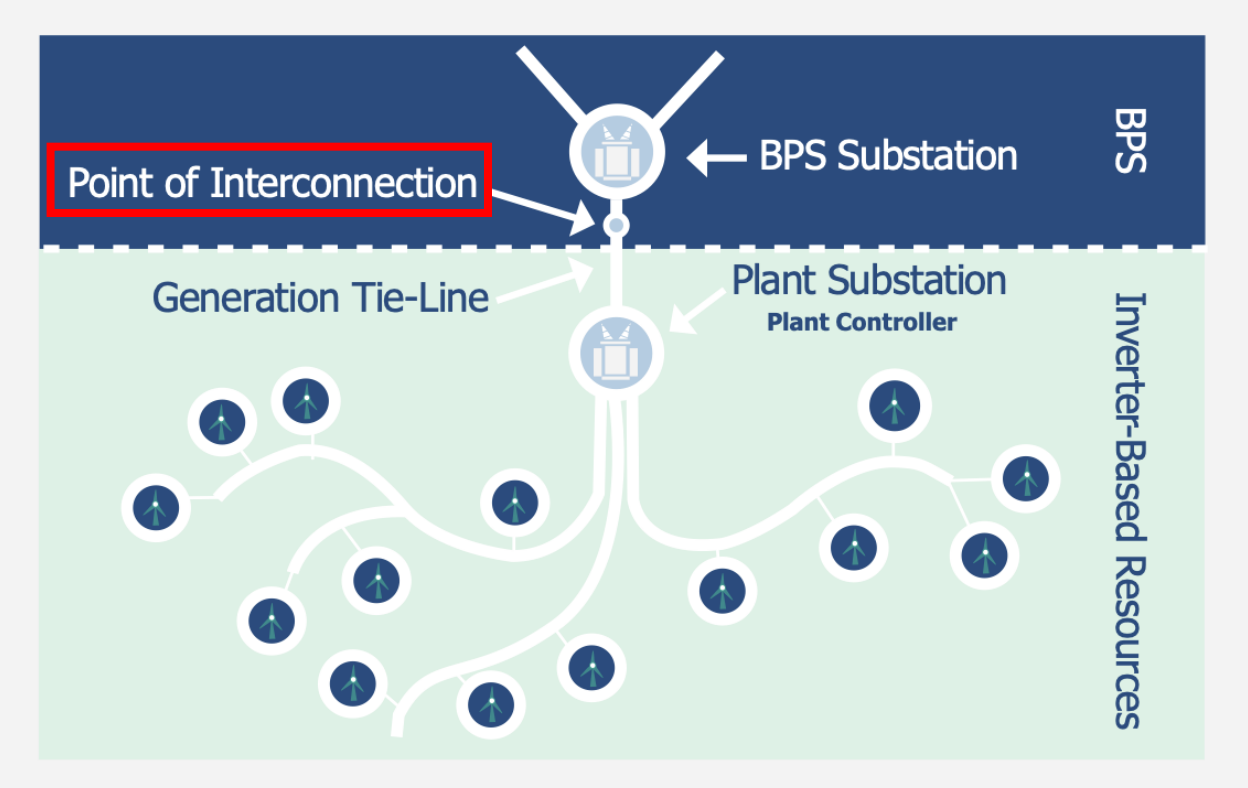
Grid Reliability During Normal Operations

ESIG
ENERGY SYSTEMS
INTEGRATION GROUP

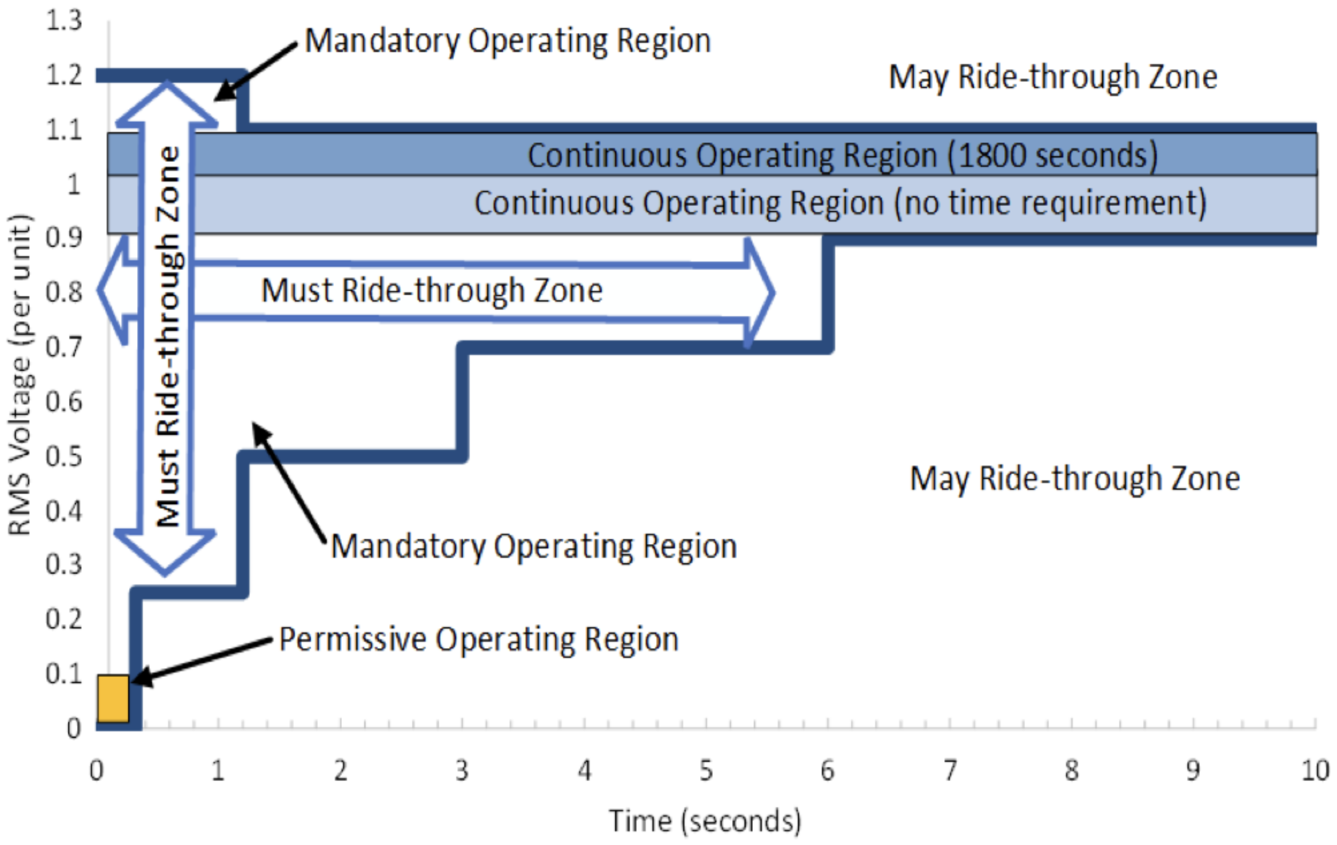
What is Normal Operation for Resources

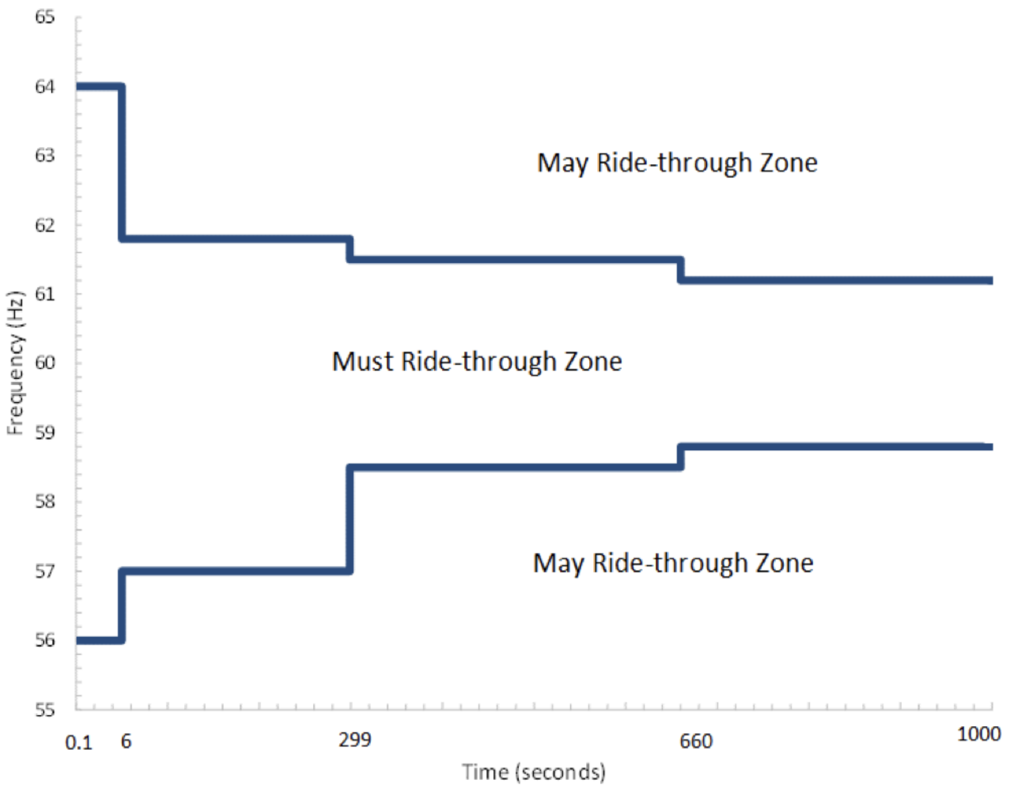
- **Oversimplified:** any operating point that is not ridethrough
  - Regions of mandatory operation for a resource
    - Measured at the POI
    - Must remain online except when damage to equipment could occur
- **Less simple:** the controls and operation of a resource when its POI measurements are within appropriate bounds
  - Reactive power control, voltage control, primary frequency response, etc.
- **Normal operating regions are specified by each transmission service provider**



