NERC Primer

PJM State & Member Training Department

Module Objectives

- To review the basic concepts of system control before actually reviewing the NERC standards
- To be able to correctly define or describe basic facts, concepts, and terms related to real-time system operations as referenced in the NERC Standards

- Americans and Canadians were first introduced to the notion of electric power system reliability on November 9, 1965
- The North American Electric Reliability Council was formed as a voluntary organization of the electric utilities of the United States and Canada following the 1965 blackout
- Since its inception in 1968, NERC has continued to change. Today, it is comprised of all segments of the electric industry

- NERC's activities include:
  - Setting standards for reliable operation and planning of the bulk power system
  - Monitor, assess, and enforce compliance with standards for bulk electric system reliability
  - Provide educational and training resources to promote reliability
  - Assess, analyze, and report on bulk power system adequacy and performance
  - Certify reliability service organizations and personnel

- **Definition of a Balancing Authority**
- Collection of generation, transmission, and loads within metered boundaries maintaining load-resource balance
  - Any electrical system bounded by tie line metering and telemetry
  - Can control generation directly to maintain its Interchange Schedule with other Balancing Authorities
  - Contributes to the frequency regulation of the Interconnection
  - Also referred to as a “Control Area”

- **Balancing Authority Obligations**
  - Instantaneous Demand
  - Interchange Schedule
  - Operating Reserve
  - Reactive Resource Requirements
  - Provide Frequency Bias Obligations
  - Balance Net Interchange and Net Scheduled Interchange
  - Use Tie-Line Bias Control
  - Comply with CPS and DCS Standards
  - Repay Inadvertent Interchange Balance

- **Control Area Balancing**
  - Interchange
    - Actual
    - Scheduled
  - Area Control Error (ACE)
    - Resources
      - Power Generated
      - Imports
    - Demand
      - Load
      - Exports
      - Losses
    - Frequency maintained ~ 60 Hz

- **Interchange:**
  - Scheduled:
    - MW's scheduled between a Balancing Authority and an external Authority
  - Inadvertent:
    - Difference between Scheduled Interchange and Actual Interchange
  - NERC: (-) Into the system / (+) Out of the system
  - PJM: (+) Into the system / (-) Out of the system

- **Balance and Frequency:**
  - In order to achieve a frequency of 60Hz, the Power Generated and the Imports must equal the Load, the Exports, and the Losses
  - Frequency defines the speed at which rotating synchronous generation must operate

- **Frequency & Voltage:**
  - Non-Motor Load: varies in magnitude with voltage and frequency, but is more dependent on voltage variations (Resistive)
  - Motor-Load: varies in magnitude with voltage and frequency, but is more dependent on frequency variations (Inductive)
  - Capacitive

- **Imbalance Conditions:**
  - Over-Generation
    - Total Generation > Total Load
    - Frequency > 60Hz
    - Inadvertent out of area increases
    - ACE is not on 0
  - Under-Generation
    - Total Generation < Total Load
    - Frequency < 60Hz
    - Inadvertent into the area increases
    - ACE is not on 0

- Area Control Error is the measure of how well balanced an Area's generation is with its customer demand
- It is also how well balanced Actual Interchange is with the Scheduled Interchange of an Area
- ACE can be impacted by:
  - System frequency
  - Governor response
- Both system frequency and governor response make up the system frequency response characteristic

