Power System Operations
Hands On Relay School
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What are we trying to do?

- Convert some form of energy into electric energy
- Transmit the energy from the generator to the load
- Deliver to the load as needed
- For an AC system
  - Spin a magnet in a coil of wire
  - Connect the wire to the load
  - Turn something on
AC System is a Rotating Machine

- Large mass
- Lots of inertia
- Frequency response / speed governors
System is Changing

- DC Inverters
- Different operating characteristics
- Distributed Energy Resources
- Still learning
Traditional Utility Model

• Integrated operations
• One owner/operator for
  – Generators
  – Transmission System
  – Distribution Systems
• Control Area Operator
  – Control from generator to retail customer
Traditional Utility Model

Control Areas
Today’s World

• NERC Functional Model – 1999 - 2004
• No single owner operator
• Markets have formed
• Reliability Coordinator established
• Control Area has been broken up into functions
  – Balancing Authority – Load resource balance, frequency control, generation dispatch
  – Transmission Operator – Voltage control, transmission scheduling, transmission switching
  – Generator Operator – Plant operations
  – Market Operators – Mishmash of BA, TOP, GOP functions
Functional Model
Balancing Authority

• The responsible entity that
  – Integrates resource plans ahead of time
  – Maintains load, interchange, generation balance within a Balancing Authority Area
  – Supports Interconnection frequency in real time

• Balancing Authority Area
  – The collection of generation, transmission, and loads within the metered boundaries of the Balancing Authority
  – Does not need to be contiguous – Pseudo Ties

• Balancing Authority is analogous to Control Area without control of transmission facilities
BA Operations Pre-Schedule

- Load Forecast
- Generation Schedule
- Net Scheduled Interchange (NSI)
  - Export is positive
  - Import is negative
- Load Forecast = Generation Schedule – NSI
- Contingency Reserves – Generators trip
  - MSSC or 3/3 percent of load/generation
- Operating Reserves – Regulation, forecast error
- This is the PLAN
BA Operations Pre-Schedule

• Net Scheduled Interchange
  – Sum of Scheduled Transactions
• Each transaction is an Electronic Tag / E-tag
  – Source BA
  – Transmission Path
  – Sink BA
• Sum of E-tags (transactions) is NSI
• NSI is verified with counterparties before operating hour
BA Operations Real-Time

• Area Control Error (ACE) – real-time measure of balancing

  ACE = NAI – NSI - 10B(Fa-Fs) – ME + ATEC
  – NAI – Net Actual Interchange
  – NSI – Net Schedule Interchange
  – Frequency Bias MW/0.1Hz
  – ME – Meter Error
  – ATEC – Automatic Time Error Correction (WECC)

• ACE drives Automatic Generation Control (AGC)
  – Negative ACE, pulse units up
  – Positive ACE, pulse units down
Control Performance Standard 1 – CPS1

<table>
<thead>
<tr>
<th>ACE</th>
<th>Frequency</th>
<th>Good or Bad?</th>
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<tbody>
<tr>
<td>Positive</td>
<td>High</td>
<td>Bad</td>
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<tr>
<td>Positive</td>
<td>Low</td>
<td>Good</td>
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- CPS1 is one-month and twelve-month measure
- Are we following the PLAN?
BA ACE Limit - BAAL

- Real-time measure
- Replaces CPS2 limits
BA Operations Real-Time

- Contingencies – Loss of Generation
- NAI decreases, driving ACE negative
- BAL-002 Disturbance Control Standard (DCS)
- ACE must be returned to pre-contingency ACE (or zero if ACE was positive) within 15 minutes
- Contingency reserves are used to recover
- Firm load shedding is not appropriate for DCS recovery
  - Interruptible load can be used as operating reserve
BA Operations Real-Time

Generator Trip and ACE Recovery
BA Operations Real-Time

• Frequency Bias Term in ACE – B MW/0.1Hz
  – Responds to off nominal frequency
  – High frequency raises ACE
  – Low frequency lowers ACE
  – AGC is slow acting – minutes, not seconds

• Governor Response
  – Instantaneous – seconds
  – Arrests frequency decline
  – Stabilizes system until AGC begins acting
BA Operations After-the-Fact

• Integrated values for the hour (Hour Ending xx)
• NAI – check out with adjacent BA’s
• Generation
• Load = Generation – NAI
• NERC Inadvertent = Inadvertent Interchange (II)
  – NAI – NSI
• Primary Inadvertent Interchange (PII) due to control error
  – \((1-Y) \times (\text{II}_{\text{actual}} - B \times \Delta \text{TE}/6)\)
  – Accumulated PII is paid back over next three hours via ATEC
• Did we follow the PLAN?
Transmission Operator

• The entity responsible for the reliability of its “local” transmission system, and that operates or directs the operations of the transmission Facilities

• Transmission Operator Area
  – The collection of Transmission assets over which the Transmission Operator is responsible for operating
Transmission Operator