Source: NERC

What is Normal Operation for Resources

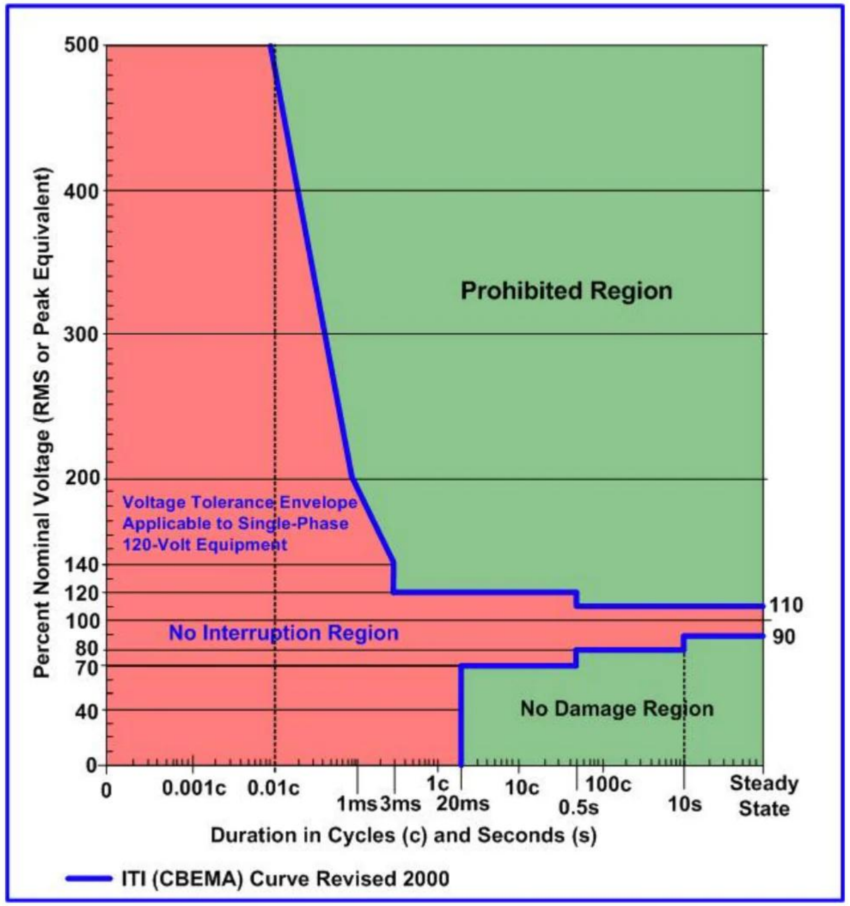




Source: NERC

What is Normal Operation for Equipment?

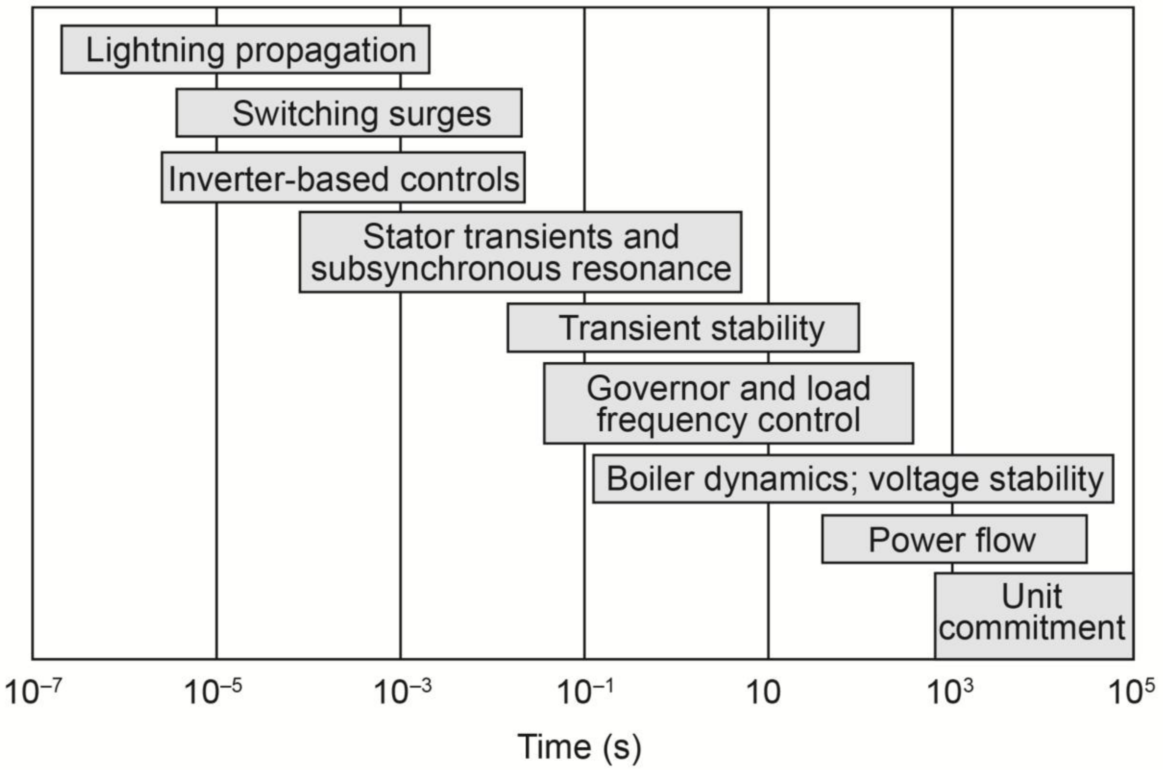
- **Generating and demand facilities may be limited by auxiliary equipment**
  - Cooling
  - Wind turbine mechanical controls
  - Transformers
  - Power supplies
  - Communication
  - IT
- Some auxiliary equipment is mandatory for operation of a facility
  - Normal operations include ensuring this equipment is supplied power within proper ranges



EPRI ELECTRIC POWER RESEARCH INSTITUTE

What is Normal Operation for the Power System?

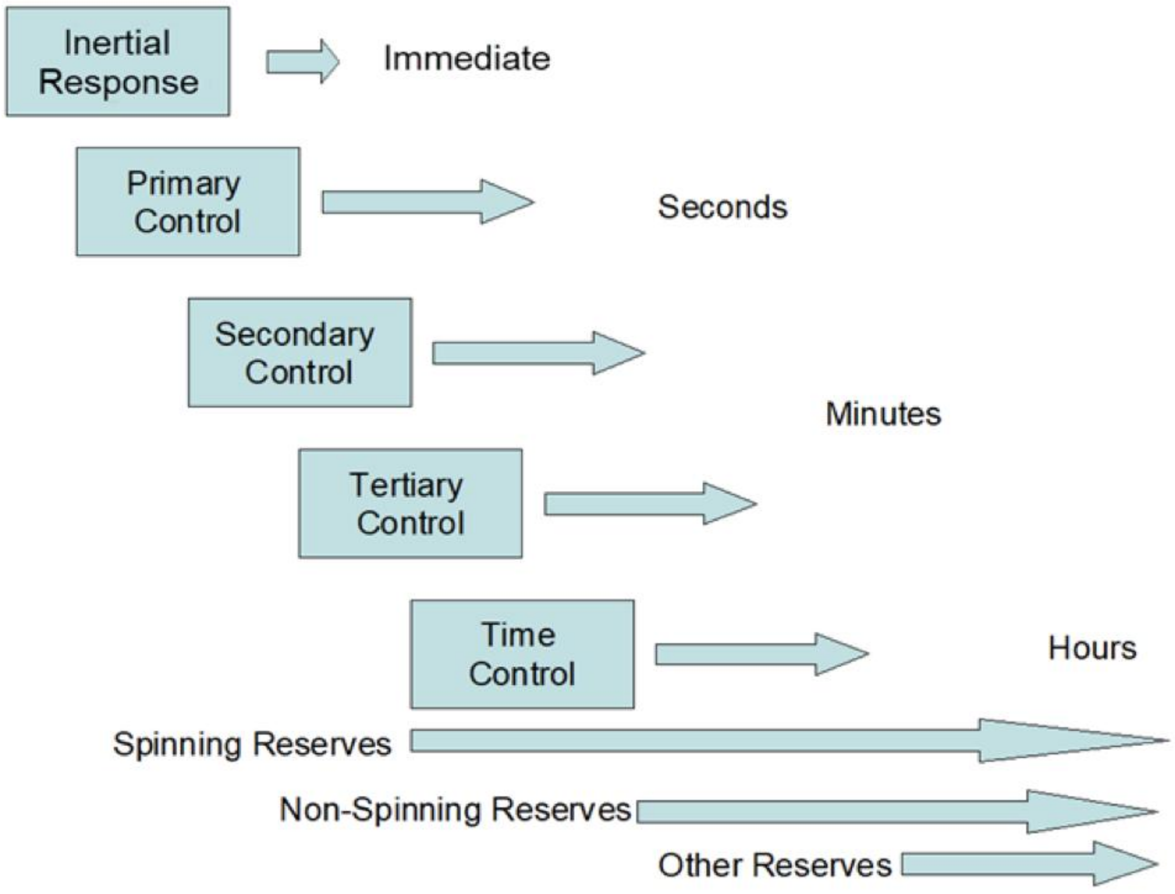
- **Ensuring quality power to demand customers**
  - Sufficient power quality
  - Minimizing disruptions in delivery
- **Maintaining system quantities within specified bounds**
  - Frequency near nominal (Frequency stability)
  - Voltage within specified operation band (Voltage stability)
- **Managing outages and ensuring reserve margins are met**
- **Posturing the system for potential disturbances**