Area Control Error

$$ACE = (NI_A - NI_S) - 10\beta(F_A - F_S) - I_{ME}$$

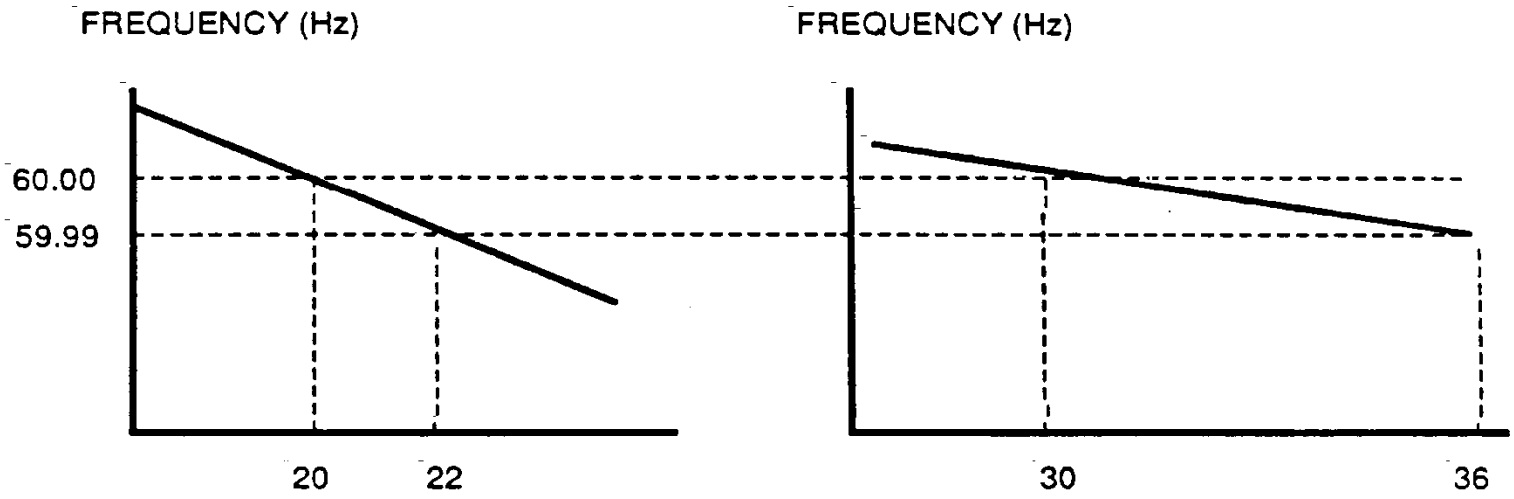
- Where:
  - NI_A = Net Interchange Actual
  - NI_S = Net Interchange Scheduled
  - β = Frequency Bias (always negative)
  - F_A = Frequency Actual
  - F_S = Frequency Scheduled
  - I_{ME} = Meter Error

- **Frequency Bias Characteristic**
  - Area's ability to respond to frequency deviations
    - Inertial Response
    - Governor Control
    - Load Response
  - Annual Determination
    - Actual system characteristic
    - At minimum 1% peak load estimate
    - Calculated value

- Inertial Response: the property of an object that resists a change in its speed and direction
- Energy stored in the rotating elements of the power system
- Inertia is dependent upon the mass, diameter, and rotational speed of the object
- All generators and spinning loads on the system are sources of inertial energy

- Governors respond to increases or decreases in system frequency by decreasing or increasing generator unit speed by adjusting the input to the prime mover
- Governor response is determined by the governor's droop characteristic
- Droop determines how much power a generator responds with in response to a frequency change
- Droop is in proportion to power rating of the unit
- This allows for parallel governor operation of all units
- Governor action does not maintain or restore frequency back to 60 Hz

- Droop is stated as a percentage; usually 5%
- A 5% change in frequency (3 Hz) would mean a 100% change in the rating of the unit
- Governors also have a deadband characteristic
- Deadband prevents governor control from “hunting,” so that a unit will not respond to very small variations in frequency
- Governor deadband is +/- .036 Hz



UNIT A GENERATOR
LOAD (MW)

LOAD PICK-UP FOR A:

2MW FOR 0.01 Hz

UNIT B GENERATOR
LOAD (MW)

LOAD PIĆK-UP FOR B:

