

# Generator Assessment & Roles During A Restoration

PJM State & Member Training Dept.



## Objectives



Students will be able to:

- Identify the process and requirements for operating during system restoration conditions

# Generator Information Reporting Requirements

- Following an event or disturbance, unit personnel shall begin an immediate inspection, communicating the status of the unit to the Generation Owner
- Generation Owners that control the output of a generation resource must take or arrange for any or all of the following actions as directed by PJM to manage, alleviate, or end an emergency, or such actions as PJM deems appropriate for these purposes:
  - Reporting the operating status and fuel situation
  - Starting, including black start, and loading such generation, as directed
- Generation Owners shall collect information, and notify PJM of known generation capabilities, equipment damage, and other pertinent information (Done thru the initial and hourly generation reports submitted thru the respective Member Company Transmission Owners)
- Generation Owners shall notify key personnel and generation plant operators regarding the extent of the outage

# Hourly Generation Report

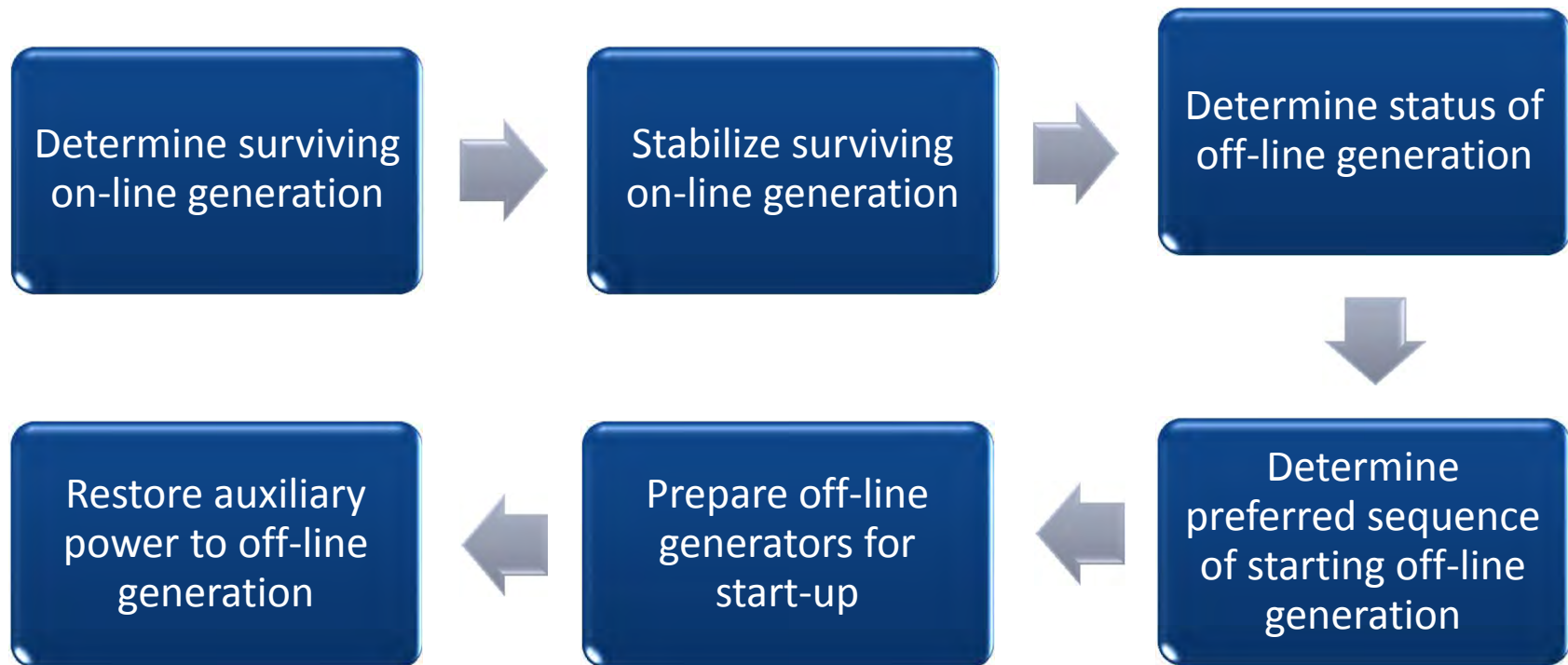
- This report is submitted every hour during the restoration process to the Transmission Owner who, in turn, will submit it to PJM
- Information includes:
  - Generation Report
    - Capacity and energy on line
    - Number of generators on line
    - Number of subsystems (islands)
  - Load Restoration Report
    - Total customer load restored
    - Number of customers restored
    - % Customers restored
    - % Customers restored last hour