Source: Smart Grid Wide-Area Transmission System Visualization

Normal Operation Timeframes

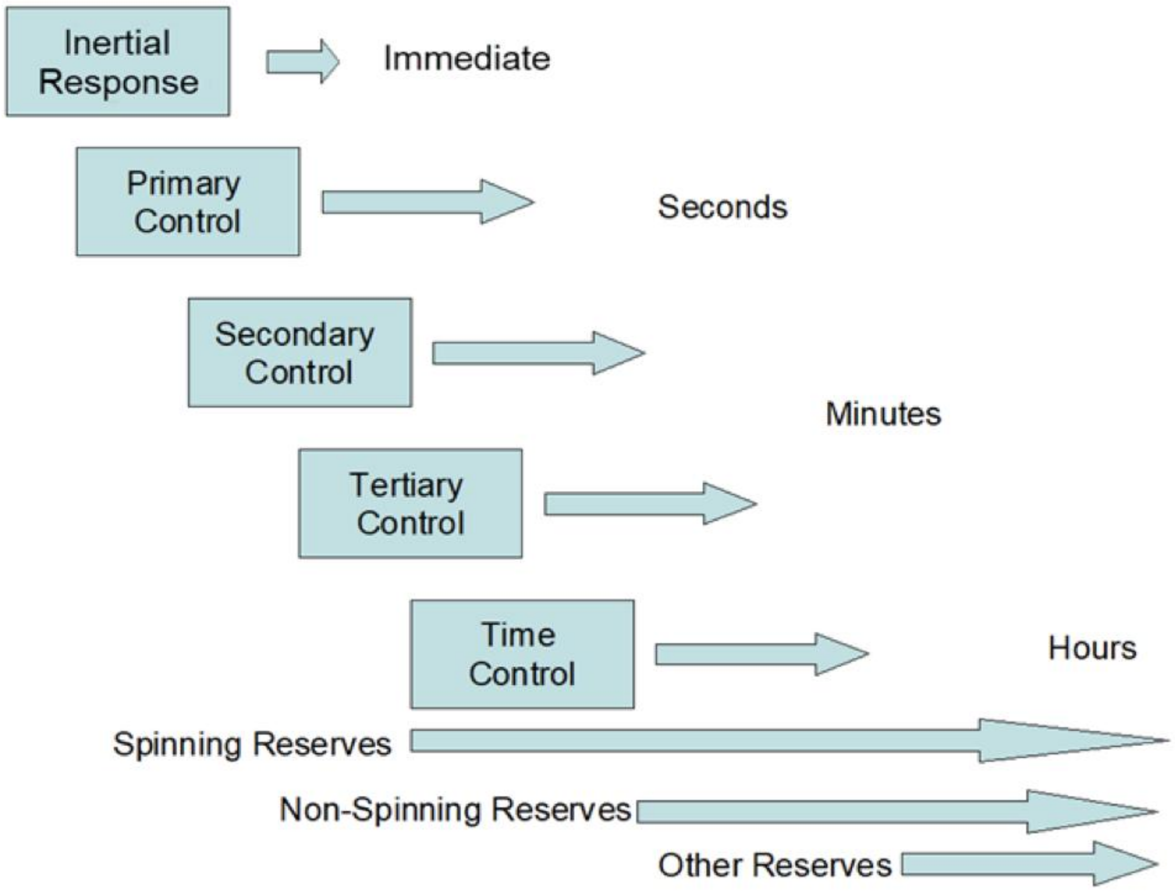
- **Primary Controls**
  - Operating on seconds timeframe
    - Autonomous controls that respond based on power system stimuli
    - Operates when measured quantities hit thresholds or trigger values
- **Examples:**
  - Primary frequency response
  - Fast frequency response*
  - Automatic voltage regulation
  - Transmission-connected power electronics devices



Source: NERC

Normal Operation Timeframes

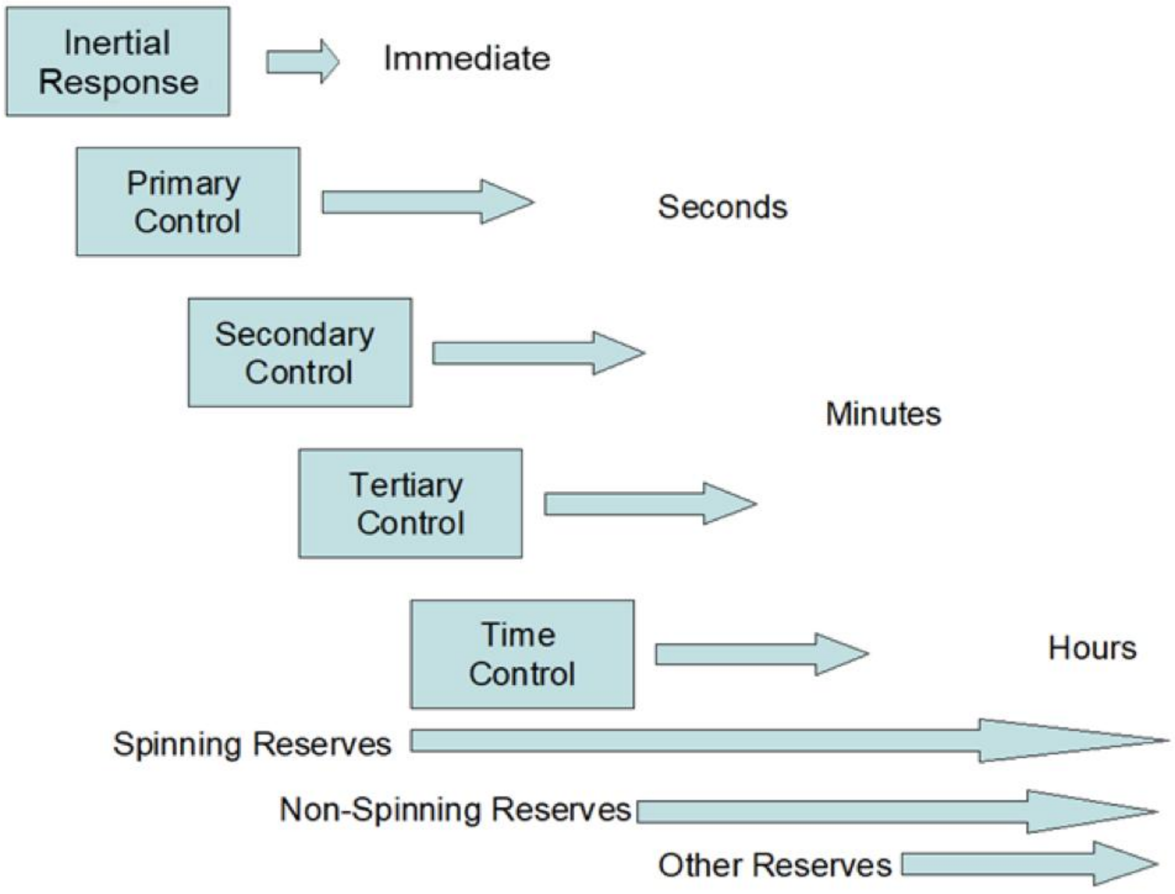
- **Secondary and tertiary controls**
  - On the minutes timeframe
  - Often involve operator inputs and manual actions
  - Used for balancing the system and recovery from disturbances
- **Examples:**
  - Active power setpoint changes
  - Reactive power setpoint changes
  - Voltage setpoint changes
  - Transmission equipment status changes



Source: NERC

Normal Operation Timeframes

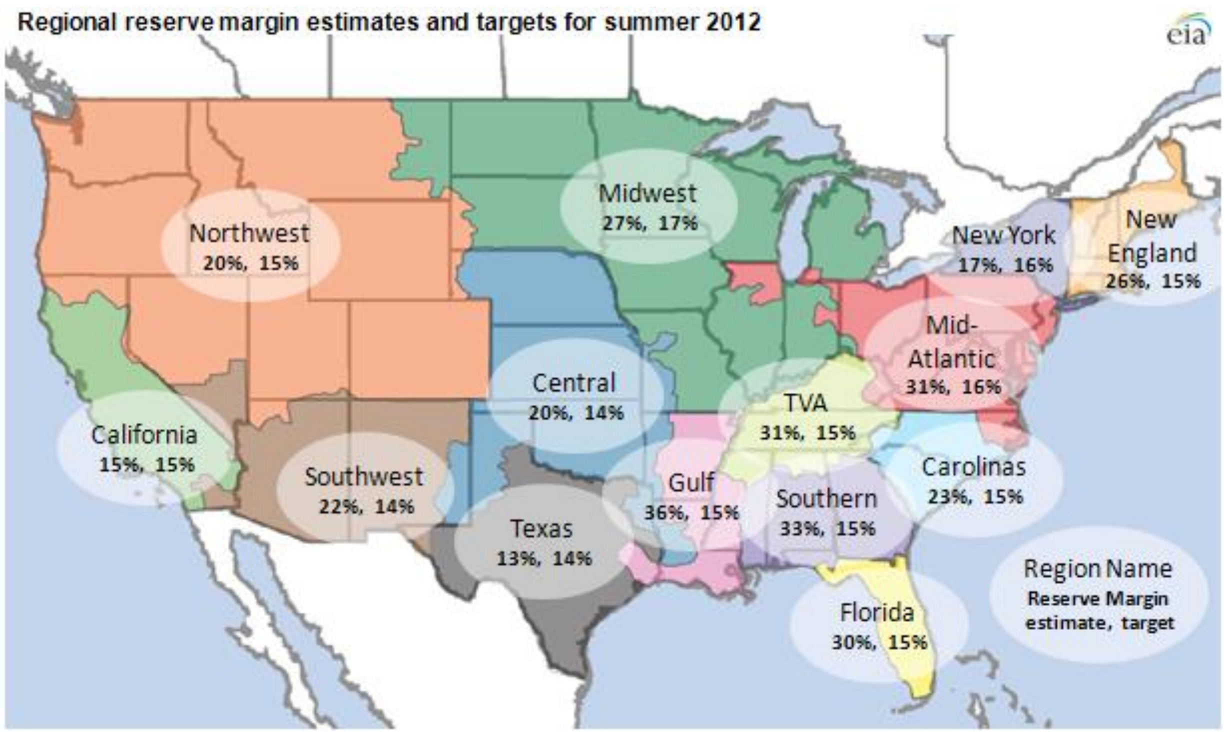
- **Time controls+**
  - On the hours timeframe
  - Involve operator inputs and manual actions
- **Examples:**
  - Ensuring reserve margins are met
  - Planning/scheduling outages
  - Balancing inter-area exchanges



Source: NERC

Reserve Margins

- **Important for ensuring sufficient energy is available during normal operations to prepare for abnormal conditions**
  - Reserve margins are based on the expected largest loss of source that a balancing area may observe
  - These are maintained through procuring generation in addition to the expected demand to help system balance in the event of a loss of source (generator or area tie)



Source: EIA

Active Power Controls: Why?