6MW FOR 0.01 Hz

Frequency Bias Example*

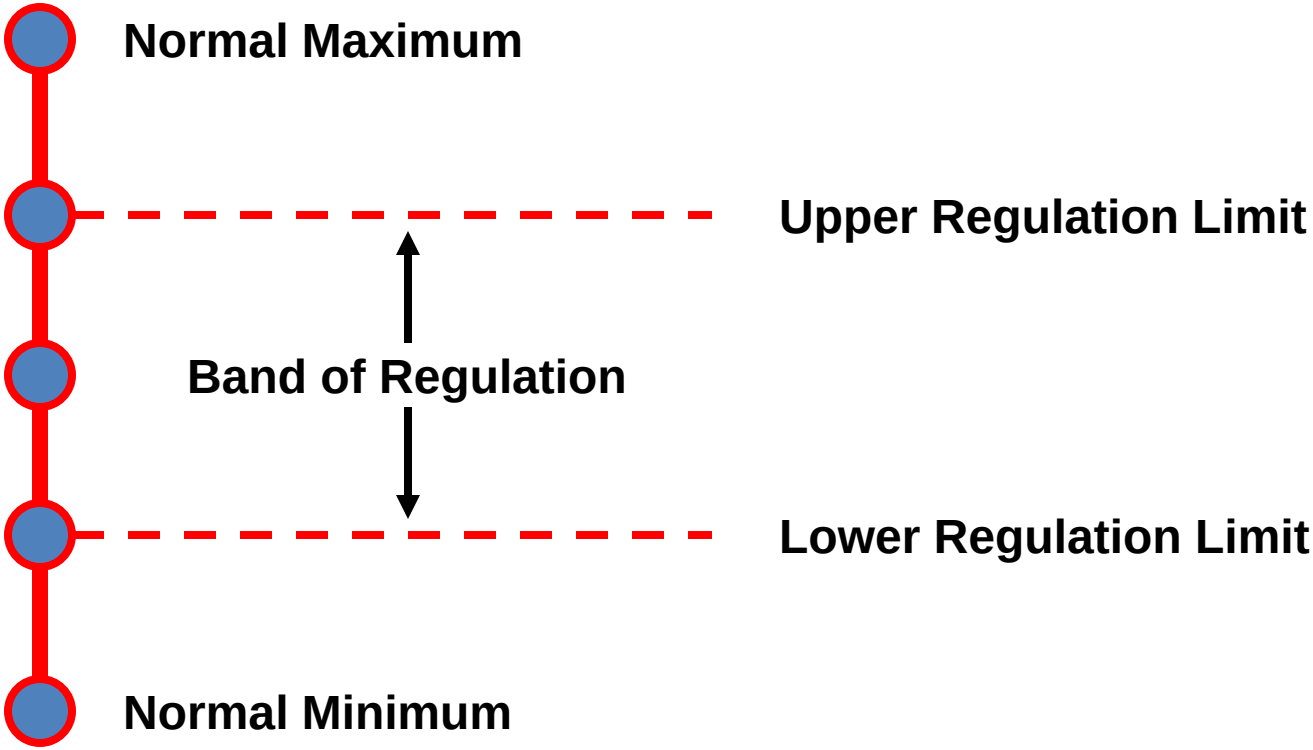
What is a Balancing Authority's contribution if the interconnection frequency equals 59.92 Hz and the Authority's frequency bias is 500 MW/0.1 Hz?

(Frequency Deviation) x (Frequency Bias) = MW Correction

(0.08 Hz) x (500 MW/0.1Hz) = 400 MW

- Regulation/AGC is the variable amount of generation under automatic control
  - Independent of normal dispatch signal
  - Can be obtained within five minutes or less
    - Governors respond to minute-to-minute load changes
  - Regulation/AGC correct for small changes in load*
    - Constantly changing
  - Economic dispatch is used for large changes in load
  - Regulation/AGC can maintain or restore frequency to 60 Hz unlike governor control

Regulation


Normal Maximum
Upper Regulation Limit
Band of Regulation
Lower Regulation Limit
Normal Minimum

- **Load Response:**
  - System load that increases or decreases in correlation to frequency increases or decreases
  - Measured in MW/0.1 Hz
  - Approximately 1-2% load change for a 1% change in frequency*

Frequency Bias Example*

System Load = 75,000 MW

Frequency Change = +/- 0.02 Hz

What is the change in system load?

