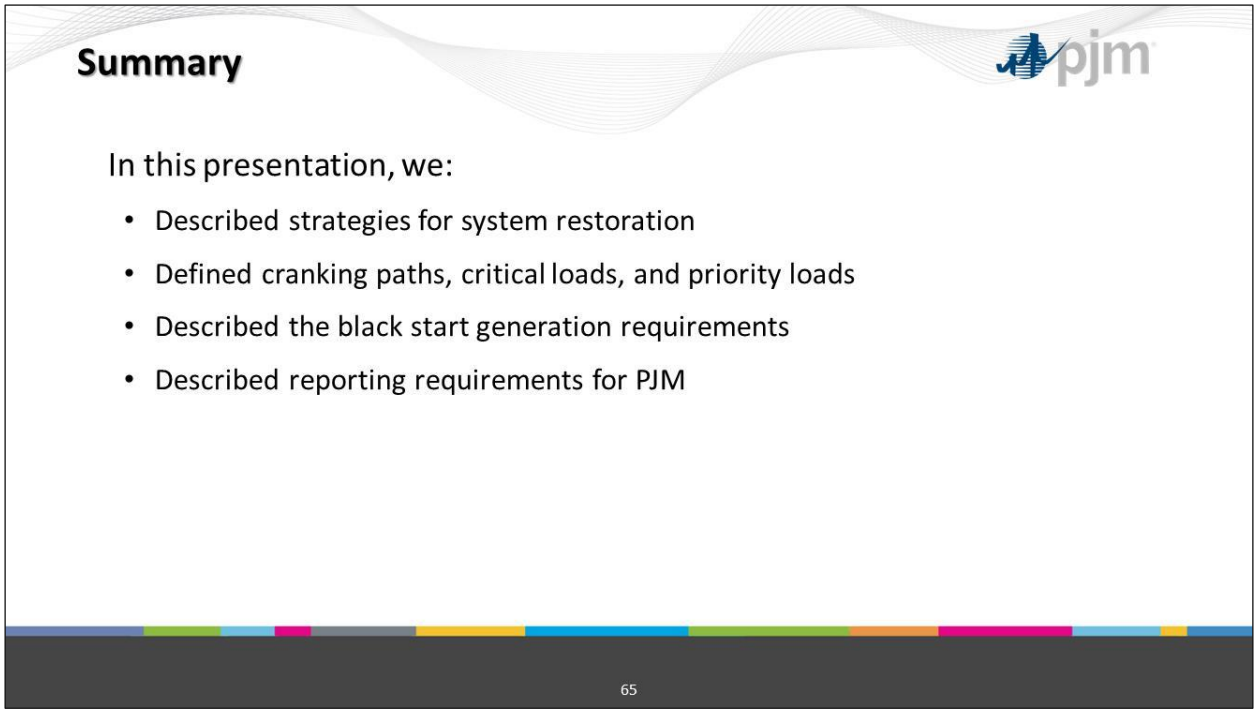
Summary



Questions?

PJM Client Management & Services	
Telephone:	(610) 666-8980
Toll Free Telephone:	(866) 400-8980
Website:	www.PJM.com
Email:	trainingsupport@pjm.com

Member Community

The Member Community is PJM's self-service portal for members to search for answers to their questions or to track and/or open cases with Client Management & Services