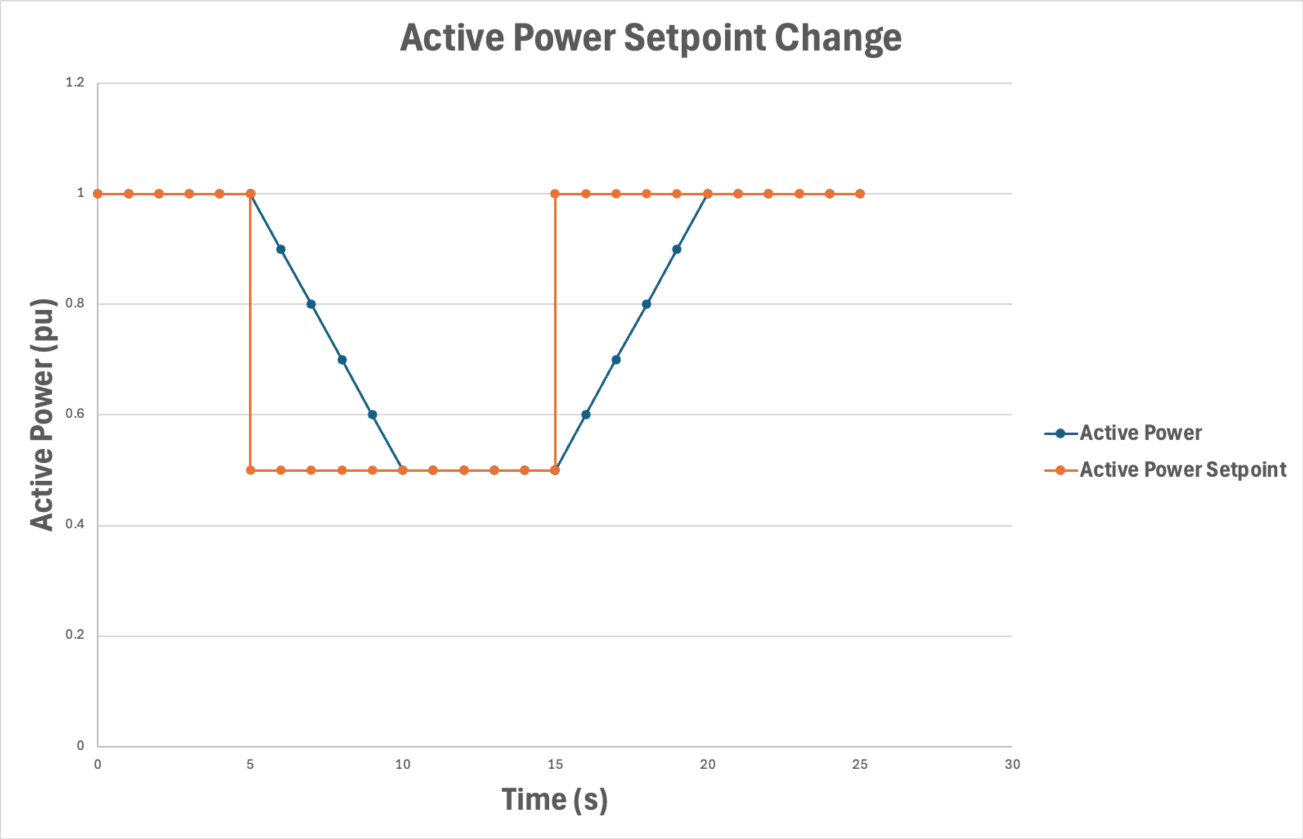
- **Balancing load and generation**
  - Automatic and grid operator initiated active power changes from generating resources are used to manage system frequency and load/gen balance
  - Balancing Authorities use these controls to maintain their ACE and interchanges
    - Also utilized to ensure reserve generation is available
  - Redispatching based on system conditions and possible next contingencies
- **Maintaining nominal system frequency (remember power quality?)**
  - Frequency is a wide-area metric and is affected by changes to generation or demand
  - Automatic frequency controls (primary frequency response) help maintain system frequency by altering active power injection based on measured system frequency

Active Power Controls: Overview

- **Active Power Setpoint Change (secondary/tertiary/time)**
  - Active power reference signal is input into the controller, and the controller moves to the new setpoint
- **Response to grid frequency disturbance (primary)**
  - **Primary Frequency Response**
    - Immediate and proportional change in active power injection in response to frequency disturbances – should move in grid-stabilizing direction
  - **Fast Frequency Response***
    - Similar to PFR in that active power injection will change in response to frequency disturbances
      - Acts on significantly faster timeframes to PFR. Capable of providing full response in ~30 cycles

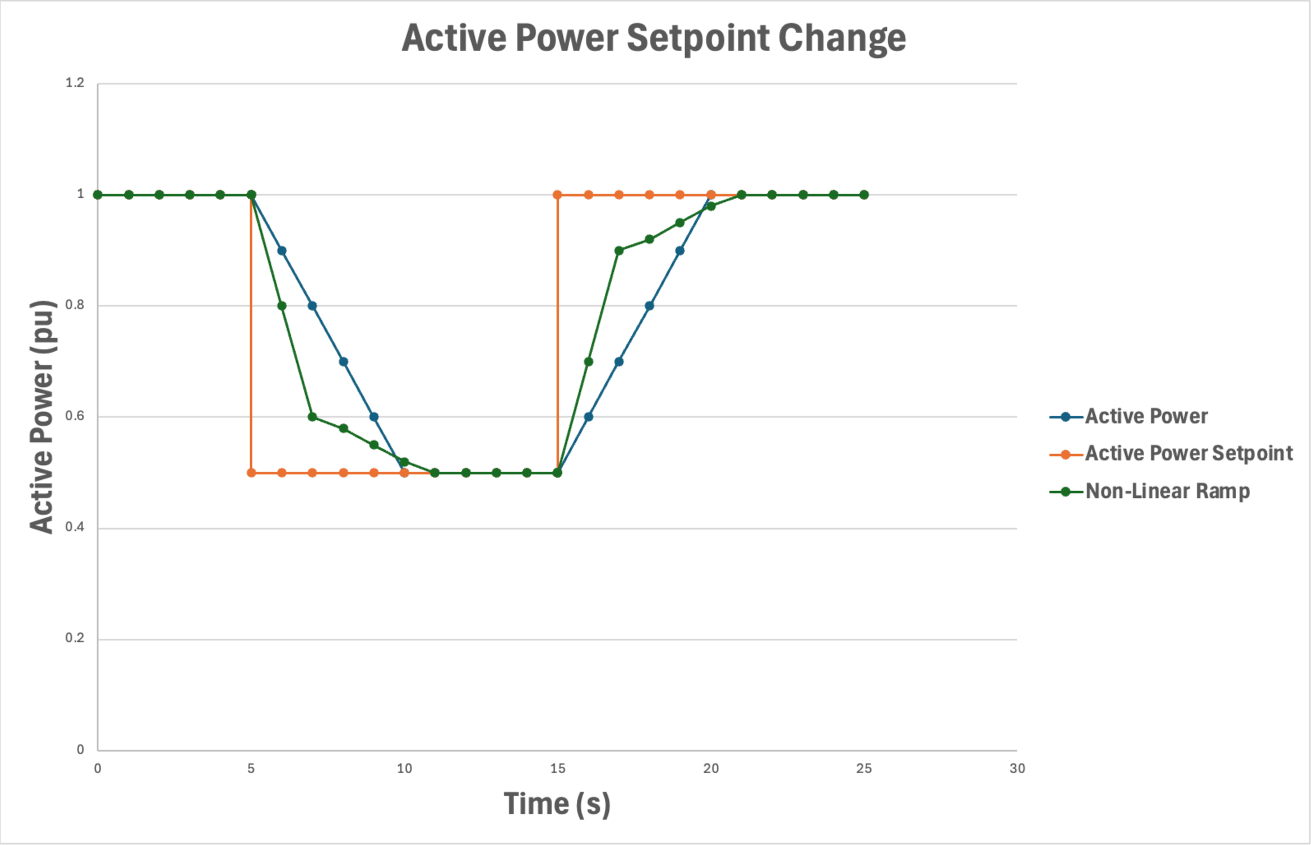
Active Power Controls: Active Power Setpoint

- **Secondary or tertiary control (or longer)**
- **Example: Active Power Setpoint Change to Power Plant Controller**
  - TSO needs to curtail the resource
  - TSO sends signal to reduce power to 0.5pu at 5 seconds
  - Active power injection **ramps** down
  - TSO sends signal to increase active power at 15 seconds
  - Active power injection ramps up