(75,000 MW) x (0.02 Hz) x (1%/0.1 Hz) = 150 MW

(75,000 MW) x (0.02 Hz) x (2%/0.1 Hz) = 300 MW

- **System Contribution:**
  - Governor Characteristic
  - Load Characteristic

- Frequency Bias is a Balancing Authority's contribution to the interconnection to mitigate deviations in frequency

- Inadvertent is the unscheduled flow of MW's between control areas
  - Bi-product of free-flowing tie lines
  - Varies over time into or out of an area
  - Balancing Authorities monitor and track accumulated inadvertent
  - Action must be taken to reduce
  - Payback can either on-peak or off-peak
  - Two methods of payback
    - Unilateral
    - Bilateral

- Unilateral:
  - Accomplished through bias in the ACE calculation control
    - Clock is slow and the area owes; the ACE is adjusted to over-generate
    - Clock is fast and the area is owed; the ACE is adjusted to under-generate

- Bilateral:
  - Arrangement is made between two control areas
  - Accumulated inadvertent must be in opposite directions; one owes, other is owed
  - Inadvertent payback; not scheduled interchange
  - Accomplished by using the manual add component in the ACE calculation
  - Tagged transaction

- **Time Error:**
  - Electric clocks operate on the assumption that frequency is a constant, steady 60 Hz
  - Clocks run slow or fast whenever frequency deviates from 60 Hz
  - Standard for time is measured by the atomic clock located in Boulder, Colorado
  - Corrections are made according to the procedures of NAESB Time Error Correction Procedure

- **Time Error Correction:**
  - Each interconnection has a designated time monitor*
  - Monitor calculates time error and requests corrections throughout the Interconnection
  - Scheduled frequency for Interconnection adjusted to correct
  - Slow Clock – 60.02 Hz*
  - Fast Clock - 59.98 Hz*
  - Time Error Correction is always +/- 0.02 Hz*

- **NERC Time Error Correction Rules**
  - Corrections start and end on the hour or half-hour*
  - 60-minute notification provided to Interconnection for starting and stopping*
  - Can be postponed or cancelled by at least 30% of the control areas*
  - Schedule has a one-hour minimum run time*

- **Manual Add:**
  - Used to compensate for meter error
    - Updated to reflect actual error
  - Tie line telemetry failures
  - Bilateral payback
  - Not used for correcting control problems

- **Control Modes**
  - Flat Frequency Control (Constant Frequency)
    - No tie line values
    - Used for islanded or isolated systems
    - Island with most generation
  - Flat Tie Line Control (Constant Tie Line)
    - No frequency values
    - Used during restoration
  - Tie Line Bias
    - Both frequency and interchange
    - Normal operating mode*

- **Control Standards:**
  - CPS1 is a measure of how well the area is operating to the outside world
    - Based on ACE and frequency; maintain ACE to 0 and the relationship to frequency
    - Calculated every minute
  - CPS2 is the "length of the road" and is calculated from load
    - Measure of ACE magnitude over 10-minute intervals within the area's L_{10}
  - DCS: return ACE to zero or pre-disturbance values within 15 minutes following a system disturbance

