Break

Reserve Modeling

First, MISO Reserves

- There are 3 (4 truly) basic reserves (there are other ancillary services like voltage support, blackstart capability)
- Regulation
- Spinning reserve
- Supplemental Reserve (10-min)
  - Similar to non-spin 10 min
- Supplemental Reserve (30-min)
  - Similar to replacement reserve

California Independent System Operator (CAISO): Reserves

CAISO Reserves

- There are 4 basic reserves (there are other ancillary services like voltage support, blackstart capability)
- Regulation
- Spinning reserve
- Non-spinning reserve
- Replacement reserve

Regulation Up and Down

- Automatic Generation Control (AGC)
  - Generators that have AGC capability

- AGC is used to ensure frequency stays at 60 Hz
  (or 50Hz depending on your system)

- Regulation up & down is used for any type of event (load uncertainty, area interchange, contingencies, renewables) that causes frequency deviations

Regulation Up and Down

- Regulation up & down is replaced by spinning reserve

- The AGC units have a baseline. If they drift too far away from the baseline they need to come back to the baseline such that they maintain a certain level of AGC capability

10-Minute Spinning Reserve

- Generators that are in-sync, connected to the grid
- Operator calls the unit to provide *X* amount of spinning reserve
    - *X* is less than or equal to the amount of spinning reserve that the unit has available
- Generator must immediately adjust its output and it must reach the required *X* output within 10 minutes

10-Minute Spinning Reserve

- Used primarily to respond to contingencies
- Can be used to replace AGC
- Spinning is replaced by Replacement Reserve

Question: How to determine how much spinning reserve the unit can provide?

10 Minute Non-Spinning Reserve

- Generators that are NOT in-sync with the grid
- Operator calls the unit to provide *X* amount of non-spinning reserve
- Generator must reach the required *X* output within 10 minutes
- Used primarily to respond to contingencies
- Non-spinning is replaced by Replacement Reserve

Question: How to determine how much non-spinning reserve the unit can provide?

30-Minute Replacement Reserve

- Used when there is a contingency
- The replacement reserve must come online and provide the required output within 30 minutes
- Replacement reserve is used to replace Spinning and Non-Spinning Reserve
  - Units providing Spinning and Non-Spinning Reserve can go back to their previous baseline output such that they can be called upon again if necessary (if there is another event)
- Operators use replacement reserve to try to get back to N-1 reliability

30-Minute Replacement Reserve

- Requirement to regain N-1 reliability in 30 minutes
- The system is supposed to operate in an N-1 reliable state (pre-contingency)
- Immediately following the contingency, they call on reserves (at this stage, they are not N-1 reliable)
- They first ensure the contingency does not lead to a blackout
- Then, they will move to getting back to an N-1 reliable operating state (the prior facility that was lost may still be out of service)
- This can be seen as achieving N-1-1 reliability