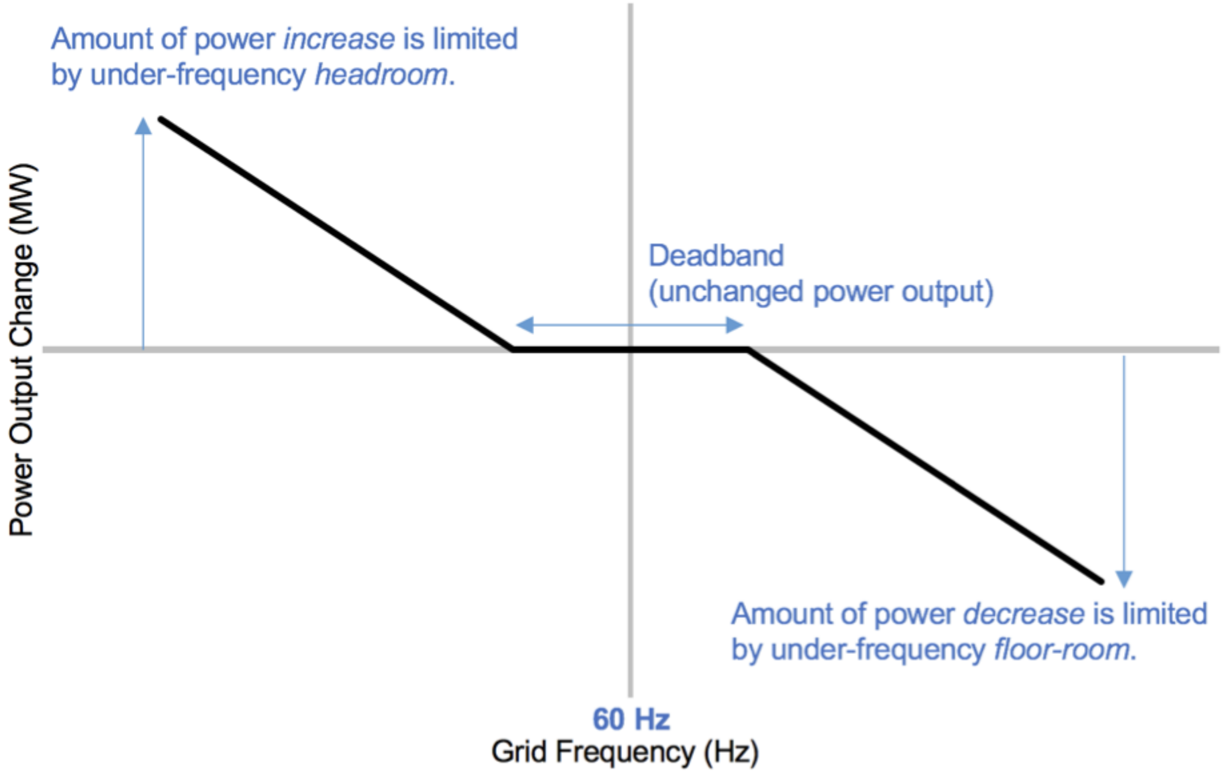
Active Power Controls: Active Power Ramp Rates

- Each resource should have parameters that control the rate of change of active power injection in response to a setpoint
  - **This is different than ramp rates for PFR or fault ride through**
- Ramp rate minimum and maximum should be specified by the TSO and may change based on:
  - System strength
  - Resource type
  - System needs
- Some resources may have non-linear ramp rates



Active Power Controls: Primary Frequency Response

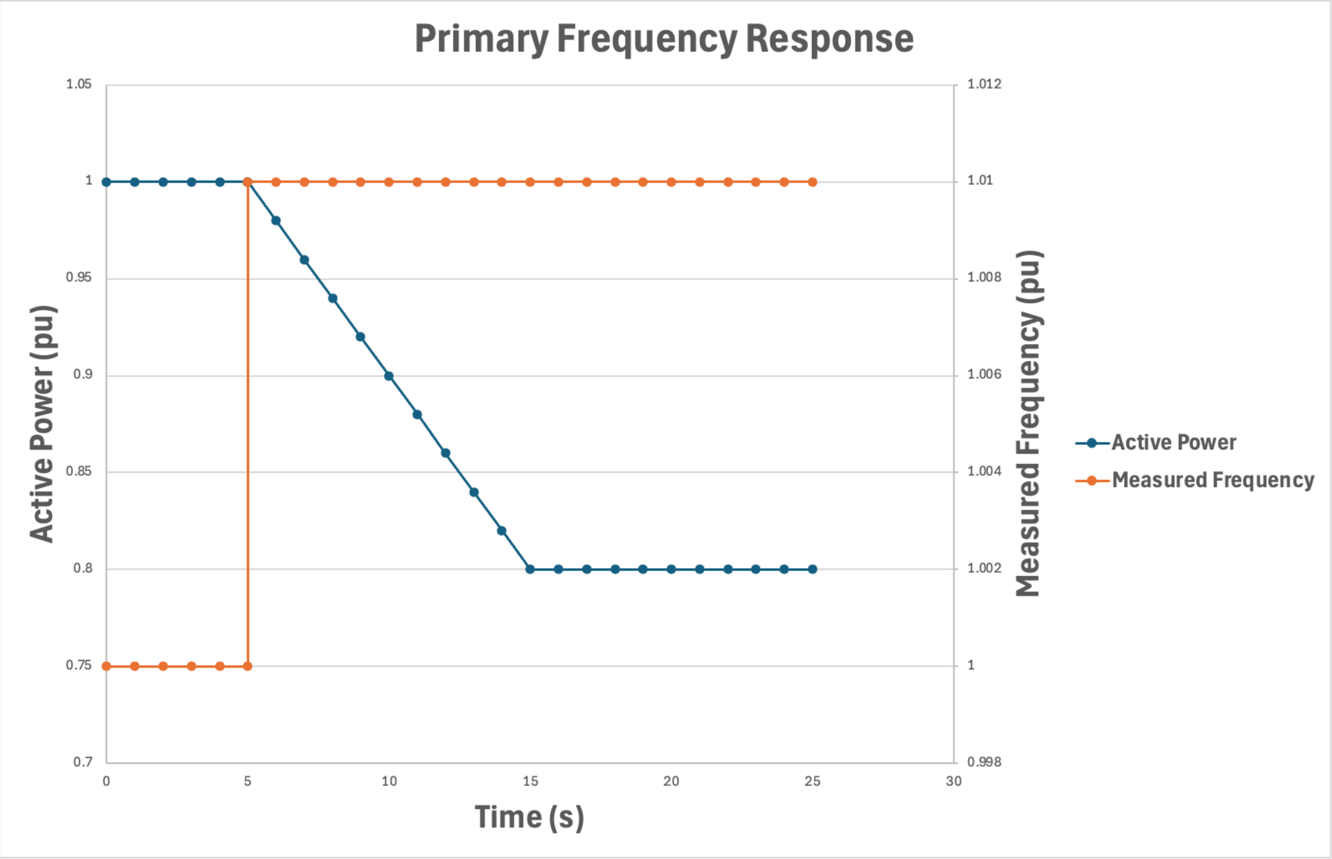
- **Primary Control**
  - Changes active power injection to support the system frequency
  - Operates with a **deadband** to avoid constant fluctuation
    - Typically either 17 or 36 mHz
    - Once measured frequency is outside deadband, control begins
      - Does the delta calculation use nominal or deadband value?
  - Operates with a **droop** to specify response magnitude
    - Typically 5%



Source: UPENN

Active Power Controls: Primary Frequency Response

- **Primary Frequency Response Example**
  - Frequency excursion occurs at 5 seconds
    - 1% frequency change (60.6 Hz)
  - IBR plant operates on 5% droop
    - With 5% droop, every 1% of frequency mismatch solicits 20% active power response
  - IBR plant reduces active power injection by 20% while system frequency remains high

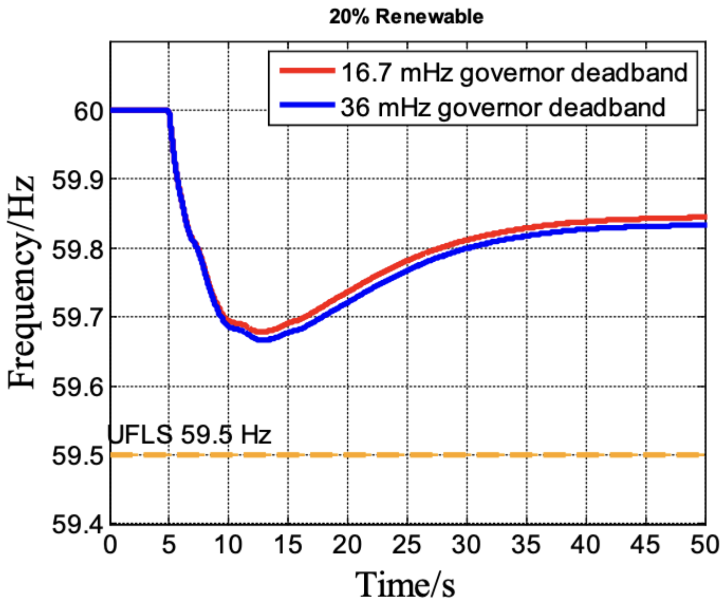


Active Power Controls: Primary Frequency Response

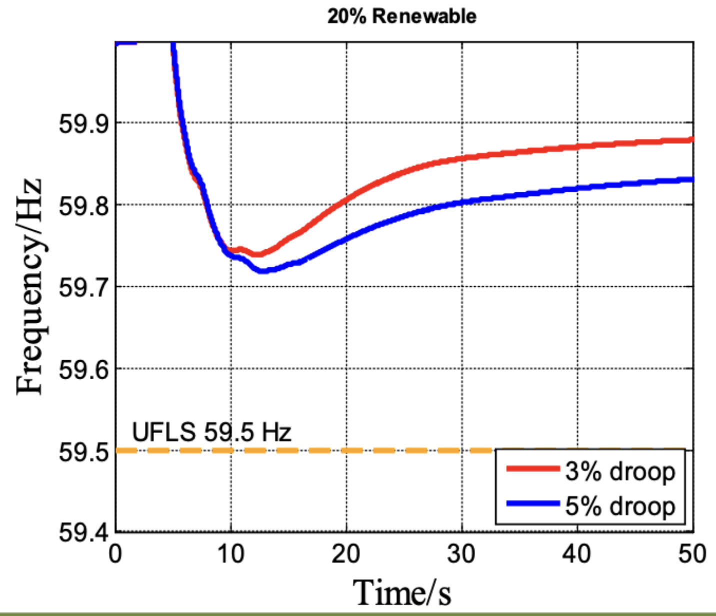
Effects of deadband and droop settings

Source: IEEE PESGM

- Dead-band



- Droop setting



- A narrow governor dead-band makes the governor kick in earlier.
- Improvement is not obvious.