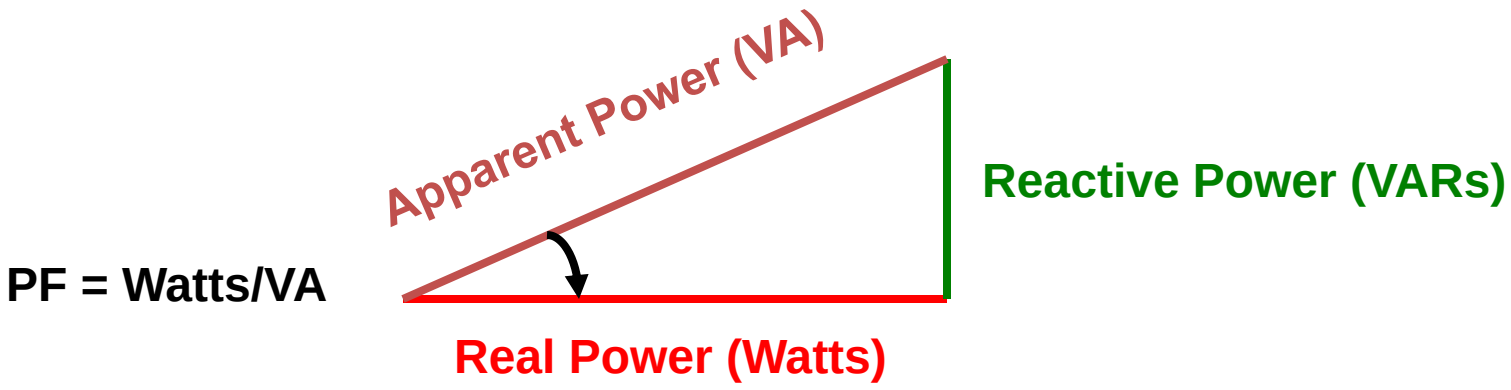
- **Voltage Control:**
  - Under normal conditions, control should equal a small percentage deviation (+/- 5%)
  - Under abnormal conditions, control should be no greater than +/- 10 %
- **Deviations > 10% can result in:**
  - Utility equipment damage
  - Customer equipment damage
  - System separation

- **Short Term/Long Term Voltage Deviations:**
  - **Short Term**
    - Higher in magnitude
      - Lightning
      - Switching
  - **Long Term**
    - Continuous on system until action is taken
      - Capacitor Banks
      - Generator Excitation
      - Reactor Banks

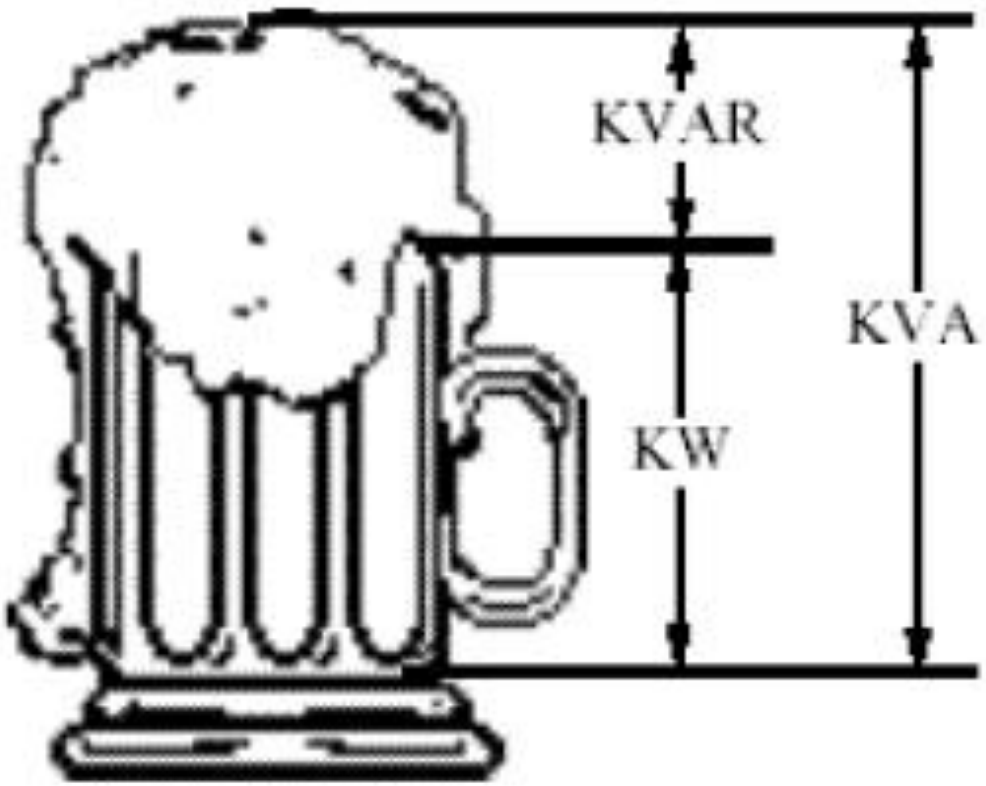
- **Low Voltage:**
  - Heavy Loading
  - Equipment Outages
  - High Customer Demand
  - Heavy Interchanges
- **High Voltage:**
  - Light Load Conditions
  - Loss of Load
  - Loss of Equipment

