System Restoration: The Restoration Process

Load Pickup & Frequency Control

Student Guide

Prepared by:
State & Member Training

Table of Contents

Objectives

- Describe the effects load pickup has on frequency
- Identify the purpose of synchronized and dynamic reserves during the restoration process
- Describe the criteria that has to be met in order to synchronize two islands
- Explain how to coordinate frequency and tie line control within interconnected systems
- Identify the minimum source guidelines for restoration
- Identify the criteria for transferring control back to PJM

Load Pickup

Coordinating Load Pickup

Transmission Restoration

- 90% - 105% of nominal voltage
- Where possible, maintain voltages at the minimum possible levels to reduce charging current
- Restore load to reduce voltages:
  - Station light and power/auxiliary load
  - Shunt reactors/transformer excitation
  - Critical customer load
  - Generators/Synchronous condensers operating in the lead

Transmission Restoration

- Shunt capacitors are removed until sufficient load (40%) has been restored to prevent high voltage
- Shunt reactors in service
- The following devices operating in the lead:
  - Automatic Static VAR Compensators (SVCs)
  - Automatic Voltage Regulators on generators (AVRs)

3

Load Restoration

Frequency Control: 59.75 Hz — 60.5 Hz

Load Restoration: 60.0 Hz — 60.5 Hz

Manual Load Shed: 6-10% load shed → 1 Hz rise

4

Load Restoration

Frequency Control

- Restore load in small increments to minimize impact on frequency
  - Maintain > 59.90 Hz
- Do not restore blocks of load that exceed 5% of the total synchronized generating capability

Example:
If you have 1000 MW of generating capacity synchronized on the system, restore *no more than 50 MW of load* at one time.

5

Load Restoration

Frequency Control

- To estimate a change in frequency due to a change in load prior to adding the block of load, use the following equation:
  - Frequency Change = (Load Change/Connected Capacity) x (Governor Droop, in Hz)
  - New Frequency = (Frequency Prior to Load Pick-up – Frequency Change)

6

Load Restoration

Frequency Control Example

- Restore 100 MW of load with 3000 MW of capacity
  - Frequency Change = (Load Change/Connected Capacity) x (Governor Droop, in Hz)
  - Frequency Change = (100 MW / 3000 MW) x (3 Hz) = (0.033) x (3 Hz) = 0.1 Hz
- Restore the same 100 MW of load with 2000 MW of capacity
  - Frequency Change = (Load Change/Connected Capacity) x (Governor Droop, in Hz)
  - Frequency Change = (100 MW / 2000 MW) x (3 Hz) = (0.05) x (3 Hz) = 0.15 Hz

Note:
Smaller systems have larger frequency fluctuations when restoring load.

7

Load Restoration

Generators will trip off automatically due to:

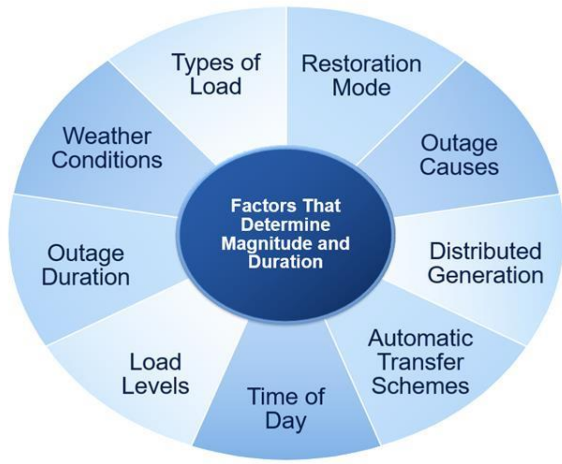
- Low frequency at **57.50 Hz** (under frequency relay)
- High frequency at **61.75 Hz** (overspeed relay)

8

Cold Load

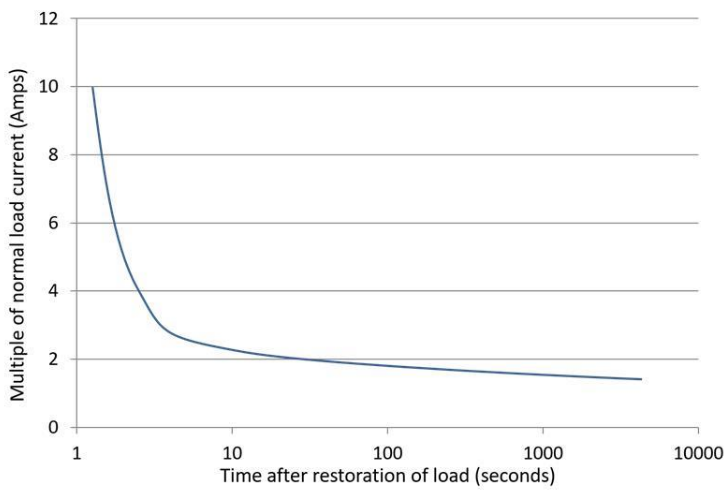
Cold Load: load which has been off for some time and has lost its diversity (cycling characteristics)

- Typically thermostatically controlled, or cyclic, and includes: air conditioners, heaters, refrigerators, and pumps



9

Cold Load Pickup



10

Load Restoration

Under Frequency Load Shed

- Feeder with relaying to automatically shed load if frequency decays below a specified level
- Last resort to save system or island from frequency collapse
- Considered as a component of *Dynamic Reserve*

11

Load Restoration

Under Frequency Load Shed

- Load equipped with under frequency relaying should NOT be restored in early stages of restoration
  - Large frequency swings early in the restoration process
- Under frequency load may be restored once system frequency is consistently above trip levels upon load restoration
  - Add load with under frequency relays set at the lowest setting

12

Load Restoration Exercises

Example 1

System Restoration Progress:

Generating Capacity Synchronized	1500 MW (5% droop)
System Load Restored	1200 MW
System Frequency	59.9 Hz

- **According to the rule of thumb for capacity, what is the maximum amount of load that should be restored at one time given the system conditions above?**

- **If you were to restore the maximum amount of load calculated above, what will be the approximate new system frequency?**

- **Based on the Rules of Thumb, should we restore all 75 MW of load at once?**

- **At what frequency could you safely energize all 75 MW of load at once?**

Example 2

System Restoration Progress:

Generating Capacity Synchronized	1100 MW (5% droop)
System Load Restored	900 MW
System Frequency	59.48 Hz, and dropping

- What course of action would you recommend?