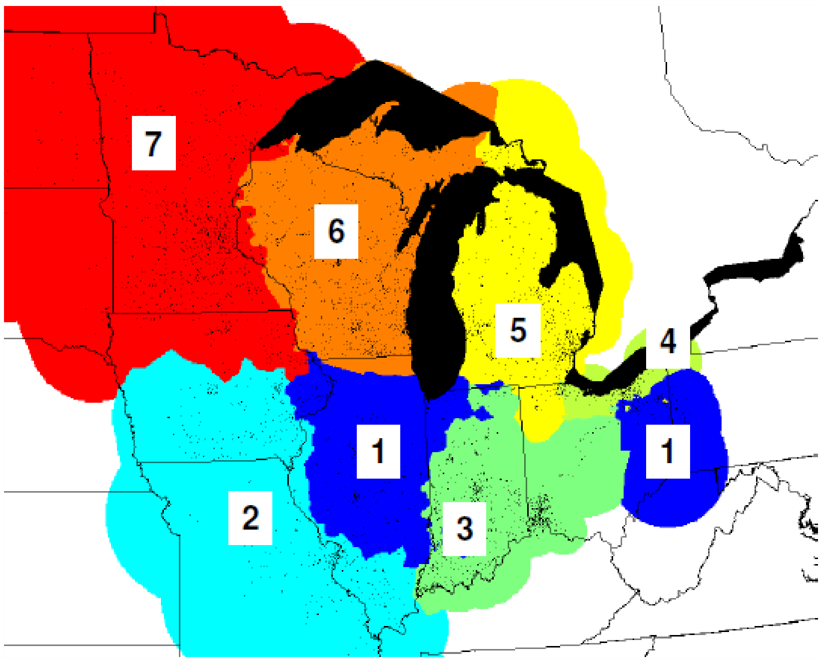
Break

Reserve Modeling

Reserve Zones

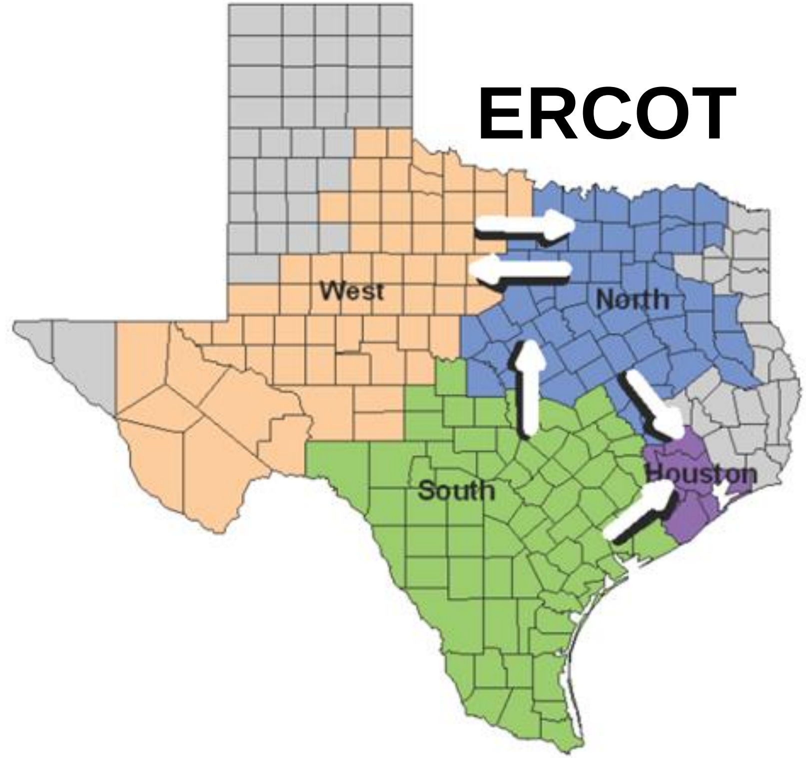
Reserve zone examples

MISO

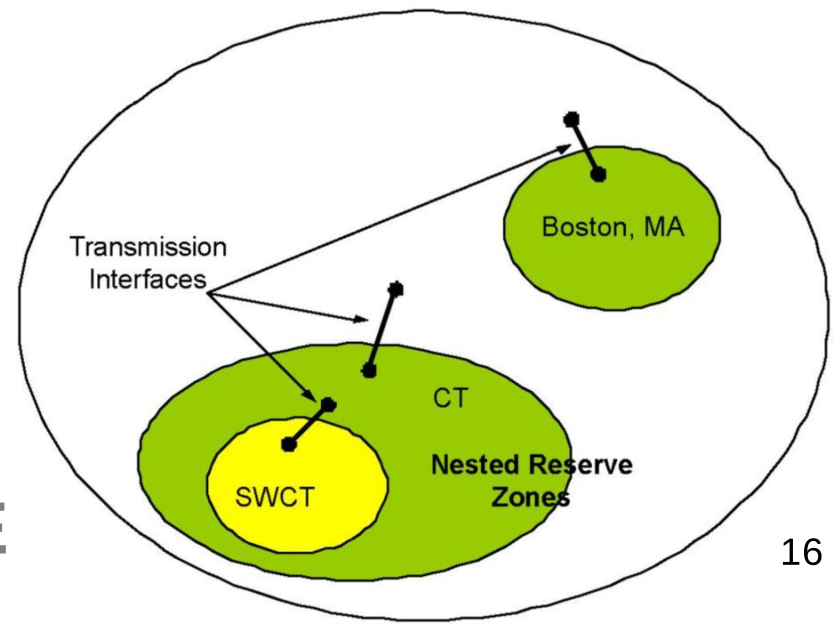


(Area 1 is part of PJM)