A 3% governor droop can significantly improve the frequency nadir and settling frequency of WECC.

Reactive Power Controls: Why

- **Maintaining nominal voltage levels at point of interconnections (remember power quality?)**
  - Voltage is much more location dependent than frequency
  - Maintaining voltage levels at numerous local control points helps keep voltages near nominal
- **Maintaining specific voltages at TSO discretion**
  - Some portions of the system may need “help”
  - For example: plants may be run ”high” (i.e 1.03pu) to support voltage levels if the local area is prone to low voltages
- **Maximizing reactive power capability for use on the grid**
  - Operating at fixed reactive power levels may not allow for additional capabilities to be utilized during disturbances
  - Choosing appropriate reactive power control modes is critical
    - Appropriate modes and settings for an individual plant or the region

Reactive Power Controls: Overview

- **Reactive Power Setpoint (secondary/tertiary/time)**
  - Reactive power setpoint is given to the controller, and the reactive power injection moves to that setpoint
- **Power Factor Setpoint (secondary/tertiary/time)**
  - The plant operates at one specified power factor at all times. Reactive power varies with active power
- **Automatic Voltage Regulation (primary)**
  - Changes reactive power injection as a function of voltage.
  - Can be **open** or **closed loop** controllers
    - **Open loop** controllers do not incorporate any feedback
      - May be unstable in most grid conditions
    - **Closed loop** controllers incorporate feedback to minimize large swings in output and controller interactions

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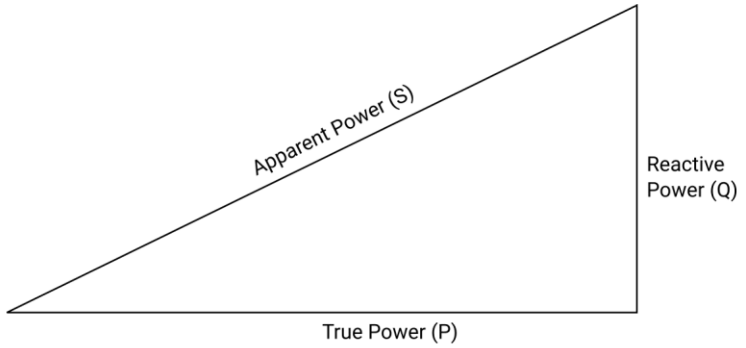
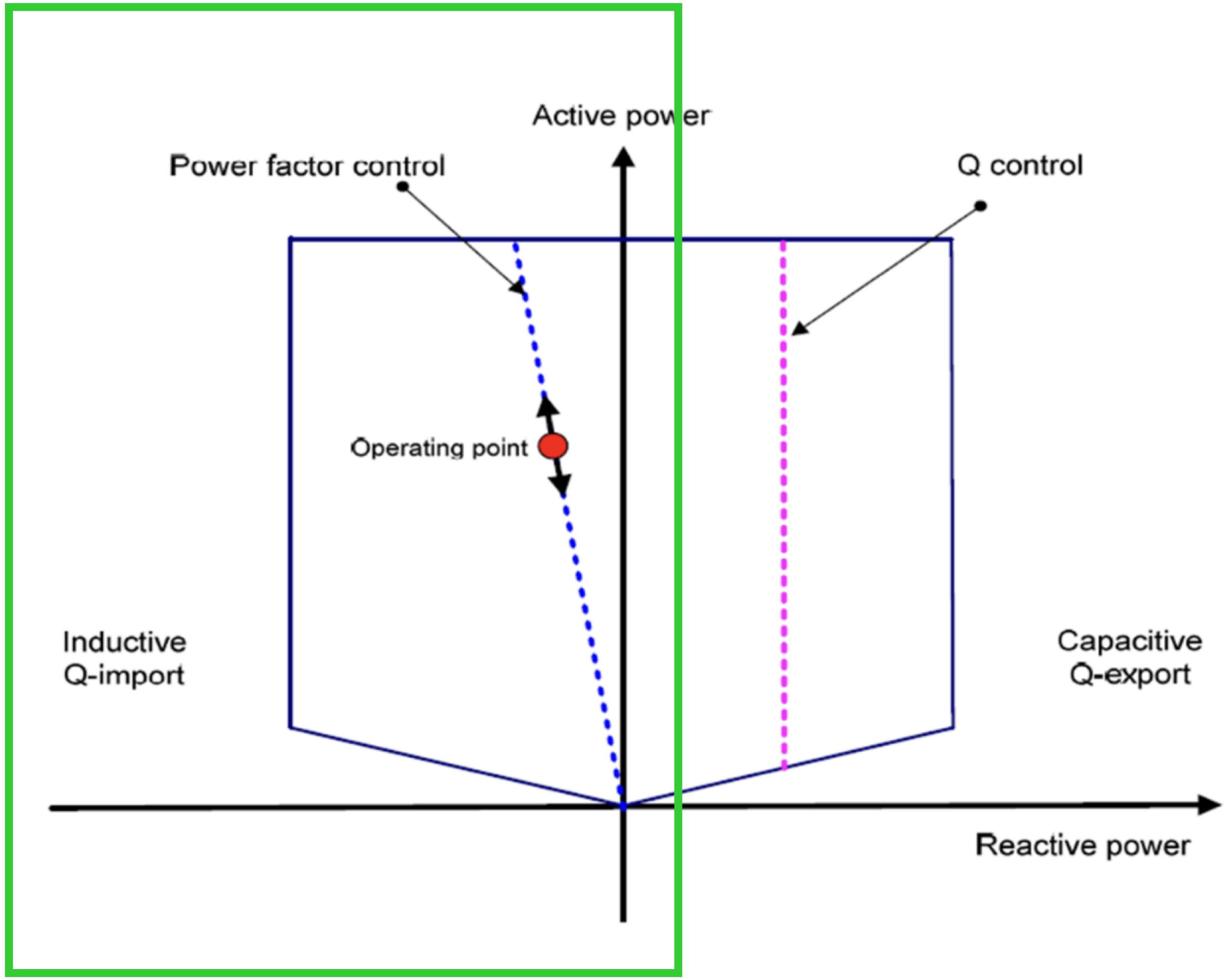
Reactive Power Controls: Power Factor Control

- **Secondary or Tertiary**
  - IBR plant operates at a fixed power factor
  - Reactive power changes based on changes to active power to maintain power factor
  - Can also be implemented along with AVR (power factor limiters)





Risks of Fixed Power Factor Control and Limiters

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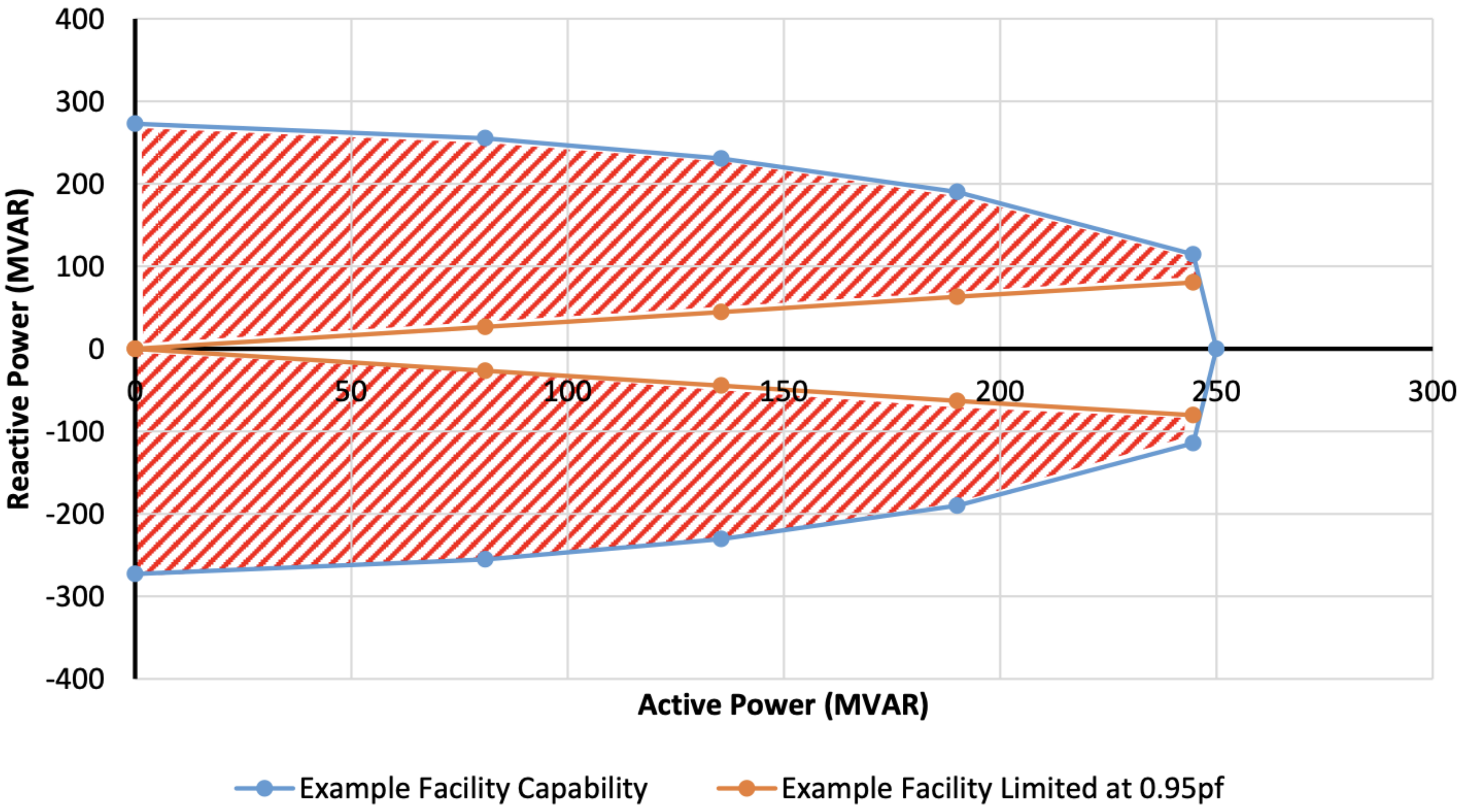
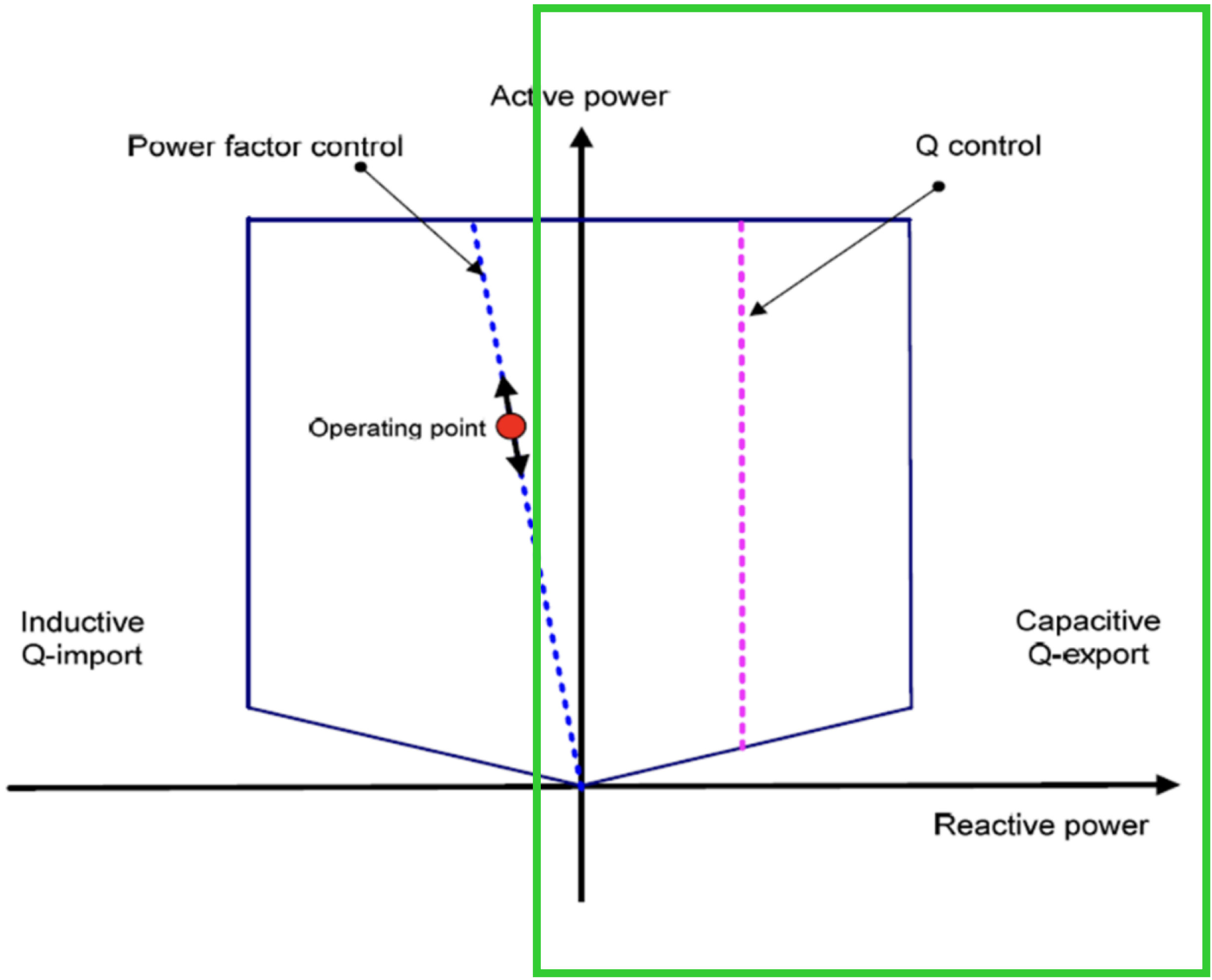


NERC Level 2 Alert data shows 35% of the currently installed IBRs are operating in this limited mode

Reactive Power Controls: Reactive Power Setpoint

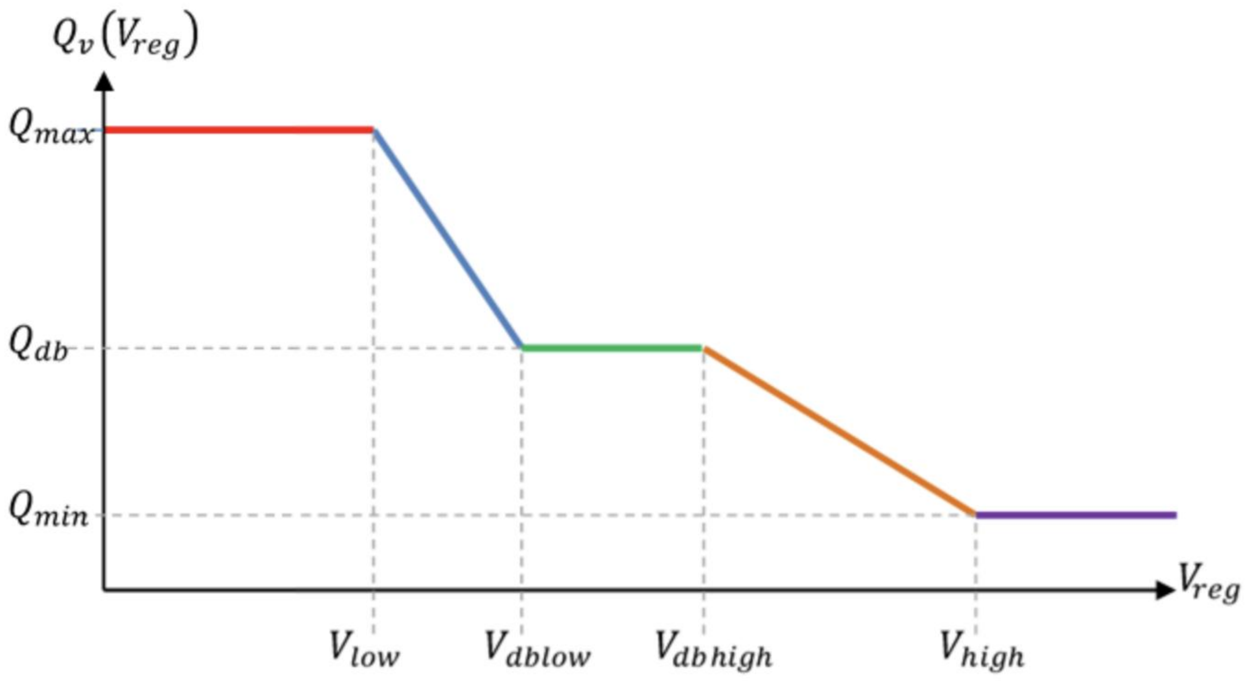
- **Secondary or Tertiary**
  - IBR plant operates at a specific reactive power setpoint
  - Reactive power remains at this level regardless of active power output
    - Also will not regulate voltage
  - Still limited by reactive power capability limits
  - Not often used in ”live operations”
    - Typically used during commissioning, maintenance, testing, or other TSO interventions