Frequency Control

Frequency Control

www.pjm.com | Public

PJM©2025

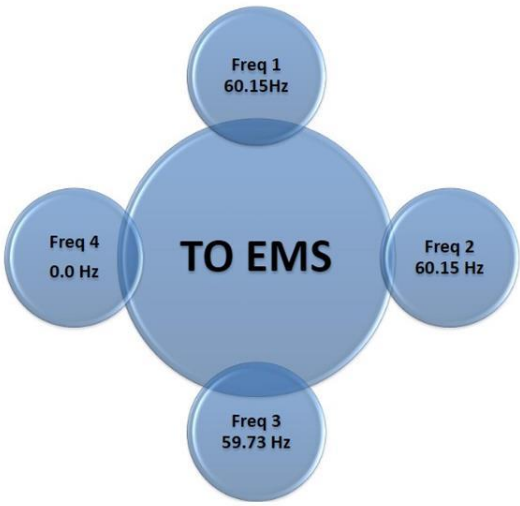
Frequency Monitoring

- Each TO must monitor frequency in their zone
  - Monitoring frequency at multiple points throughout the TO zone will provide better situational awareness when analyzing the boundaries of a event that has led to system separation
    - Operators should be able to determine the number of islands and boundary of the affected area using frequency along with other measurements
    - It is also important to know what source the frequency measurement is coming from

60.000Hz

14

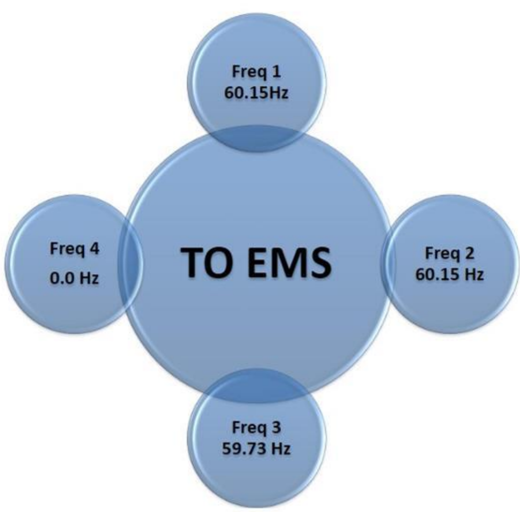
Frequency Monitoring



- A Transmission Owner is monitoring 4 frequencies in their area after a system disturbance and their EMS indicates the frequencies shown.
  - What can be deduced from these measurements?

15

Frequency Monitoring



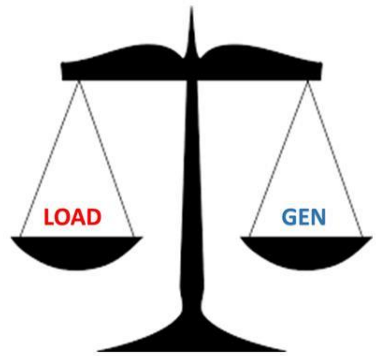
- What can be deduced from these measurements?
  - Areas #1 and #2 are interconnected (same frequency/over-generation)
  - Area #3 is isolated (under-generation)
  - Area #4 is isolated and blacked out

16

Frequency Monitoring

Frequency Monitoring

- Frequency will also be critical when it is time to interconnect these islands, as it must match to prevent damage to equipment or the shutdown of the island(s)
  - Generation or load may have to be adjusted in the islands in order to match the frequencies



17

Reserves During Restoration

Maintaining Adequate Reserves

Reserves During Restoration

Types of Reserves During Restoration	
Synchronized Reserve	Dynamic Reserve

Reserves During Restoration - Synchronized Reserve

- Within the PJM RTO, during the process of system restoration, ***Synchronized Reserve*** is defined as:
  - Online generation that can be loaded *within 10 minutes* **OR**
  - Load that can be shed manually *in 10 minutes*
- Enough synchronized reserve must be carried to cover an area's largest energy contingency
- Largest contingency may or may not be the largest generator on the system
  - A transmission line carrying generation from a plant may cause more of a loss of generation than the loss of a single unit

20

Reserves During Restoration - Dynamic Reserve

Dynamic Reserve is defined as the amount of reserve available in order to preserve the system during a frequency disturbance to allow the system to survive the loss of the largest energy contingency.

- **Dynamic Reserve** consists of two components:
  - Generator Reserve available through governor action
  - Automatic under frequency load shed

21

Dynamic Reserve from Generation

Load Pickup Factors: Maximum load a generator can pick up as a percentage of generator rating without incurring a decline in frequency below safe operating levels (57.5 Hz)

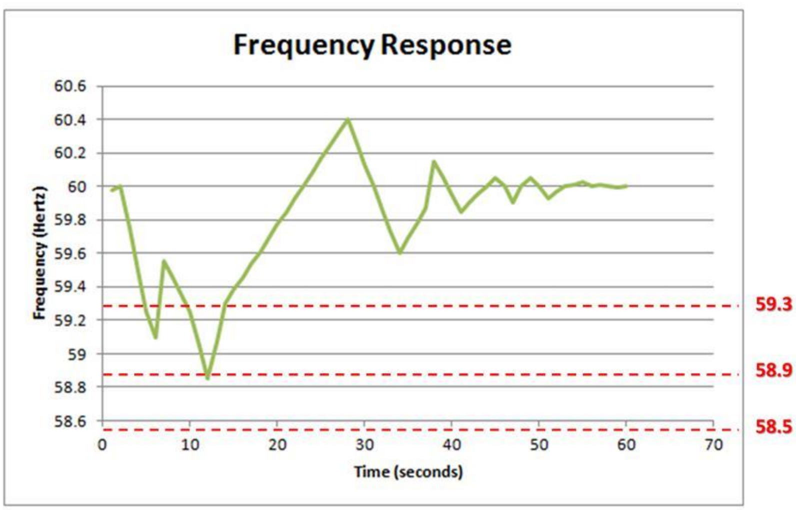
"Rule of Thumb" Load Pickup Factors

Unit Type	Load Pickup Factor (% of Unit Capacity)*
Fossil Steam	5%
Hydro	15%
Combustion Turbine	25%

***OR** unloaded capacity, whichever is less

22

Dynamic Reserve from Under Frequency Relaying



23

Reserves During Restoration

During *early stages* of restoration

→**Do not** restore under-frequency load

As system becomes *more stable* and upon *interconnection*

→**Monitor** dynamic reserves

As system becomes *very large* and *stable*

→All parties agree to **suspend dynamic reserve calculation**

24

Reserves During Restoration

Calculate the Available Dynamic Reserve

- Generation Capacity:
  - 300 MW of Steam (5% pickup factor)
  - 400 MW of CT (25% pickup factor)
  - 100 MW of Hydro (15% pickup factor)
- 50 MW of under frequency load shed is restored
- Largest contingency is a 100 MW steam unit

25

Reserves During Restoration

Governor Response

(5%)(300 MW) = 15 MW

(25%)(400 MW) = 100 MW

(15%)(100 MW) = 15 MW

= 130 MW

Largest Contingency Adjustment

(5%)(100 MW) = - 5 MW

Governor Response Total

= 125 MW

U/F Load = 50 MW

Dynamic Reserve = 175 MW

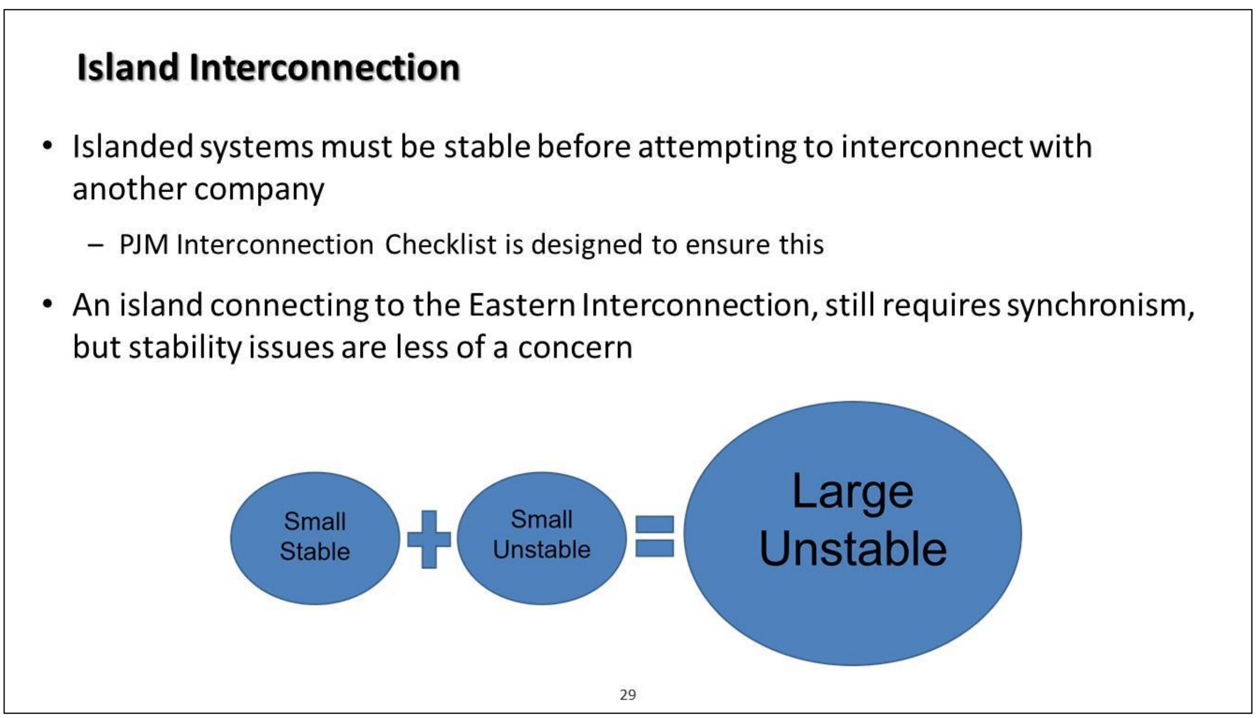
26

Calculating Dynamic Reserves - Captivate Exercises

www.pjm.com | Public

PJM©2025

Synching Islands



Island Interconnection

How do I know if my system is stable?

- The precursors to knowing if the system is stable and ready for interconnection include:
  - Area voltages are within limits (90%-105% of nominal), and when adding load blocks, or transmission to the system, the deviations from nominal voltage are small.
  - Area frequency is within limits (59.75 Hz-61.0 Hz), and when restoring load deviations from scheduled frequency are small.
  - Adequate Synchronized and Dynamic Reserves are available within the area.
  - Significant circuits are energized with under-frequency load shed relaying enabled.

30

Generator Synchronizing

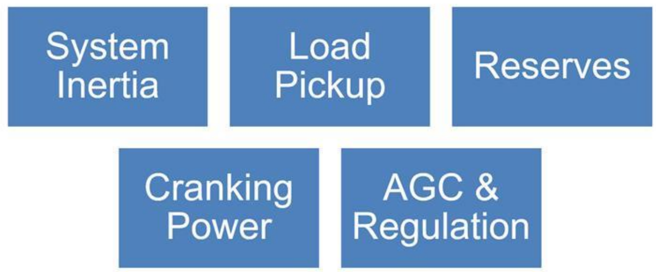
- **Reference (running) voltage**: Bus voltage
- **Incoming voltage**: Generator voltage

Clockwise motion:
Generator frequency is greater than bus frequency

31

Island Interconnection

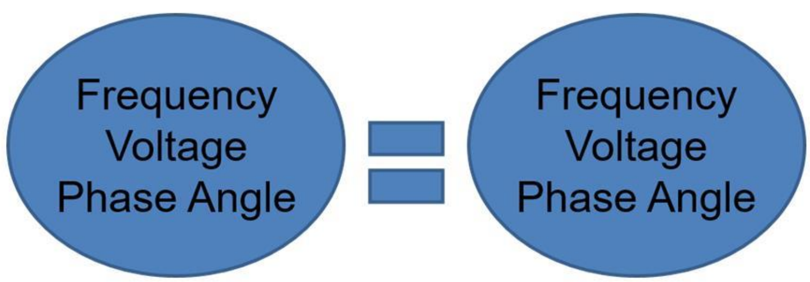
Synchronization is defined as re-establishing electrical ties between generators in two or more areas, or subsystems, within a single TO, or between two or more TO's or systems, by synchronizing the areas to a common speed or frequency.



32

Island Interconnection

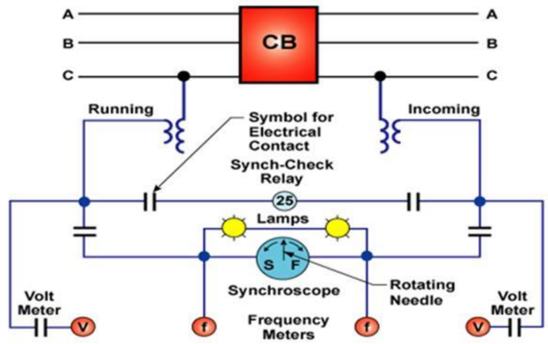
- Islands cannot be connected unless they are in synchronism
- Adjust the smaller island to match the larger island
- Failure to match frequency and voltage can result in significant equipment damage and possible shut-down of one or both areas



33

Island Interconnection

- Synchro-check Relay
  - Measures voltage on each side of breaker
  - Set for angular difference (~20 degrees) with timer
  - Will only prevent closure if out of synchronism



34

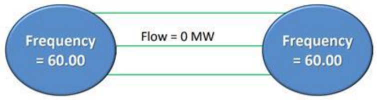
Island Interconnection

- Synchroscope
  - Permits manual closing of breaker when two systems are in synch

35

Island Interconnection

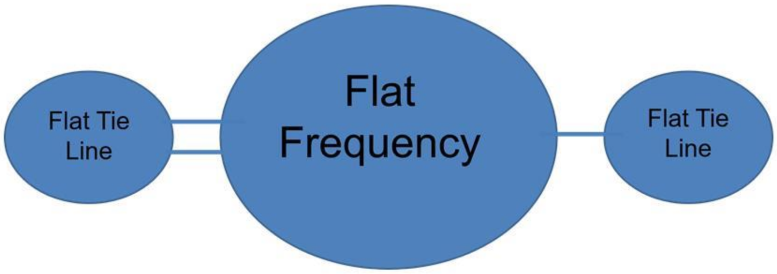
- Pre-tie preparations include:
  - Organize both field personnel and generating station personnel within both areas to be joined.
  - Identify line to "tie" areas together. The tie line must be of sufficient capacity to carry the anticipated flow between the two areas.
  - Identify the substation for "tie-in."
    - Must be equipped with a synchroscope and/or synchro-check relay with phase angle indication that can be used for synchronizing the two areas.
    - Must have reliable communication with the system operator who will direct the tie-in.
    - Specific locations of synchronization devices can be found in the individual TO restoration plans.



36

Island Interconnection

- Post-synchronism
  - If possible, close any other available tie-lines between the two newly connected systems to strengthen stability



37

Island Interconnection

- Benefits of interconnecting:
  - Stability
    - More Inertia
    - Larger blocks of load can be energized
  - Reserve sharing
    - Reserves allocated based on share of total capacity
  - Allows for supply of cranking power or energy for load among connected areas
  - AGC control and regulation

Any opportunity to connect to the Eastern Interconnection should be explored as soon as possible

38

Island Interconnection

- Interconnected Island Expectations:
  - Based on NERC Standards, cranking power should be supplied to requesting companies as a priority to restoring native load
  - Companies/areas that have restored all native load (or never lost it) are expected to consider supplying both cranking power and energy for load to requesting systems.
    - Up to normal operating limits.
    - As long as security of supplying company is not compromised.

39

Interconnection of TOs

- During the pre-restoration process, PJM has the following responsibilities:
  - Act as the coordinator and disseminator of information relative to generation and transmission availability.
  - Keep the TOs/GOs apprised of system conditions to assist in the formation and on-going adjustments of a cohesive System Restoration Plan.
  - Provide TOs/GOs with updated run-of-river hydro capability.
  - Direct the restoration of the RTO's EHV system.
  - Direct island synchronization within the RTO.
  - Coordinate with neighboring entities to establish interconnections and establish tie schedules with neighbors.

40

Interconnection of TOs

- Prior to synchronizing TOs have the following responsibilities during the restoration process:
  - Ascertain that reserves are available to cover the largest energy contingency within the interconnected area.
  - Share Dynamic and Synchronized Reserves.
  - Agree on a plan to act in a coordinated manner to respond to area emergencies.
  - Regulate area frequency by adjusting generation and load within the acceptable range.
  - Frequency is adjusted to slightly above 60.00 Hz before load is picked up.
  - If needed, Synchronized Reserve, including manual load shed, is used to keep the frequency above 59.50 Hz.
  - Collect the required information from the GOPs or plant operators within each zone for the Company Hourly Restoration Reports.
  - Complete and submit the Company Transmission Restoration Reports.

41

Interconnection of TOs

- Post-Interconnection:
  - Member Company TOs/GOs maintain communications with PJM to provide updated status of system conditions, in addition to submitting the hourly reports.

42

INTERCONNECTION CHECKLIST				
DATE:		DATE:		
ISLAND "A":		ISLAND "B":		
CONTACT:		CONTACT:		
INFORMATION EXCHANGE				
			ISLAND "A"	ISLAND "B"
1	Are you currently interconnected?		YES /NO	YES /NO
2	If YES, which company (ies):			
3	Existing Tie-line Schedules:			
	FROM:	To:	MW	MW
	FROM:	To:	MW	MW
	FROM:	To:	MW	MW
4	Do you need start-up power?		YES /NO	YES /NO
	4a	If YES, how much?	MW	MW
5	Can you supply energy?		YES /NO	YES /NO
	5a	If YES, how much?	MW	MW
LOAD INFORMATION				
6	Load Restored:		MW	MW
	6a	% of Load Restored	%	%
7	Load Restored With Underfrequency Relaying Enabled		MW	MW
			%	%
			Hz MW	Hz MW
			Hz MW	Hz MW
			Hz MW	Hz MW
			Hz MW	Hz MW
	7a	Total Load Restored w/ Underfrequency Relaying In-Service:	MW	MW
CAPACITY/ENERGY INFORMATION				
8	Largest Energy Contingency		MW	MW
9	Generation On-Line: Total Capacity		MW	MW
10	Generation On-Line: Energy		MW	MW
11	Synchronous (Spinning) Reserve (Not Including Load Shedding):		MW	MW
12	Governor Reserve:		MW	MW
13	Total Dynamic Reserve: (Governor Reserve + Total Restored Underfrequency Relaying) (Row 7a + 12) (N/A if company is tied to the Eastern Interconnection)		MW	MW
14	Frequency Range over the Last Hour: (N/A if company is tied to the Eastern Interconnection)		/ Hz	/ Hz
TIE-LINE LOCATION AND SCHEDULING INFORMATION				
15	Tie-line to be established:			
16	Tie-line schedule to be established:			MW
17	Which company will coordinate synchronization?			
18	Which breaker / substation will be used for synchronization?			
19	Which company will control frequency?			
20	Which company will control tie-line flow?			
21	Voltage At Boundary Buses:		KV	KV
22	Realy or SPS concerns @ sync locations?			
SYNCHRONIZATION				
23	What time will synchronization occur?			
	23a	Contact name:		
	23b	Phone #:		
24	What is the maximum amount of load pick-up without notification?		MW	MW
25	Conditions that would cause the opening of the tie-line:			
ADDITIONAL COMMENTS:				

TO to TO

INTERCONNECTION CHECKLIST			
DATE:		TIME:	
ISLAND "A":		ISLAND "B":	
CONTACT:		CONTACT:	

INFORMATION EXCHANGE		ISLAND "A"	ISLAND "B"
1	Are you currently interconnected?		
2	If YES, which company (ies):	YES ☐ Check NO ☐ Check	YES ☐ Check NO ☐ Check
3	Existing Tie-line schedules		
	FROM: TO:	MW	MW
	FROM: TO:	MW	MW
	FROM: TO:	MW	MW
4	Do you need start-up power?	YES ☐ Check NO ☐ Check	YES ☐ Check NO ☐ Check
4a	If YES, how much?	MW	MW
5	Can you supply energy?	YES ☐ Check NO ☐ Check	YES ☐ Check NO ☐ Check
5a	If YES, how much?	MW	MW
	LOAD INFORMATION		
6	Load Restored	MW	MW
6a	% of Load Restored	%	%
7	Load Restored With Underfrequency Relaying Enabled:	Hz MW	Hz MW
		Hz MW	Hz MW
		Hz MW	Hz MW
		Hz MW	Hz MW
7a	*Total Load Restored w/ Underfrequency Relaying In-Service*	MW	MW

44

TO to TO

	CAPACITY / ENERGY INFORMATION		
8	Largest Engery Contingency	MW	MW
9	Generation On-line: ***Total Capacity***	MW	MW
10	Generation On-line: ***Energy***	MW	MW
11	Synchronous (Spinning) Reserve (Not including Load Shedding):	MW	MW
12	Governor Reserve:	MW	MW
13	Total Dynamic Reserve: (Governor Reserve + Total Restored Underfrequency Relaying) (Row 7a + 12) (N/A if company is tied to the Eastern Interconnection)	MW	MW
14	Frequency Range over the Last Hour: (N/A if company is tied to the Eastern Interconnection)	-N36 Hz	- Hz
	TIE-LINE LOCATION AND SCHEDULING INFORMATION		
15	Tie-line to be established.		
16	Tie-line schedule to be established:		MW
17	Which company will coordinate synchronization?		
18	Which breaker / substation will be used for synchronization?		
19	Which company will control frequency?		
20	Which company will control tie-line flow?		
21	Voltage At Boundary Buses:	kV	kV
22	Relay or SPS concerns @ sync locations?		
	SYNCHRONIZATION		
23	What time will synchronization occur?		
23a	Contact name:		
23b	Phone #:		
24	What is maximum amount of load pick-up without notification?	MW	MW
25	Conditions that would cause the opening of the tie-line:		

45

TO to Eastern Interconnection & Cross Zonal Coordination

INTERCONNECTION CHECKLIST			
DATE:		TIME:	
ISLAND "A":		ISLAND "B":	
CONTACT:		CONTACT:	

INFORMATION EXCHANGE

		ISLAND "A"	ISLAND "B"
1	Are you currently interconnected?	YES ☐ Check NO ☐ Check	YES ☐ Check NO ☐ Check
2	If YES, which company (ies):		
3	Existing Tie-line schedules		
	FROM: TO:	MW	MW
	FROM: TO:	MW	MW
	FROM: TO:	MW	MW
4	Do you need start-up power?	YES ☐ Check NO ☐ Check	YES ☐ Check NO ☐ Check
4a	If YES, how much?	MW	MW
5	Can you supply energy?	YES ☐ Check NO ☐ Check	YES ☐ Check NO ☐ Check
5a	If YES, how much?	MW	MW