ERCOT

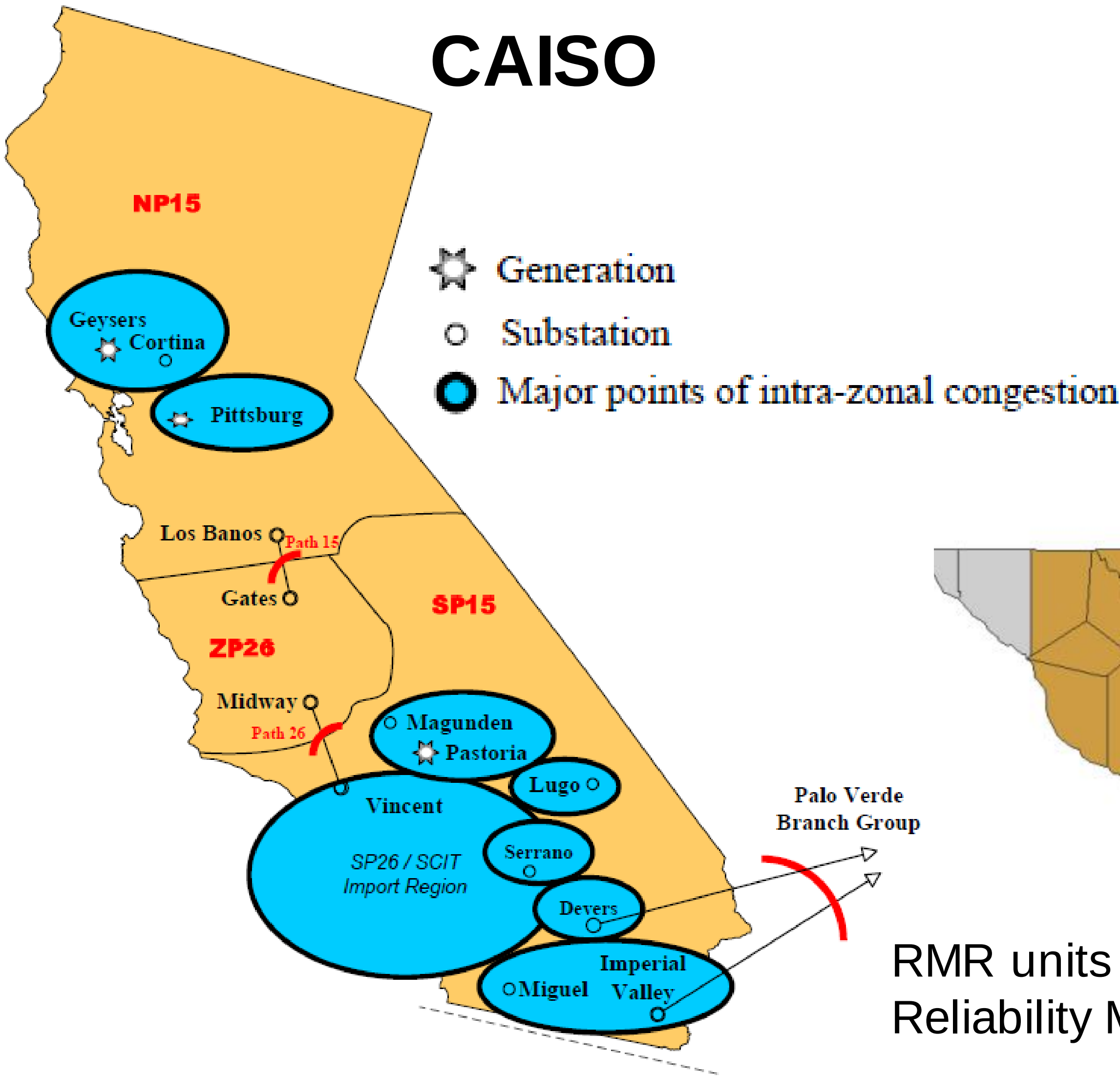


ISO-NE



Zones don't address intra-zonal congestion

CAISO



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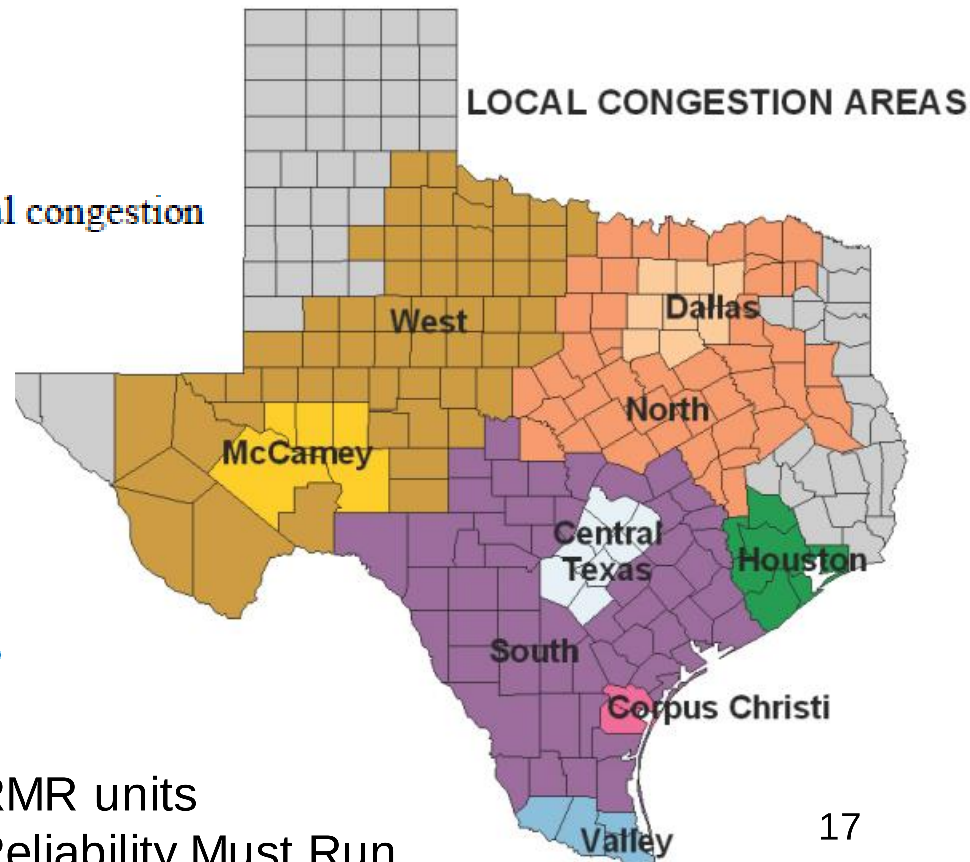


RMR units
Reliability Must Run

Reserve Zones

Question: What is the purpose of defining a reserve zone?

Break

Reserve Modeling

Reserve Sharing Groups

Reserve Sharing

Question: How much contingency reserve should we have for the entire eastern interconnection?

Should we acquire contingency reserve equal to the single largest contingency?

What factors should be considered?