# Hourly Generation Report

- Information includes:
  - Capacity Due In:
    - Generation in one hour
    - Generation in three hours
    - Generation in six hours
  - Units On-line Since Last Report
  - Units Expected During Next Hour
  - Damage Detected Since Last Report
  - Cranking Power

# Hourly Generation Report

COMPANY HOURLY *GENERATION RESTORATION REPORT					
Date:			Time:		
Reporting Company:					
Transmission Zone:					
Company Contact:			Estimated Time to Complete Total Restoration:		
			Date: Time:		
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



## Determining Generator Status

- For generation that is still on-line determine:
  - Location
  - Damage
  - Stability
    - Frequency of island
    - Can load be added
  - Unloaded capacity
  - Connectivity to the rest of the system
    - Islanded
    - Part of Eastern Interconnection



## Determining Generator Status

- For generation off-line determine:
  - Status prior to blackout (running, hot, on maintenance)
  - Blackstart capability of unit
  - Type of unit
    - Individual unit characteristics
  - Damage assessment
  - On-site source of power available or is off-site source (cranking power) required
  - Availability and location of cranking power

## Determining Generator Status

- Sequence of restoration of off-line generation will be determined by:
  - Type of generator
    - Hydro - can be started quickly without outside source
    - CT - small CTs can be started quickly (10 minutes); large CTs will take longer (up to 1 hour)
    - Drum - type steam - 1-20 away hours depending on status
    - Super Critical steam - 4-20 away hours depending on status
    - Nuclear - at least 24 hours away (probably 48 hours or longer)
  - State of operation of unit prior to blackout
    - Hot units may be returned quicker than cold units
  - Unit availability

## Determining Generator Status

- Auxiliary power should be restored to generation stations as soon as possible
- Short delays in restoring auxiliary power could result in long delays in restoring generation due to:
  - Congealed fuel oil
  - Sludge thickening in scrubbers (large demand of auxiliary power; as much as 30 MW)
  - Battery life expended
  - Bearing damage
  - Bowed shaft due to loss of turning gear

## Determining Generator Status

- Prioritization of available cranking power to off-line generation depends on:
  - NRC requirements (more on this later!)
  - Individual restoration plan
  - Start-up time of unit
  - Availability of on-site auxiliary power
  - Distance of cranking power from generation
- Effective communication with generating stations is essential in this process!

## Determining Generator Status

- Generating plant operators take actions to perform a safe plant shutdown
- Steam plant operators implement start-up procedures immediately following a plant shutdown unless instructed otherwise by the dispatcher
- Governors must be in service to respond to large frequency deviations
- Frequency control is maintained between 59.75 Hz and 61.0 Hz
- Plant operators must take action on their own to control frequency outside the range of 59.5 Hz - 61.0 Hz

## Cranking Power

- Shutdown generating units that do not have black start capability require start-up cranking power from an offsite source
  - A start-up path consisting of transmission and distribution and buses must be established
  - Each TOs individual restoration plan must provide for cranking power to non-black start units to include arrangements with other TOs or systems to provide start-up assistance (Cross Zonal Coordination)
- Cranking path is a transmission path from a Black Start Unit to another generator with the intent to facilitate start-up of that generator to aid in the restoration process

## Cranking Power

- Priority access to start-up power is given to “hot” units that can return to service within a 4-hour time frame
- Preference is also given to regulating units to assure stable system frequency after the units are loaded
- Auxiliary power is restored to generation as soon as possible to improve availability
  - Helps to control equipment damage
  - Minimize the time for required unit re-starts
- If start-up power is required from an outside entity, implications could include:
  - Isolation of the unit from its own system
  - Unintentional interconnection between the two areas

## Loading of generation during a restoration

- PJM policy is that:
  - During a system restoration, Transmission owners will direct the loading of all generation within their footprint
  - This includes both Black Start and conventional units
  - IPP units may participate when available, and to the extent their contracts permit
- Once PJM resumes control of an island, they will direct the operation and output of units



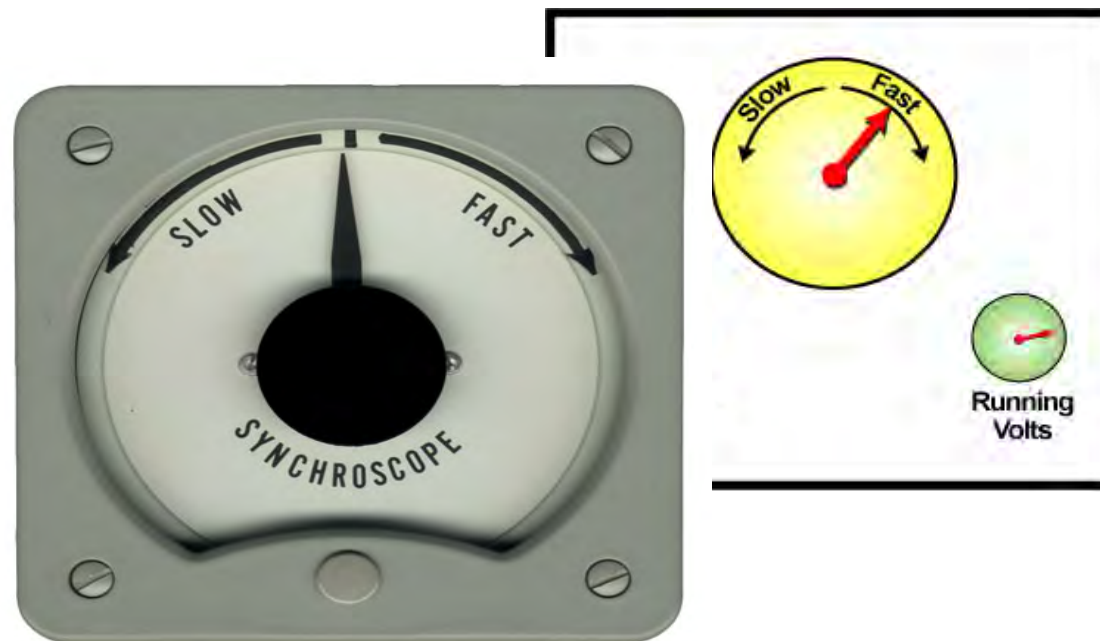
## Generator Synchronizing

- In order to synchronize properly, three different voltage variables must be monitored:
  - Voltage magnitudes
  - Frequency of the voltages
  - Phase angle difference between the voltages
- If voltage magnitudes are not matched, Mvar will rise suddenly when the breaker is closed
- If frequencies are not matched, a sudden change in MW flow will occur when the breaker is closed
- Most important, if phase angle difference is not minimized, MW flow will increase when the breaker is closed

## Generator Synchronizing

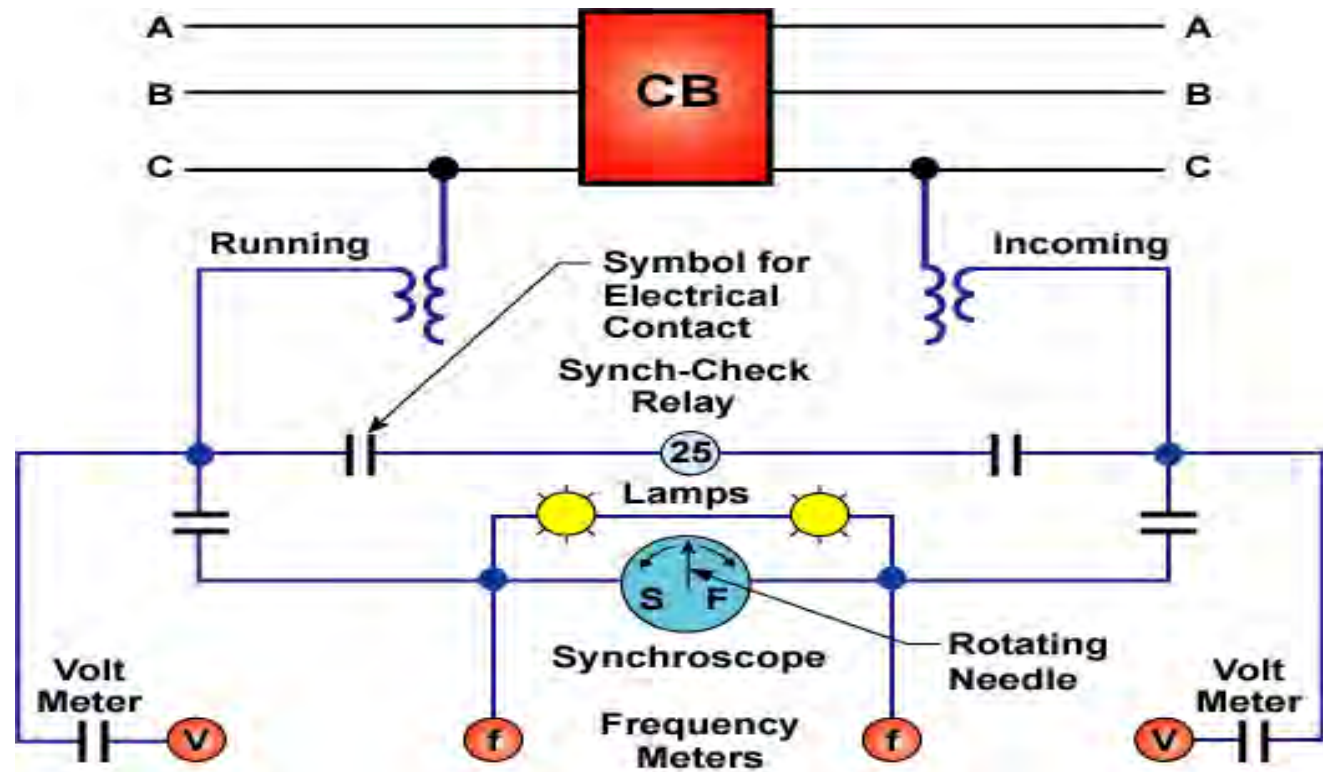
- System is modeled as an infinite bus
- With the unit output breakers open, the generator is operated at slightly above system frequency
- Excitation is adjusted for equal voltage magnitudes on either side of the output breakers
- The phase angle difference between the unit and system is monitored through the use of a synchroscope
- When the phase angle is small and heading towards zero in a clockwise direction, the output breakers are closed pulling the generator in step with the system

# Generator Synchronizing



# Generator Synchronizing

Voltage  
Frequency  
Phase Angle



## Generator Synchronizing

- Reference (Running) voltage: Bus voltage
- Incoming voltage: Generator voltage
- Clockwise motion: Generator frequency is greater than bus frequency
- Once synchronized, excitation system can be put into automatic voltage regulation, and speed governor can be put in automatic generation control
- 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

# Bismarck Sync Demo

## Synchronization

- Restoration of an interconnected system 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
  - Increased inertia tends to dampen fluctuations in frequency
  - Increases the capability to pick up larger blocks of load
  - Establishes or maintains Dynamic and Synchronous Reserves
  - Allows for supply of cranking power or energy for generation and load among the connected areas
  - Additional AGC control and regulation

## Island Interconnection

- Islanded systems must be stable before attempting to interconnect with another company
- How do I know if my system is stable?
  - Voltage within limits
  - Small voltage deviations when restoring load or transmission
  - Frequency within 59.75 and 61.0
  - Small frequency deviations when restoring load
  - Adequate reserves (synchronous and dynamic)
  - Significant amount of U/F relayed load picked up



## Island Interconnection

- Pre-tie Preparations
  - Identify transmission line to tie area together
    - Must be able to handle expected flow on tie
  - Identify substation and circuit breaker to use for synchronism
    - Circuit breaker must be equipped with either synchro-check relay or synchroscope availability
  - Ensure reliable communications between field personnel, control center and generating stations

## Island Interconnection

- Synchronization of islands within a single transmission zone:
  - Prior to synchronizing, the TO will communicate with PJM
  - PJM's approval is not needed
- Synchronization of islands between Transmission Owners, or externally to an outside entity:
  - Prior to synchronizing, the TO's will communicate with PJM for approval
- PJM will then coordinate with neighbors, as needed, before the TO adjusts frequency and voltage of the islands
  - Upon synchronization, the regulation requirement for frequency control must be recalculated
  - Once synchronization is achieved, frequency levels must be maintained (59.75 Hz and 61.0 Hz) requiring close coordination between plant operators and TO's