LOAD INFORMATION

		ISLAND "A"	ISLAND "B"
6	Load Restored	MW	MW
6a	% of Load Restored	%	%
7	Load Restored With Underfrequency Relaying Enabled:	Hz MW	Hz MW
		Hz MW	Hz MW
		Hz MW	Hz MW
		Hz MW	Hz MW
7a	*Total Load Restored w/ Underfrequency Relaying In-Service*	MW	MW

46

TO to Eastern Interconnection & Cross Zonal Coordination

CAPACITY / ENERGY INFORMATION

8	Largest Engery Contingency	MW	MW
9	Generation On-line: ***Total Capacity***	MW	MW
10	Generation On-line: ***Energy***	MW	MW
11	Synchronous (Spinning) Reserve (Not including Load Shedding):	MW	MW
12	Governor Reserve:	MW	MW
13	Total Dynamic Reserve: (Governor Reserve + Total Restored Underfrequency Relaying) (Row 7a + 12) (N/A if company is tied to the Eastern Interconnection)	MW	MW
14	Frequency Range over the Last Hour: (N/A if company is tied to the Eastern Interconnection)	-N36 Hz	- Hz

TIE-LINE LOCATION AND SCHEDULING INFORMATION

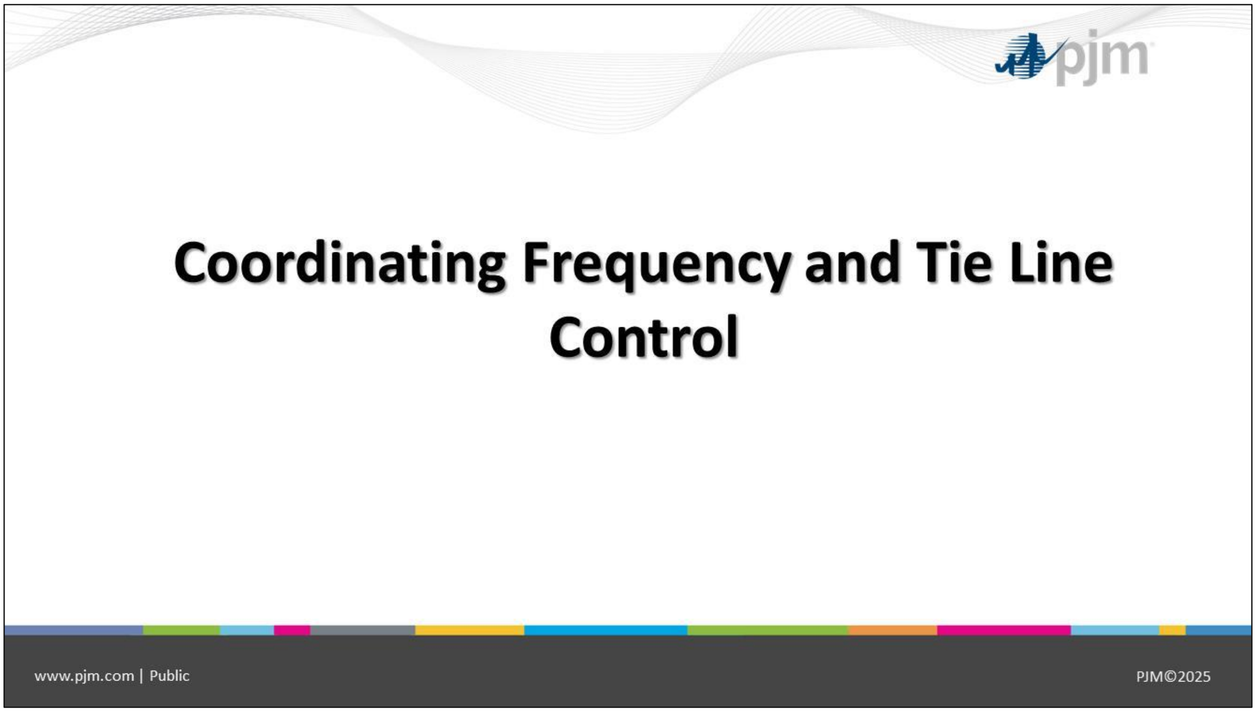
15	Tie-line to be established:		
16	Tie-line schedule to be established:		MW
17	Which company will coordinate synchronization?		
18	Which breaker / substation will be used for synchronization?		
19	Which company will control frequency?		
20	Which company will control tie-line flow?		
21	Voltage At Boundary Buses:	kV	kV
22	Relay or SPS concerns @ sync locations?		

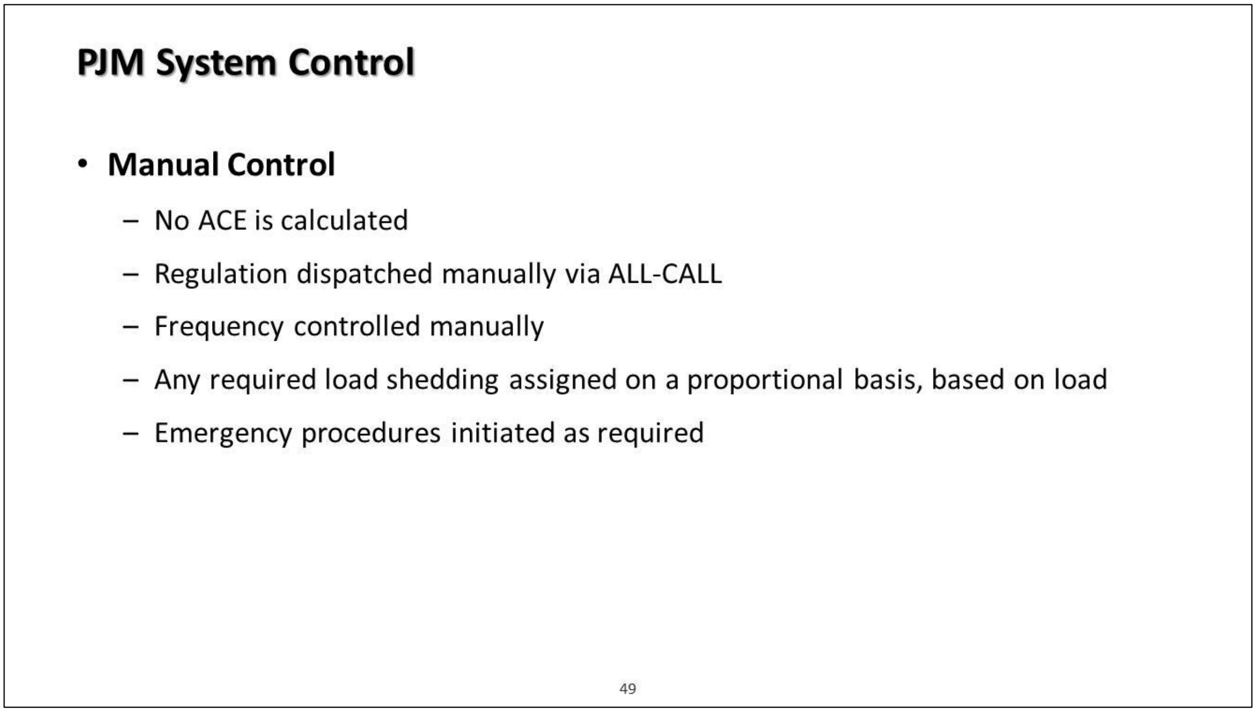
SYNCHRONIZATION

23	What time will synchronization occur?		
23a	Contact name:		
23b	Phone #:		
24	What is maximum amount of load pick-up without notification?	MW	MW
25	Conditions that would cause the opening of the tie-line:		