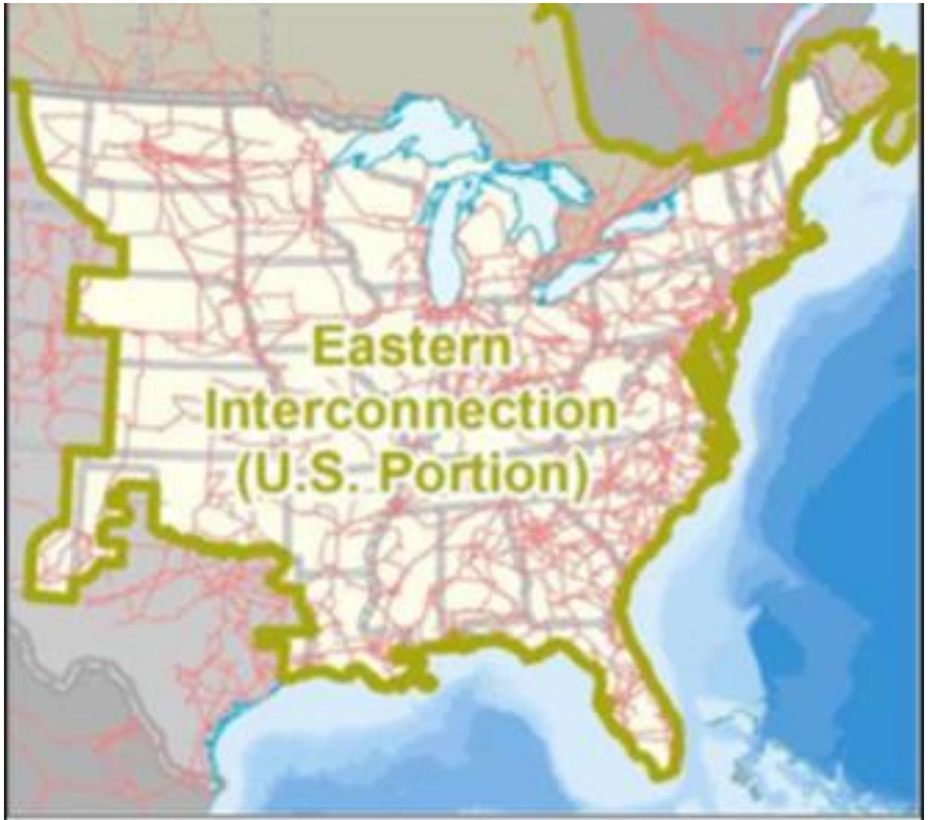
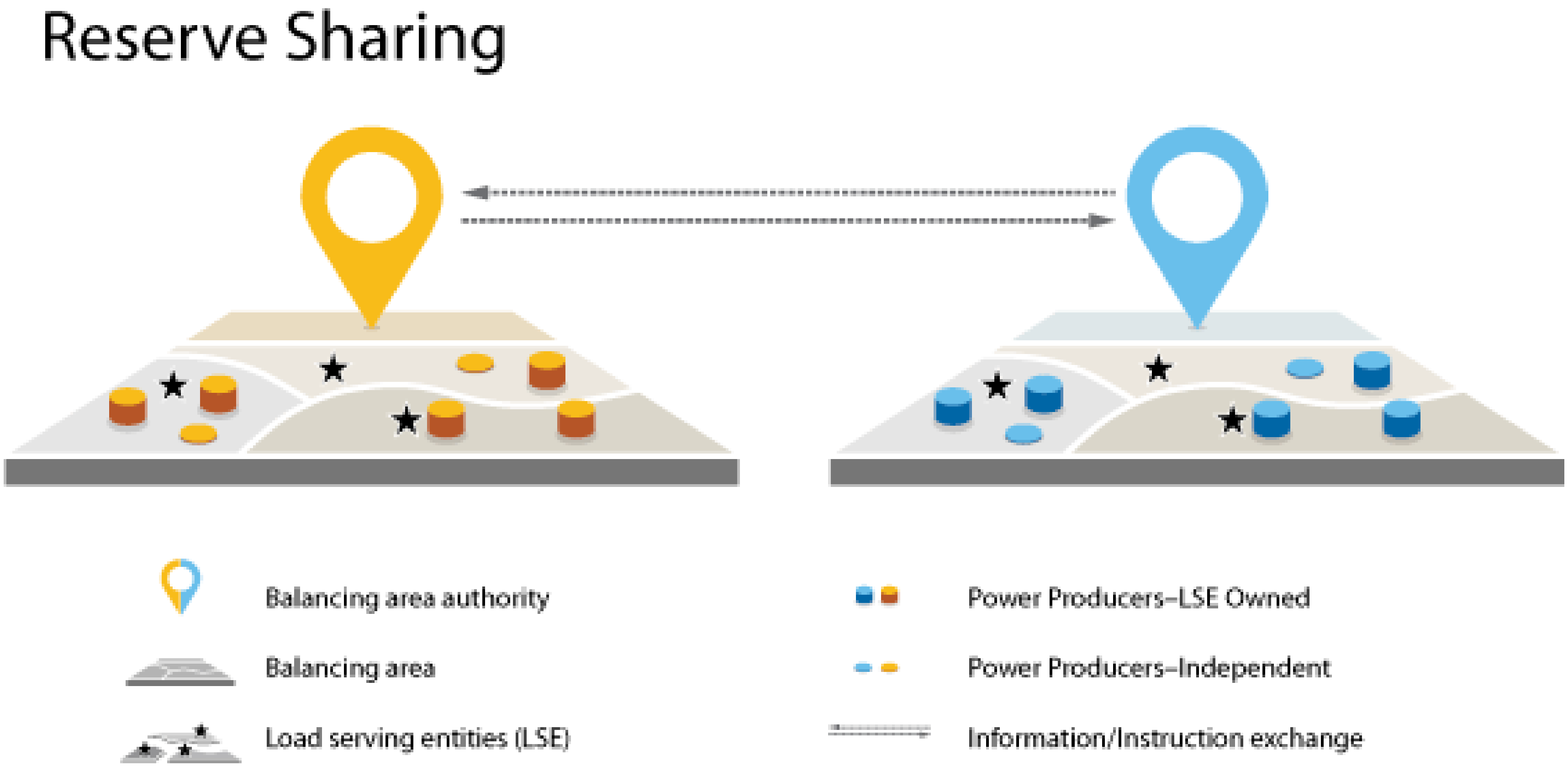


Figure 1: U.S. Portion of the Eastern Interconnection

Reserve Sharing



http://greeningthegrid.org/resources/image-gallery/reserve-sharing/view

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Reserve Modeling

Reserve Modeling: Constraints

Important Note

- The definitions of reserve products varies from system to system
- Even with the same definition, there may be slight variations as to how an entity may choose to restrict, model their reserves
- The following slides are *one common way* to model reserves for a SCED/SCUC *but they are not the only way*

Regulation Reserve Up/Down Modeling

- Previously: $P_g^{min} u_{gt} \leq P_{gt} \leq P_g^{max} u_{gt}, \forall g, t$
- Now: $P_g^{min} u_{gt} \leq P_{gt} - r_{gt}^{reg\_dn}, \forall g, t$

$$P_{gt} + r_{gt}^{reg\_up} \leq P_g^{max} u_{gt}, \forall g, t$$

$$r_{gt}^{reg\_up} \geq 0, r_{gt}^{reg_{dn}} \geq 0, \forall g \in G^{AGC}, t$$

$$r_{gt}^{reg\_up} \leq R_g^{5\min} u_{gt}, r_{gt}^{reg_{dn}} \leq R_g^{5\min} u_{gt}, \forall g \in G^{AGC}, t$$

$$r_{gt}^{reg\_up} = 0, r_{gt}^{reg_{dn}} = 0, \forall g \notin G^{AGC}, t$$

- Suppose the regulation reserve is defined over a 5 minute period and, thus, it is restricted by a 5 minute ramp; for a different rule, adjust mathematical model

Regulation Reserve Modeling

- Key features:
- Gen must have AGC capability to provide regulation reserve
- Gen cannot provide more upward reserve than its capacity minus its production
- Gen cannot provide more down reserve than its production minus its min capacity
- Note that usually a generator will provide only upward reserve or downward reserve, not both