Reactive Power Controls: Voltage Droop/Slope

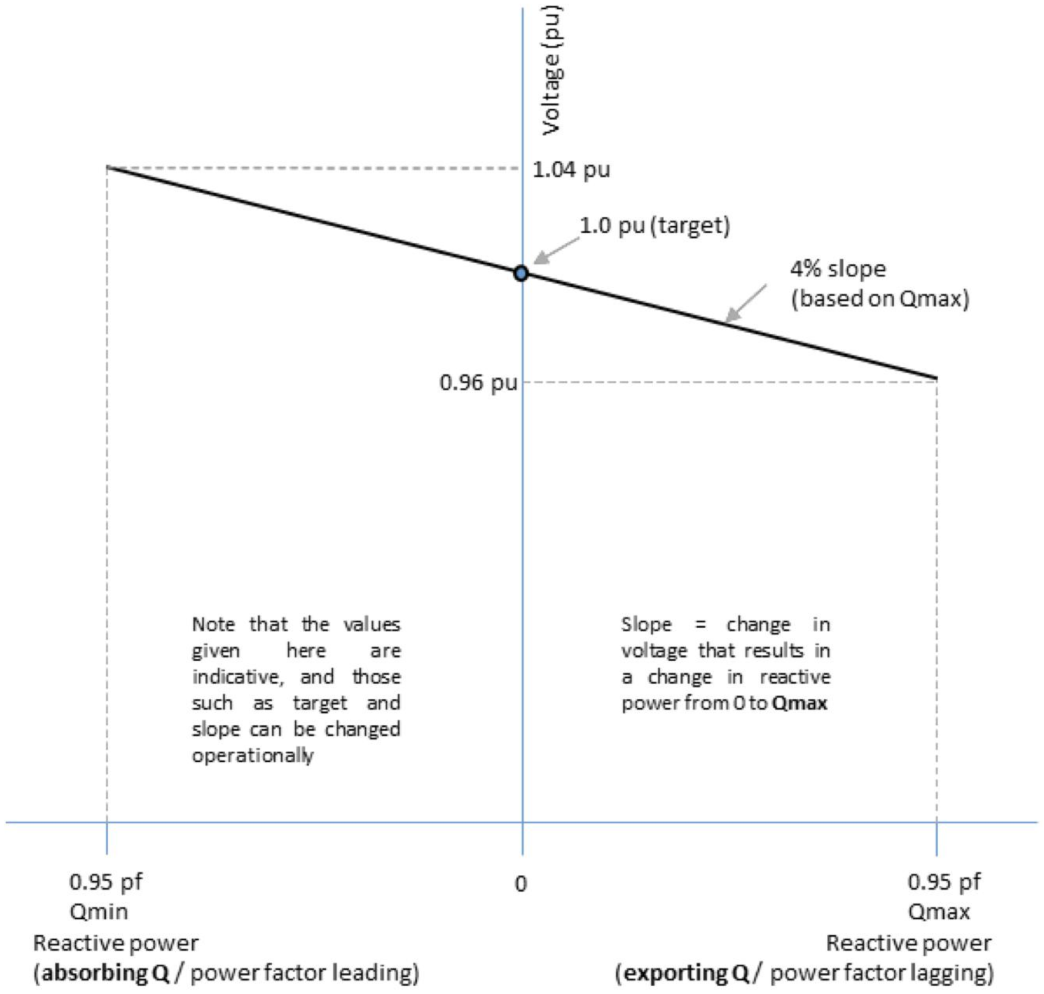
Source: [Powerworld]

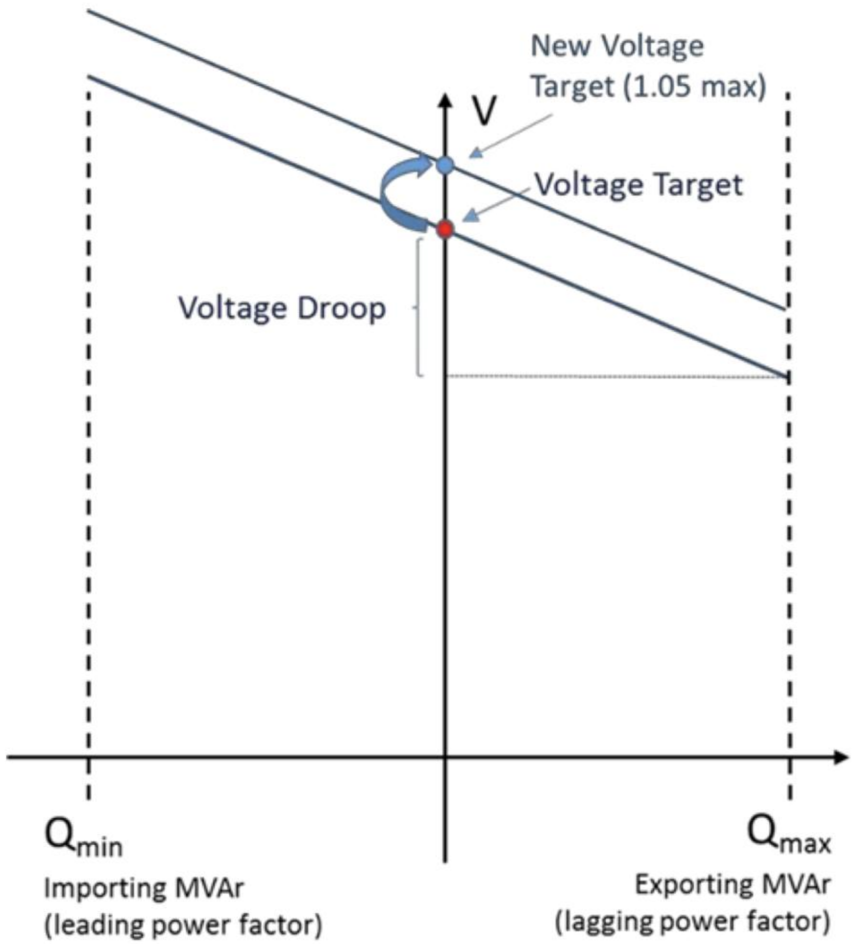
- **Primary**
  - Voltage regulation is primary goal
  - Reactive power injection changes based on difference between measured voltage and a target
  - Deadbands are utilized to avoid controller interactions and “hunting”
  - Droop or slope determine the magnitude of the total reactive power response
  - Control gains determine rise time and other response speed



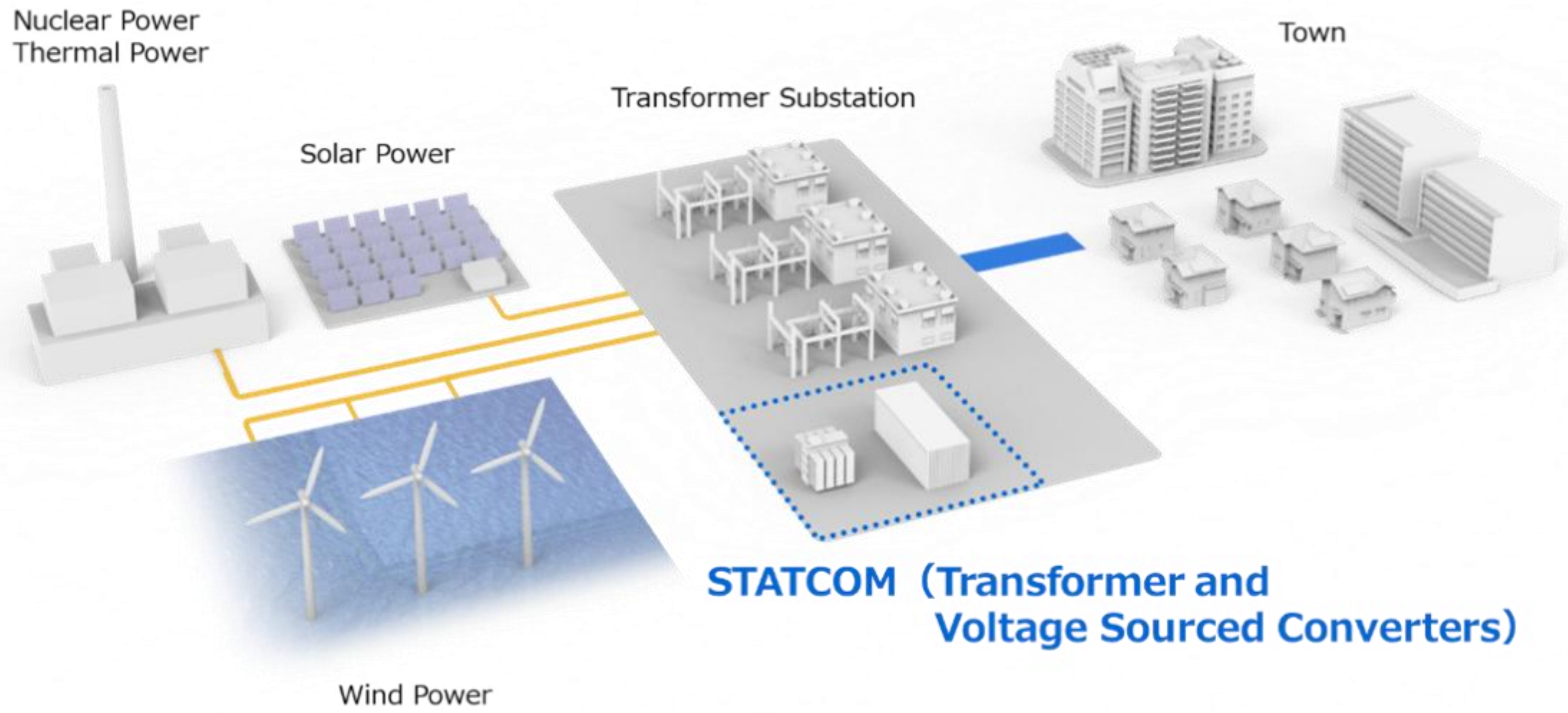
Reactive Power Controls: Voltage Droop/Slope

Source: NESO





Brief Detour for Andrew to Talk STATCOM



Source: Toshiba

Inertial and Primary Controls in Practice

- **As discussed, these controls react to disturbances faster than operators can**
  - **Inertial controls**
    - Need to be studied and validated
    - Devices capable of response on this timeframe need to be in-service and in the right locations
    - Dependent on **quality modeling and study work**
  - **Primary Controls**
    - Need to be studied and validated
    - Control parameters should be based on real system needs confirmed by TSO
    - May need to be studied/assessed together with multiple resources to minimize controller interactions
    - Dependent on **quality modeling and study work**

Key Takeaways

- **There are many tools available to maintain normal operation reliability**
  - Utilizing these tools requires detailed study work and accurate representations of the system and its components
    - Need to be sure of performance before connecting to the system
- **Interconnection studies and processes are the cornerstone of reliability**
  - Feeds new representations into the system models
  - Changes to equipment to ensure reliability are significantly easier before commercial operation
  - Studying how a resource will perform on the system **before** interconnection is critical
- Part of normal operation reliability is **posturing the system to be prepared for operation in abnormal conditions** and recovery from those conditions