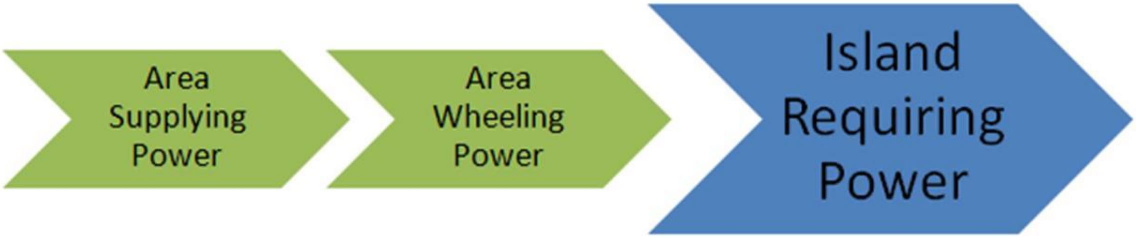
47

Coordinating Frequency and Tie Line Control





PJM System Control - Tie-Line Bias Control



ACE = (Frequency Deviation (Hz) X Frequency Bias (MW/0.1 Hz) X 10) + (Tie Schedule - Tie Actual)

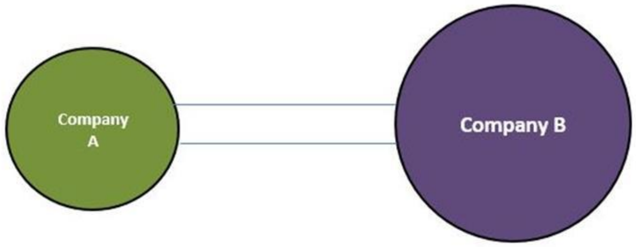
50

PJM System Control - Single Island

Flat Frequency Control	
Requires:	Frequency Source, Frequency Bias
Frequency Bias = (0.01) * (Company A Load)	

51

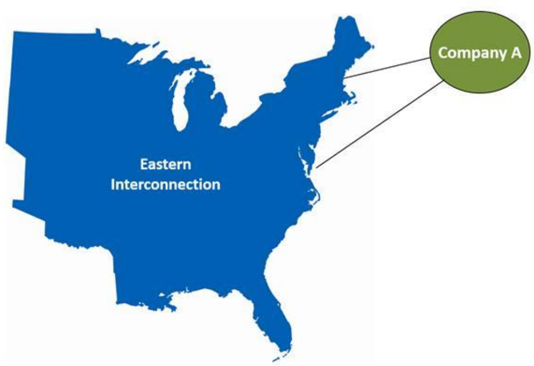
PJM System Control - Multiple Islands



Company A: Flat Tie Line Control		Company B: Flat Frequency Control	
Requires:	Tie Line Schedule, Actual Tie Line Flow	Requires:	Frequency Source, Frequency Bias
ACE = (Tie Schedule – Tie Actual)		Frequency Bias = (0.01) * Total System Load	

52

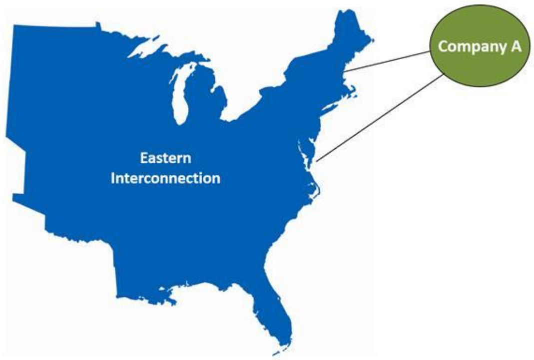
Company A has Synchronized Generation



Tie-Line Bias Control	
Requires:	Frequency Source, Frequency Bias, Tie Line Schedules and Actual Tie Line Flow
Frequency Bias = (0.01) * (Company A Load)	

53

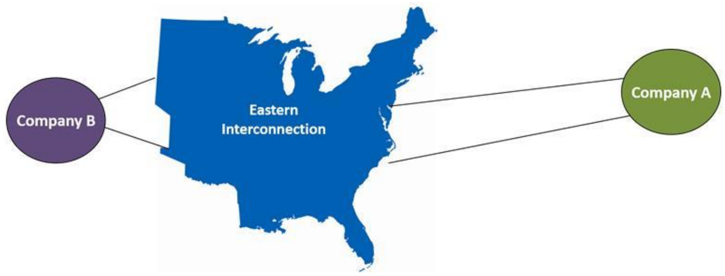
Company A is Radial Load



Flat Tie Line Control	
Requires:	Tie Line Schedules and Actual Tie Line Flow

54

Two Companies with Synchronized Generation



Tie-Line Bias Control	
Requires:	Frequency Source, Frequency Bias, Tie Line Schedules and Actual Tie Line Flows with Eastern Interconnection

55

PJM System Control

- When conditions permit, PJM will notify TO that PJM Control Area is returning to normal operation
  - Free flowing internal ties
  - Generation under AGC control
  - Control area tie line control
  - Published regulation and reserve requirements

56

Minimum Source Guidelines

Identifying Minimum Source Guidelines

Transmission Restoration

EHV Energization Concerns

- Overvoltage caused by excessive MVAR supply from line capacitance
- Reduction in proper relaying protection reliability due to insufficient fault current
  - Critical in restoration due to higher probability of faulted equipment due to overvoltage and unclear system status

Transmission Restoration

Minimum Source Guidelines

- Requirements that must be met prior to the energization of EHV transmission to prevent or reduce EHV energization concerns
- PJM has established minimum source requirements for energization of 500 kV and 765 kV lines

59

Minimum Source Guidelines

Minimum Source Guidelines
Capacity Requirement
Load Requirement
Energy Requirement
System Configuration Requirement

60

Minimum Source Guidelines

- PJM 500 kV and 765 kV Minimum Source Guidelines
  - Primary and backup relays in service
  - Shunt capacitors out of service

Generation

- 600 MW of electrically close generation (energy) connected at 230 kV or higher
- Minimum of 30 MW of generation (capacity) per mile of energized 500 kV or 765 kV line

61

Minimum Source Guidelines

Load

- Minimum of 20 MW of load per mile of energized 500 kV or 765 kV line
  - Energized line = Already Energized + Line Being Energized

62

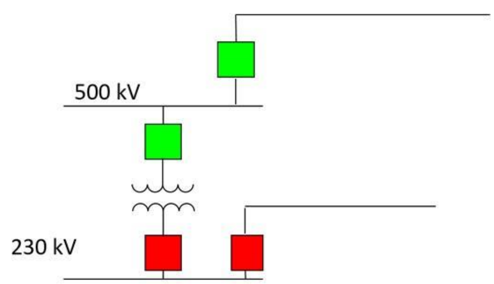
Minimum Source Guidelines

- Energizing guidelines:
  - Clear dead bus sections
  - Reduce 500 kV / 765 kV voltage via tap changer
  - Reduce sending end voltage to 475 kV or lower and 230 kV or lower
  - Energize lines from strongest source
  - Parallel with 500 kV / 765 kV circuit breaker

63

Minimum Source Guidelines

- Other switching considerations:
  - Energize 500 kV / 765 kV lines and transformers separately
  - Energize transformers ideally from low side
  - Add load to energized lines prior to energizing additional transmission lines
  - Only energize lines that will carry significant load (prevents unwanted MVARs)



64

Minimum Source Guidelines

Description	Reason
VAR Absorption — A minimum of 3.0 MVAR of electrically close VAR absorption per mile of 500 kV / 765 kV line connected must be available. May be generator reactive (leading), reactive load, shunt reactors, etc. Static VAR compensator may assist in accomplishing this if available.	This will control line voltage less than 500 kV / 765 kV.
At least 3 MW of load per mile control of 500 kV / 765 kV line to be energized must be established on the underlying system.	To provide damping to dynamic over- voltage when energizing transformers.

Guidelines for when detailed *system information* is ***known***.

Description	Reason
Minimum Generating Capacity — 30 MW/ mile of 500 kV / 765 kV to be connected	Provides approximately two MVAR/mile VAR absorbing capability at full load
Minimum Load — 20 MW/mile of 500 kV / 765 kV line to be connected	Provides approximately 1.8 MVAR/mile VAR load to prevent machine from excessive loading operation. This will help balance the capacitive voltage rise.

Guidelines for when detailed *system information* is ***unknown***.
Provides a 2:1 safety factor.

65

Minimum Source Guidelines - Example

PJM 500 kV & 765 kV Minimum Source Guidelines - Example

- You have 1200 MW of load restored, 1700 MW of generating capacity and your frequency is 60.00
- All your relays are in service and capacitors are switched off
- You want to energize a 50 mile 500 or 765 kV line

Do you meet all the minimum source guidelines?

66

Minimum Source Guidelines - Example

PJM 500 kV & 765 kV Minimum Source Guidelines - Example

1. Required Energy for fault current clearing = 600MW
   - You have 1200 MW load at 60.00 Hz – **Condition Met ✓**
2. Required Load for MVAR absorption = 20 MW / mile
   - (50 miles)(20 MW/mile) = 1000 MW load required
   - You have 1200 MW of load = **Condition Met ✓**
3. Required Capacity for MVAR absorption = 30 MW / mile
   - (50 miles)(30 MW/mile) = 1500 MW capacity required
   - You have 1700 MW of capacity = **Condition Met ✓**

67

Minimum Source Guidelines

Nominal Voltage	Charging MVAR/Mile
69 kV Line	0.025
115/138 kV Line	0.100
230 kV Line	0.300
345 kV Line	0.800
500 kV Line	1.700

Transmission Line Charging

Nominal Voltage	Charging MVAR/Mile
115/138 kV Cable	2.0-7.0
230 kV Cable	5.0-15.0
345 kV Cable	15.0-30.0

Transmission Cable Charging

68

Minimum Source Guidelines Exercise

1. You would like to energize a 70 mile long 500 kV line. You currently have the following:

    - 1600 MW of Capacity
    - 900 MW of Load
    - Broken tap changer on the 500/230 kV transformer

Determine if the minimum source guidelines are met and if you should proceed.

	Met	Not Met
Energy Requirement	☐	☐
Capacity Requirement	☐	☐
Load Requirement	☐	☐
Configuration Requirement	☐	☐

2. You would like to energize 20 miles of a 500 kV line. You currently have the following:

    - 650 MW of Capacity
    - 350 MW of Load
    - You have energized a 500/230 kV transformer from the 230 kV system and have adjusted the taps to reduce the voltage on the 500 kV system to 475 kV

Determine if the minimum source guidelines are met and if you should proceed.

	Met	Not Met
Energy Requirement	☐	☐
Capacity Requirement	☐	☐
Load Requirement	☐	☐

3. You currently have 20 miles of 500 kV transmission energized. You are considering energizing an additional 40 miles of 500 kV line. You currently have the following:

    - 2500 MW of Capacity
    - 1500 MW of Load
    - Your 500 kV voltage is around 510 kV

Determine if the minimum source guidelines are met and if you should proceed.

	Met	Not Met
Energy Requirement	☐	☐
Capacity Requirement	☐	☐
Load Requirement	☐	☐

4. You currently have a 30 mile 500 kV transmission line energized. You are considering energizing an additional 40 mile 500 kV line. You currently have the following:

- 2500 MW of Capacity
- 1500 MW of Load
- Your 500 kV voltage is around 505 kV

Determine if the minimum source guidelines are met and if you should proceed.

	Met	Not Met
Energy Requirement	☐	☐
Capacity Requirement	☐	☐
Load Requirement	☐	☐

5. Current conditions include:

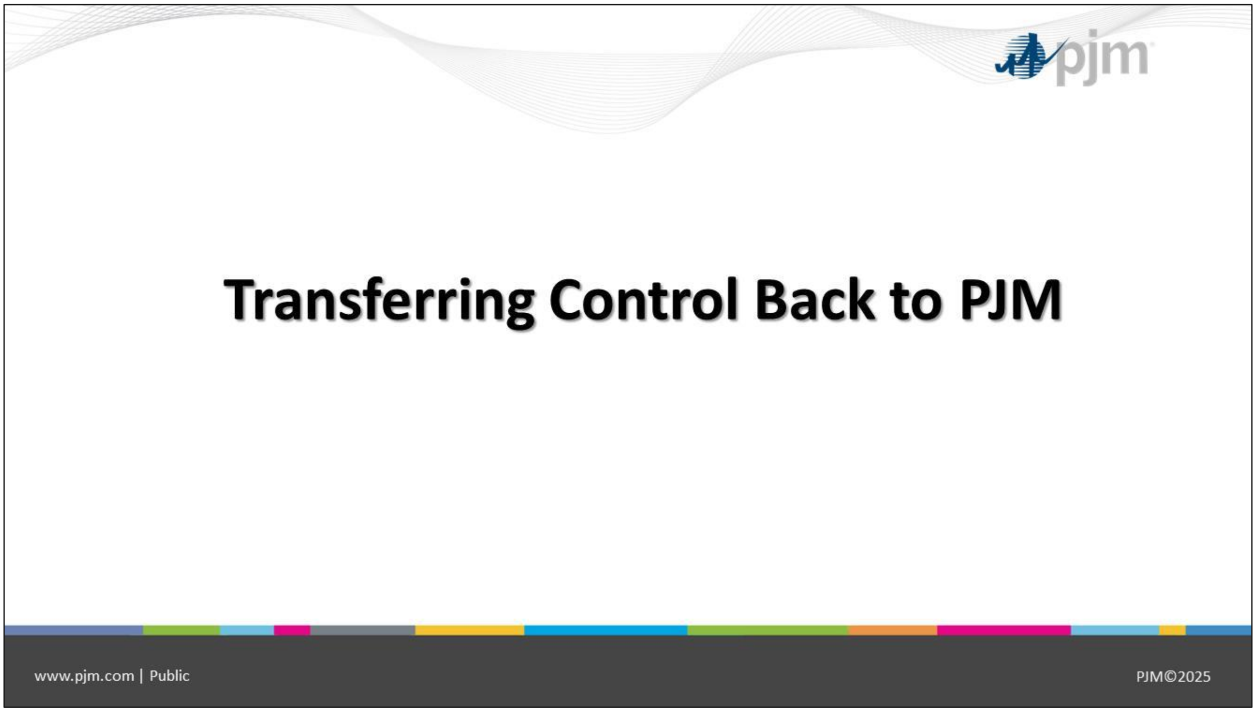
- A 15 mile 500 kV line energized
- 3000 MW of generation capacity
- 1760 MW of load connected to the system
- 500 kV voltage is currently around 515 kV

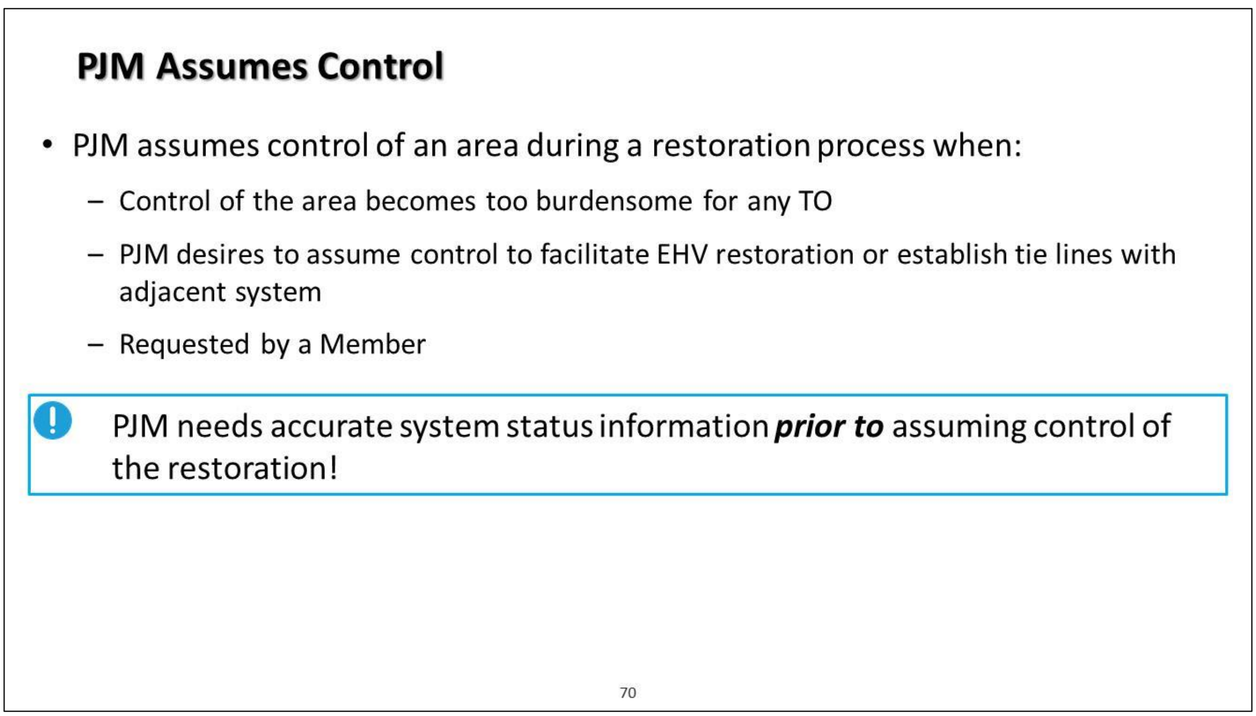
What is the longest length of additional 500 kV line that you can energize?

Line Length:

____

Transferring Control Back to PJM





PJM Assumes Control	
Date:	Time:
Reporting Company:	
Regulation MW	Synchronous Reserve MW
Frequency Controlled by:	Frequency Maintained From to HZ

Dynamic Reserves:

Underfrequency Relays:

Percent at 59.5 HZ______% Percent at 59.3 HZ______% Percent at 59.1 HZ______%
Percent at 59.0 HZ______% Percent at 58.9 HZ______% Percent at 58.7 HZ______%
Percent at 58.5 HZ

Governor Response:

Steam MW CT's MW Hydro MW

Load Pick - up Factors: Steam Units **5%** CT's **25%** Hydro Units **15%**

Total Load with Underfrequency Relaying ___________MW
Total Governor Response: ___________MW
Total Dynamic Reserves: MW

INTERCHANGE SCHEDULES (Company To Company, Company To Outside)					
From Co.	**To Co.**	**MW**	**From Co.**	**To Co.**	**MW**

Connected Load	
765 kV MW of Connected Load MW	
500 kV MW of Connected Load MW	
345 kV MW of Connected Load MW	
230 kV MW of Connected Load MW	

Comments:

PJM Assumes Control

PJM Actions

- Gather required information reporting form
- Determine required Dynamic and Synchronous Reserve for each area based on the largest energy contingency
- Determine regulation requirement
- Coordinate hydro operations
- Update DMT to reflect unit capability, as reported by the Generator Operators

72

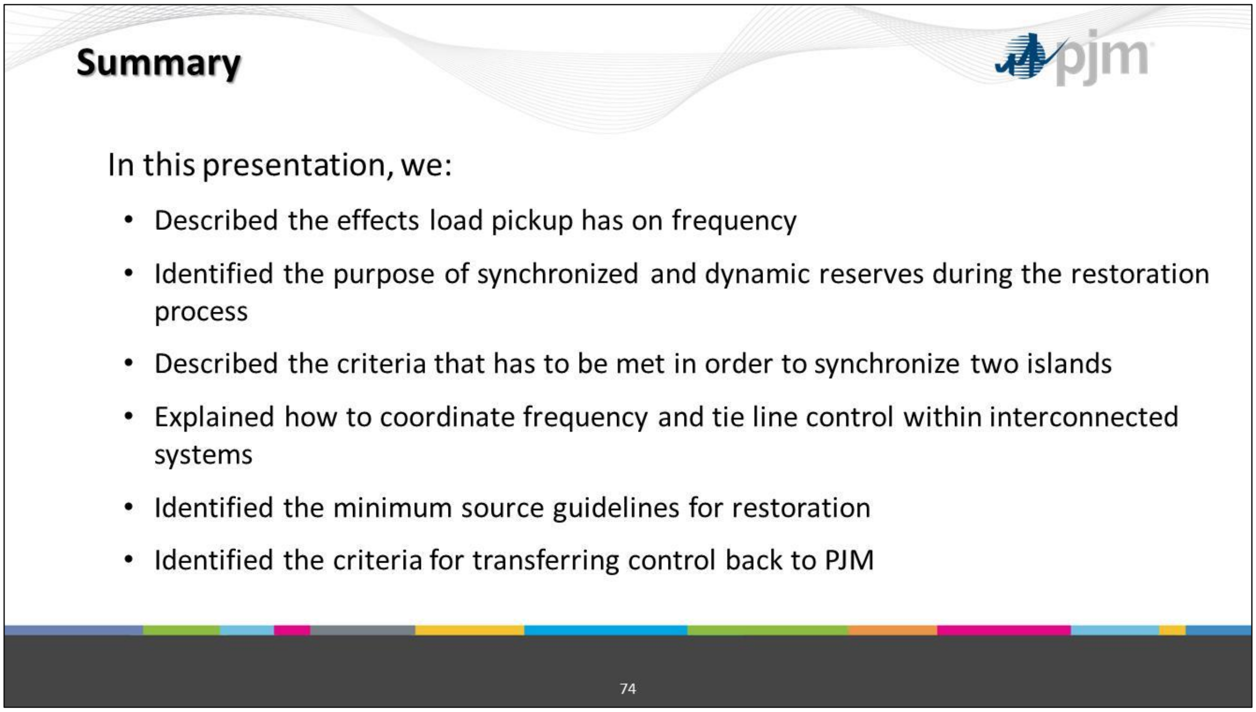
PJM Assumes Control

Member Actions

- Continue returning generation and load to maintain frequency, and report returning units to PJM
- Respond to emergency procedures
- Maintain established tie schedules with other TOs until PJM returns to free-flowing tie conditions
- Maintain communications with PJM to provide an updated status of system conditions
- Request PJM approval before closing any reportable line or a line that established an interconnection to an external system

73

Summary



Questions?

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

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