Regulation Reserve Modeling

- For the ramp restriction, it is assumed (for these notes) that the unit cannot provide more than its 5 min ramp rate
- Note that regulation reserve is exercised (called upon) based on AGC and that happens much faster than on a 5-min basis (roughly every 4 seconds)
- While AGC happens very frequently, the generator is not going to provide all of its regulation reserve over 4 seconds but it will continually adjust its output over the time period that it is designated to provide the reserve (in this case, that is assumed to be 5 minutes)
- This is something that the energy management system and/or operator should handle (how much regulation reserve to acquire from the fleet and, during the time interval, how much to activate from each unit relative to the net load fluctuation)

Spinning Reserve Modeling

- Previously:

$$P_g^{min} u_{gt} \leq P_{gt} - r_{gt}^{reg\_dn}, \forall g, t$$

$$P_{gt} + r_{gt}^{reg\_up} \leq P_g^{max} u_{gt}, \forall g, t$$

- Now:

No change →

$$P_g^{min} u_{gt} \leq P_{gt} - r_{gt}^{reg\_dn}, \forall g, t$$

Change →

$$P_{gt} + r_{gt}^{reg\_up} + r_{gt}^{spin} \leq P_g^{max} u_{gt}, \forall g, t$$

$$r_{gt}^{spin} \geq 0, \forall g, t$$

$$r_{gt}^{reg\_up} + r_{gt}^{spin} \leq R_g^{10\min} u_{gt}, \forall g, t$$

- Most spinning reserve rules use a 10 minute description for spinning so its ramp is based on 10 minutes

Spinning Reserve Modeling

Key features:

- Usually, spinning reserve is only modeled associated to an upward movement
- Spin reserve is restricted based on its current production and whether the unit is already allocating some of its ramping capability to regulation reserve
  - Note that sometimes a unit may be designated as only providing regulation reserve and nothing else – the prior formulation states that, if you are on and have AGC capability, you can contribute towards both requirements
- Spin reserve amount cannot be negative and is bounded above by the ramping rate
- The unit must be on

Spinning Reserve Modeling

Different ways of modeling spinning reserve:

- Often, it is assumed that a generator's ramp rate is not dependent on its current level of production
- In the California ISO, the ramp rate restriction for the generator's spinning reserve is dependent on the level of production chosen
- You can think of this as to the acceleration that your car may experience when driving at different speeds
- Incorporating such a more complex model changes the complexity of CAISO's SCED formulation from a linear program to a mixed-integer linear program
  - They change the ramp restriction relative to some defined state of the unit

Break

Reserve Modeling

Reserve Modeling: Constraints

Non-Spinning Reserve Modeling

- Previously:

$$P_g^{min} u_{gt} \leq P_{gt} - r_{gt}^{reg\_dn}, \forall g, t$$ No change

$$P_{gt} + r_{gt}^{reg\_up} + r_{gt}^{spin} \leq P_g^{max} u_{gt}, \forall g, t$$

No change

- Now:

$$r_{gt}^{non\_spin} \geq 0, \forall g, t$$

$$r_{gt}^{non\_spin} \leq R_g^{10\min} (1 - u_{gt}), \forall g \in G^{Fast\_start}, t$$

$$r_{gt}^{non\_spin} \leq 0, \forall g \notin G^{Fast\_start}, t$$

- There are different ways to model non-spin
- The above formulation assumes that you will only ever provide non-spin reserve if you are offline
- Technically, a unit only could still provide non-spin reserve because it will be able to satisfy the requirements of non-spin reserve
- Note that again we are assuming a 10-min non-spin reserve product
- The unit must be classified as a fast start unit

Replacement Reserve Modeling

$$r_{gt}^{replace} \geq 0, \forall g, t \qquad r_{gt}^{replace} \leq 0, \forall g \notin G^{30\min\_Fast\_start}, t$$

$$r_{gt}^{non\_spin} + r_{gt}^{replace} \leq R_g^{30\min}(1 - u_{gt}), \forall g \in G^{30\min\_Fast\_start}, t$$

$$r_{gt}^{reg\_up} + r_{gt}^{spin} + r_{gt}^{non\_spin} + r_{gt}^{replace} \leq R_g^{30\min}(u_{gt}), \forall g, t$$

- Again, modeling can vary based on their chosen way to operate
- This more so describes the main issues:
- If the plant is off, you must be able to turn on within 30 min and if the unit is providing non-spin, that takes away from the unit's ability to provide the same ramp capability as if it were not providing non-spin so that must be accounted for.
- If the plant is on, you must account for the other reserve products that are being provided. They may be zero. They may not be zero.
- Must be able to respond within 30 minutes, reserve restricted based on 30 min ramp and other reserve products offered (depending on system rule)

Break

Reserve Modeling

Reserve Modeling: Constraints

System Wide Regulation Reserve Modeling

- System-wide reg up must satisfy some fraction ($\alpha\%$) of total system wide demand

$$\sum\nolimits_{\forall g} r_{gt}^{reg\_up} \geq \alpha \sum\nolimits_{\forall n} d_{nt}, \forall t$$

- Or a zonal requirement:

$$\sum\nolimits_{\forall g \in Zone(z)} r_{gt}^{reg\_up} \geq \alpha \sum\nolimits_{\forall n \in Zone(z)} d_{nt}, \forall t, z$$

- Or a fixed predetermined value:

$$\sum\nolimits_{\forall g} r_{gt}^{reg\_up} \geq 500MW, \forall t$$

- Regulation down will have a similar structure, just with a different value on the right hand side
- Question: between the first and the third, which would you prefer?
- You can make it many different things – from 577, you should learn typical ways to model it as well as how to mathematically formulate some different way

System Wide Spinning Reserve Modeling

- Spinning Reserve by itself (different ways to model it):

$$\sum_{\forall g} r_{gt}^{spin} \geq \frac{\alpha}{2} \sum_{\forall n} d_{nt}, \forall t \qquad \sum_{\forall g} r_{gt}^{spin} \geq \frac{1}{2} 1200MW, \forall t$$

$$\sum_{\forall g^*} r_{g^*t}^{spin} \geq \frac{1}{2} \left(P_{gt} + r_{gt}^{spin}\right), \forall g, t \qquad \sum_{\forall g} r_{gt}^{spin} \geq \frac{\alpha}{2} \max(P_g^{max}), \forall t$$

- With reserve sharing:

$$\sum_{\forall g} r_{gt}^{spin} + r_t^{import\_reserve} \geq \alpha/2 \sum_{\forall n} d_{nt}, \forall t$$

- The reserve sharing structure is basic, just to illustrate the point – it will become more complex

System Wide Spinning and Non-Spinning Reserve Modeling

- Spinning Reserve and Non-Spinning Reserve (different ways):

$$\sum_{\forall g} r_{gt}^{spin} + \sum_{\forall g} r_{gt}^{nonspin} \geq \alpha \sum_{\forall n} d_{nt}, \forall t$$

$$\sum_{\forall g^*} r_{g^*t}^{spin} + \sum_{\forall g^*} r_{g^*t}^{nonspin} \geq \left(P_{gt} + r_{gt}^{spin}\right), \forall g, t$$

$$\sum_{\forall g} r_{gt}^{spin} + \sum_{\forall g} r_{gt}^{nonspin} \geq (\alpha)\max(P_g^{max}), \forall t$$

$$\sum_{\forall g} r_{gt}^{spin} + \sum_{\forall g} r_{gt}^{nonspin} \geq 1200MW, \forall t$$

Replacement Reserve Modeling

- There are other ways to restrict replacement as well

$$\sum_{\forall g} r_{gt}^{replace} \geq \sum_{\forall g} r_{gt}^{spin} + \sum_{\forall g} r_{gt}^{nonspin}, \forall t$$

Break

Reserve Modeling

Reserve Modeling: Constraints

Question

- Assume that there is no transmission contingency or component failure
- Assume that there is no issue with any system dynamics (instability issue)
- Assume there is no load uncertainty
- Does the prior modeling guarantee that you will be able to recover from any single generator contingency?

Question

- You have seen various reserve modeling examples
- Future power systems with high renewables: what should change?

State of the Art Industry Examples

- MISO: Zonal reserve deliverability constraints

- CAISO: Generation Loss Distribution Factors (GDF)