- **Loss of Generation or Transmission facilities:**
  - Creates low voltage situations
  - Can Create overloads
  - Removes voltage control devices
  - Can leave the system without sufficient reactive resources

- **Reactive Power:**
  - Establishes and maintains electric and magnetic fields
  - Oscillates between capacitive and inductive loads without being used up
  - Exchanged between magnetic fields (inductive) and electric fields (capacitive**)**



The Beer Analogy



- **System Reactive Control:**
  - Automatic Voltage Regulators
  - Capacitors
  - Reactors
  - Static Var Compensators
  - Synchronous Condensers
  - Load Tap Changers
- **Two types of reactive reserves**
  - Static
  - Dynamic

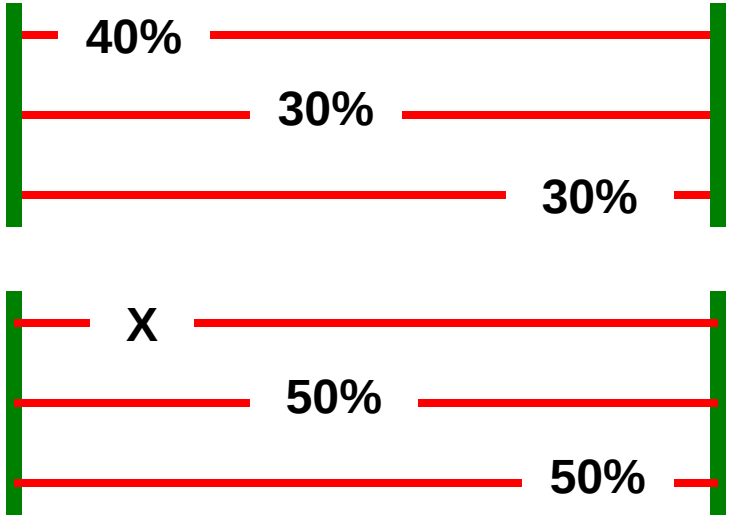
- **Phase Angle Relationship:**
  - Inductive reactance increases with frequency
  - Capacitive reactance decreases with frequency
  - Pure resistive circuits have a zero phase angle
  - Capacitive reactance circuits have a leading phase angle
  - Inductive reactance circuits have a lagging phase angle

$_{E}L_{I}$ the $_{I}C_{E}$ Man

- **Voltage Drops:**
  - System load is primarily inductive (source to sink)
  - Voltage drops can be reduced by reducing reactive needs
  - Capacitive resources should be close to loads
  - Voltage drops and reactive losses are related
  - Reactive loss is a function of I^2
  - Capacitance is a function of V^2

- **Surge Impedance Loading:**
  - At SIL, VAR's inherent in the transmission line cancel the VAR's needed; supplies itself
  - Below SIL, the transmission line acts like a capacitance source supplying VAR's to the system
  - Above SIL, the transmission line acts like an inductive load, absorbing VAR's from the system
  - Above SIL at full load,
    - Active power transfers double
    - Reactive power losses are quadrupled

- Distribution Factor is a relative change in power flow on a particular line due to a change in injection
- Dependent on line impedance



- **Distribution Factors:**
  - Monitor to determine and mitigate limitations on the system
  - NERC Standards address security analysis to ensure reliable operation in both normal and contingency situations
  - Electricity follows the path of least resistance

- **Ferranti Rise:**
  - Long term overvoltage
  - Occurs with lightly loaded or open-ended lines
  - Voltages greater than 10% above nominal can occur
  - Increases with voltage
  - Magnitude is determined by source-end voltage and length of line*

- **$V_R = V_S/\text{cosine}\ (L/8.61)$**

- **Stability Limits:**
  - Ensure that torque and power angles remain controllable
  - Stability exists when angles between buses are relatively small
  - Instability exists when angles grow to high magnitudes and vary over a wide range
  - System collapse:
    - 90% power angle theoretically
    - In reality, it is less

