Locational Ancillary Service Procurement and Transmission Constraints

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Energy and Operating Reserve Market

- **In 2009, MISO started its co-optimized energy and operating reserve market.**
  - Energy requirements modeled on nodal basis.
  - Reserve requirements not modeled on nodal basis.
    - Global regulating, spinning and supplemental reserve requirements.
    - Minimum zonal requirements set via off-line study.
  - Transmission model
    - Effects of energy schedule on transmission modeled.
    - Effect of deploying reserves on transmission constraints not modeled in co-optimization.
      - Operators may disqualify resources from clearing reserves when deployment would cause transmission violations.

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Modeling Transmission Impacts of Reserve Deployment

- **In 2011, MISO modified the co-optimized Security Constrained Economic Dispatch (SCED) problem to model effect of deploying reserves on transmission constraints.**
- **To limit the increase in the size of the SCED problem:**
  - Model a limited number of events driving reserve deployment;
  - Limit variables used to model deployment of reserves in response to an event;
  - Assume that only a single event occurs at a time.

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Events Modeled for Deployment

- **Contingency Reserve Events**
  - