System Dynamics and the Changing Resource Mix

Rich Hydzik, Transmission Operations, Avista
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Essential Reliability Services

• Simple grid description
  • Spin a magnet in a coil of wire and connect it to a load
  • Spins 60 times per second, or 3600 revolutions per minute
  • Big spinning machine at 3600 rpm – not too fast, not too slow, just right

• Inertia
  • Rotating mass tends to stay rotating
    • Balancing a bicycle moving instead of stopped
  • Larger the mass, the more inertia (ratio of kinetic energy to rating)
    • Coal plants are very large
      • Hydro, steam, and combustion turbines have similar per unit inertia constants
        • 2-7 MW*sec/MVA
      • Wind and solar facilities have very little or no inertia – no spinning mass

• More inertia makes system resistant to fast changes
Essential Reliability Services

- Concern about changing generation fleet
  - Large coal fired power plants are being retired
  - Natural gas, renewables, and variable generation are increasing
  - Large synchronous generators inherently provide Essential Reliability Services

- Essential Reliability Services – ERSTF formed September 2014
  - Generation Ramping – ability to adjust to meet changing loads
  - Frequency Control
    - Inertia – object in motion tends to stay in motion
    - Primary frequency control – automatic response compensating for the loss of a large generator - fast
    - Secondary frequency control – Automatic generation control (AGC) to 60 Hz - slow
  - Voltage control – maintain within limits

- Reliability Effects
  - How does reliability change with newer resources?
Generation Ramping

- Variable resources are variable
- Generating resources must accommodate load and variable generation
- Load is very predictable hour to hour – 3% or so 24 hours out
- Solar generation has a very predictable pattern
  - Fast ramp up in morning
  - Large ramp down in evening
- Wind is more variable
  - Continuous changes
Generation Ramping

- Wind Generation – December 1, 2015
Generation Ramping - Variability

- Wind Generation – Avista 2014 Summer Peak
Generation Ramping “Duck Curve”

Actual net-load lower than originally estimated due to increased amount of renewable resources including DER

Typical Spring Day

- Net Load 11,663 MW on May 15, 2016
- Actual 3-hour ramp 10,892 MW on February 1, 2016

ramp need ~13,000 MW in three hours

over generation risk
Generation Ramping “Duck Curve”

- 9/25/2016 CAISO Renewable Generation
- Evening solar ramp out must be made up by other generation
- 10,000 MW over three hours
- CAISO has 5,000 MW of distribution connected (DER) solar that is not counted in this
- BA Load = Generation – Interchange
  - DER is not counted in generation
  - DER decreases BA load
Primary Frequency Control

- Responds in seconds to change in frequency (speed control)
  - Steam turbines respond quickest
  - Gas turbines are almost as fast
  - Hydro is slower
- Higher inertia slows frequency decline
  - More kinetic energy in the system
  - Allows more time for governor response
  - Frequency nadir is not as low
- Governor responding according to droop characteristic (3-5%)
- Automatic response
- Each generator increases output a little – adds up fast
- If not enough generators respond
  - Torque out exceeds torque in
  - System slows down and stops
Primary Frequency Control

01/21/2016 01:08:56 Colstrip 3 and 4 – 1500 MW
Primary Frequency Response

- Inertia – object in motion tends to stay in motion – 3600 rpm
  - 0.036 Hz deadband is 2.16 Hz
- Inertia determines Rate of Change of Frequency (ROCOF)
- More inertia, slower frequency decline
  - More time for governors to respond
- Less inertia, faster frequency decline
  - Less time for governors to respond
- How much is enough?
  - WECC and Eastern Interconnection – don’t know
  - ERCOT – They know and plan and operate to it
- Renewables have little or no inertia
  - Inverters – solar
  - Type 4 Wind Turbines – similar to inverters
- Renewables can have fast frequency response (synthetic inertia)
  - FFR can mitigate effects of low inertia and high ROCOF
Secondary Frequency Control

- **Automatic Generation Control (AGC)**
  - Slow acting – follows Area Control Error (ACE)
  - ACE measures schedule error and frequency error

- **Contingency Reserve**
  - Deployed following loss of a generator within ten minutes

- **Load Following Reserve**
  - Generation brought online to meet load variations within the hour

- **Regulating Reserve**
  - Generation controlled by AGC automatically responding to ACE changes
  - Avista generally carries +/- 25 MW going into each hour
Voltage Control

- Synchronous machines provide the voltage source
  - Adjust voltage (supply or consume vars) in real-time – regulators
  - Automatic voltage regulation maintains voltage stability during contingencies
- Capacitors and inductors store and release energy each cycle
  - Capacitors release energy when inductors store energy and vice versa
  - AC systems take advantage of this
    - Power factor correction
    - Series compensation
- Most inverters are current sources clocking off of system voltage
  - Not an independent voltage source
  - Inverters can supply vars
  - Type 3 and 4 Wind Turbines can supply vars
- Voltage pushes and pulls current (AC)
Voltage Control

- Voltage must be maintained near ratings under all conditions
  - Generally 95% to 105% of nameplate rating
  - Equipment guarantee to operate correctly does not apply when voltage limit is exceeded
- Heavy load
  - Tends to depress voltage
  - Capacitors are used to compensate – produce vars
- Light load
  - Voltage tends to rise
  - Reactors are used to compensate – consume vars
- Contingencies
  - 95% to 105% limit post-contingency
- Synchronous machines are the voltage source
Inverters

• Frequency and voltage ride through
• Momentary Cessation
  – Cease output for a period of time (cycles to seconds)
• Loss of inverter resources during system faults
• Blue Cut Fire – August 2016
• Canyon 2 Fire – October 2017
• Fast Rate of Change of Frequency
• Deep nadir point
Gas Electric Interdependencies

- West Coast states are moving towards de-carbonizing electric generation
Hydro Provides Essential Reliability Services

- ERS
  - Ramping Capability
  - Frequency Control
  - Voltage control
- Synchronous generators
- Inertia
- Active voltage control
- Primary frequency response
- Storage (depending on facility)
- Dispatchable
- Very reliable and dependable
Frequency Excursion – Interconnection
Wide Phenomenon
Reference Links

• Essential Reliability Services Work Group

• Distributed Energy Resources Report

• ERS Concept Paper

• ERS Videos
  ▪ https://vimeopro.com/nerclelearning/erstf-1
Questions?

• Rich Hydzik, Transmission Operations Engineer
• rich.hydzik@avistacorp.com
• (509) 495-4005