- **Reliability Authority:**
  - Directs all operational reliability functions within its area
  - Determines Interconnected Reliability Operating Limits (IROL's)
  - Monitors area to ensure system operates within its thermal, voltage, and stability limits
  - Specifies requirements for Interconnected Operations Services
  - Directs Transmission Operators or Balancing Authorities in mitigating Operating Reliability Limits

- **Reliability Authority:**
  - Assists Transmission Operators in relieving equipment or facility overloads
  - Approves transactions with respect to transmission reliability and provides approval or denial to Interchange Authority
  - Performs day-ahead analysis
  - Calls for emergency actions

- **Planning Authority:**
  - Ensures long-term plan for adequate resources and transmission
  - Assesses and publishes industry trends
  - Provides reports and data
  - Monitors the implementation of the transmission and resource plans

- **Balancing Authority:**
  - Maintains balance between loads and resources
  - Keeps actual interchange equal to scheduled interchange
  - Controls generators capable of regulation
  - Performs generator commitment and economic dispatch
  - Receives interchange schedules
  - Provides commitment and dispatch schedule to the Reliability Authority

- **Balancing Authority:**
  - Approves bilateral transactions with respect to ramping requirements
  - Implements emergency procedures in coordination with the Reliability Authority

- **Resource Planner:**
  - Develops long-term plans for resource adequacy of specific loads
  - Collects and develops related resource information for planning purposes
  - Identifies resources considered firm resources
  - Verifies resource plans meet adequacy resource requirements
  - Works with Planning Authority to identify potential alternative solutions to meet resource requirements

- **Transmission Operator:**
  - Responsible for the reliability of its transmission system
  - Operates or directs the operation of the transmission facilities
  - Implements Reliability Authority actions to mitigate emergencies
  - Provides maintenance plans to the Reliability Authority and others as needed

- **Interchange Authority:**
  - Collects approvals or denials for interchange transactions
  - Provides Balancing Authorities with individual bilateral interchange transactions
  - Sends interchange “tag” to each Transmission Service Provider
  - Ensures interchange transactions are balanced and valid
  - Coordinates curtailments ordered by the Reliability Authority

- **Transmission Planner:**
  - Develops plans for transmission service and interconnection requests beyond one year
  - Coordinates and jointly plans with other Planners
  - Ensures new facilities do not adversely affect the reliability of neighboring systems
  - Verifies its plans for new or reinforced facilities to meet reliability standards

- **Transmission Service Provider:**
  - Authorizes the use of the transmission system
  - Approves interchange transactions from the reservation perspective
  - Determines the Available Transfer Capability (ATC)
  - Manages requests for transmission service according to the tariff
  - Arranges for transmission loss compensation

- **Transmission Owner:**
  - Owns and maintains its transmission facilities and specifies the equipment operating limits
- **Distribution Provider:**
  - Provides the physical connection between the end-use customer and the electric system and is responsible for “local” safety and reliability
- **Generator Operator:**
  - Operates generating facilities
- **Generator Owner:**
  - Owns and maintains generation facilities specifying the equipment operating limits

- **Purchasing-Selling Entity:**
  - Arranges for and takes title to energy for delivery to a Load-Serving Entity
  - Arranges for transmission service with the Transmission Service Provider
  - Submits transaction information to the Interchange Authority

- **Load-Serving Entity:**
  - Provides energy to its end-use customers
  - Owns or contracts with Generator Owners for capacity and energy
  - Reports its generation arrangements to serve load
  - Contracts for Interconnected Operations Services

Questions?

Disclaimer:

PJM has made all efforts possible to accurately document all information in this presentation. The information seen here does not supersede the PJM Operating Agreement or the PJM Tariff both of which can be found by accessing: http://www.pjm.com/documents/agreements/pjm-agreements.aspx

For additional detailed information on any of the topics discussed, please refer to the appropriate PJM manual which can be found by accessing: http://www.pjm.com/documents/manuals.aspx