- Outage coordination
- Real-time switching
- Voltage control
- Secure operations
- Forced outages and restoration
Reliable Operation

• N – 1 Criterion
• System must be able to suffer any credible contingency
  – No cascading outages
  – Stable – voltage and transient
  – No System Operating Limit (SOL) exceedances (WECC)
• Definition of “credible” contingency is open to some interpretation
  – Transmission Operator defines “credible” contingency
  – Varies depending on time horizon
  – Any single outage – generator, transformer, line – 3P fault
  – Credible multiple (N-2) – double circuit tower, breaker failure
    – LG fault
System Studies

- Thermal and voltage
  - Thermal overloading
  - High/low voltage
- Transient stability
  - Power system swings
  - Model fault impedance, relay times, breaker times
  - 3P faults for N-1
  - 1LG faults for N-2
- Voltage stability
  - Reactive margin
  - Voltage collapse
  - Does reactive switching help or not?
Operating Horizons - Seasonal

- Next peak season – Summer, Winter
- Studies based on worst case conditions
  - Peak loads
  - Peak generation – runoff in Northwest
  - Off peak
- Outage conditions studied to update procedures
  - Major transmission facilities, generators, etc
- Reliable operating points for outage conditions
- Usually conservative – guaranteed safe operating point
- Thermal/voltage, transient stability, voltage stability
Operating Horizons
Weeks, Next-Day, Real-Time

• Weeks Ahead
  – Outage coordination
  – Check thermal/voltage and voltage stability based on procedure limits

• Next-Day
  – Check thermal/voltage and voltage stability based on procedure limits

• Real-Time
  – State Estimation (SE) – Set powerflow model based on actuals
  – Real-Time Contingency Analysis (RTCA)
  – Check thermal/voltage, some voltage stability
N – 1 Criterion

- N-1 Criterion is based on present system
- When outage occurs (N-1), system then must perform for next outage (N-1-1)
- This is difficult – system is designed for N-1
- Rely on SE/RTCA to identify next problem
- N-1-1 does not equal N-2
N-1-1 In Action

- N-0 All facilities in service – All is OK
N-1-1 In Action

- N-1 Loss of 230/115 transformer – All is OK
N-1-1 In Action

• N-1-1 Loss of 115 circuit - All is NOT OK
**N-1-1 In Action**

- SOL exceedance is NOT acceptable post-contingency
- Pre-contingency mitigation is required
- Available actions
  - Radialize system if possible
    - We do this often to manage outages
  - Load shedding before the contingency occurs
    - This has been done, definitely to be avoided if possible
  - Change generation dispatch
N-1-1 in Action

- System is designed to absorb ONE credible contingency – Planning Scenario
  - N-1 – Category B
    - No post-contingency SOL exceedances allowed
    - Limited mitigating actions
  - N-2 or N-1-1 Category C
    - Post-contingency SOL exceedances allowed with mitigation
    - Load shedding, other actions permissible to mitigate

- System is operated with something always out of service – Operating Scenario
N-1-1 In Action

• Before March 2014 (WECC)

• N-1-1 SOL exceedances were handled with post-contingency action
  – Manual actions
  – Load shedding or loss acceptable
  – No cascading allowed

• N-1-1 Operations After March 2014 (WECC)
  – Same performance requirement as Planning Category B N-1
  – NO SOL exceedances are allowed post-contingency
N-1-1 In Action

• Reveals any weak links in the system
• This changes the system design philosophy
• Requires significant excess capacity or reduced planned outages
• Limits outage windows
  – Construction
  – Maintenance
  – Lots of spring and fall outages
  – Fewer summer outages
  – Fewer winter outages
Variable Generation Resources
Variable Generation Resources
Variable Generation – BA Operations

- **100% known**
  - Conventional generation dispatch
  - Net Scheduled Interchange
- **97% known**
  - Load – forecasts are very good 24 hours out
- **Not quite known**
  - Wind generation
  - Forecasts are good, but get worse further out (two hours)
  - Can significantly increase regulating reserve required
Variable Generation – Not always there when it is needed
Variable Generation

BPA Balancing Authority Load & Total Wind, Hydro, and Thermal Generation, Last 7 days
11Jan2016 - 18Jan2016 (last updated 17Jan2016 15:12:07)

Based on 5-min readings from the BPA SCADA system for points 45583, 79687, 79682, and 79685
Balancing Authority Load in Red, Wind Gen. in Green, Hydro Gen. in Blue, and Thermal Gen. in Brown
Click chart for installed capacity info
BPA Technical Operations (TOT-OpInfo@bpa.gov)
Variable Generation Growth

WIND GENERATION CAPACITY IN THE BPA BALANCING AUTHORITY AREA

Last update: 12/19/2014. Chart displays sequential changes in wind generation capacity in the BPA BA, based on date when actual generation first exceeded 50% of nameplate. Note that movements of wind generation facilities out of the BPA BA are shown as negative increments to capacity.
Questions?