## Island Interconnection

- Synchronization
  - Frequency and voltage of the *smaller* island should be adjusted to match the frequency and voltage of larger island
    - Frequency and voltage in a smaller system are able to be moved more easily with smaller generation shifts
  - Failure to match frequency and voltage between the two areas can result in significant equipment damage and possible shut-down of one or both areas

## Interconnection of TOs

- **PJM Actions:**
  - Act as coordinator and disseminator of information relative to generation and transmission availability
    - Identify opportunities
  - Keep Member Companies apprised of developing system conditions
  - Provide updated hydro capability
  - Direct the restoration of the EHV system
  - Direct synchronizing of islands in the RTO

## Interconnection of TOs

- Member Company Actions:
  - Adjust frequency and voltage to as close as possible at synchronization point
  - Regulation = 2% of system load
  - Use synchronous reserve (including load shed) to keep frequency above 59.5 Hz
    - Shed 6-10 % of load for 1 Hz
- Post-synchronism
  - TO's/GO's continue to maintain communications with PJM to provide updated status of system conditions, in addition to the hourly report

## Island Interconnection

- Expectations of Interconnected Island
  - 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 system
    - Up to normal operating limits
    - As long as security of supplying company is not compromised

## Communications

- Communication between the TO and the generating units is critical as the restoration progresses
- Transmission and Generation Owner dispatchers shall keep generating plants apprised of system conditions and the status of the restoration process
- Generating plant personnel should be aware of certain evolutions, because of the potential effects on the generator, and the need for the generator operator to take controlling actions
  - Picking up significant blocks of load
  - Energizing long transmission lines, and the resulting voltage swings

## Reserve Requirements

- Synchronized and Dynamic Reserves are the only reserve monitored during a system restoration
  - Synchronized reserves should be sufficient to cover the largest energy contingency in each island
    - Can be made up of generation that can be manually increased or;
    - Load that can be manually shed in within 10 minutes
  - Dynamic reserves should be sufficient to cover the largest energy contingency in each island
    - Comprised of governor reserve on units and load equipped with under-frequency load shed relays



## PJM Assumes Frequency Control

- PJM will assume control:
  - When requested by Members
    - When one or more TO feels system control has become too burdensome
  - To facilitate restoration of the EHV system
  - When establishing ties to another control area

# PJM Assumes Control

PJM ASSUMES CONTROL					
Date:			Time:		
Reporting Company:					
Regulation MW			Synchronous Reserve MW		
Frequency Controlled by:			Frequency Maintained From HZ to		
<b>DYNAMIC RESERVES:</b>					
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		
<b>Total Dynamic Reserves:</b>			<b>_____ MW</b>		
INTERCHANGE SCHEDULES (Company To Company, Company To Outside)					
From Co.	To Co.	MW	From Co.	To Co.	MW
Connected Load			Minimum Source Requirements:		
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:					

- This form is submitted to PJM, when the control of an interconnected area becomes too burdensome for any one TO within the RTO

## PJM Assumes Frequency Control

- **PJM Responsibilities:**
  - Assimilates information contained in Attachment B of Manual 36
  - Determines the required Dynamic Reserve and Synchronous Reserve for the area based on the largest energy contingency (Assignments are made on a proportional basis)
  - Determine the regulation requirement (2%) (Assignments are made on a proportional basis of connected load)
  - Continues to coordinate run-of-river hydro operations
  - Updates the DMT to reflect unit capability as reported by TO's/GO's

## PJM Assumes Frequency Control

- **Member Responsibilities:**
  - TO's/GO's continue to return generating units to on-line status and restore native load in small increments to maintain generation and load balance
  - Report status of generating units to PJM
  - Respond to emergency procedures when initiated by PJM
  - Coordinate any pre-existing schedule changes with PJM
  - Update status to PJM on a hourly basis
  - Maintain communications with PJM to provide an updated status of system conditions, in addition to the hourly report

## Resources and References

- PJM. (2013). *PJM Manual 36: System Restoration* (rev. 20). Retrieved from <http://pjm.com/~media/documents/manuals/m36.ashx>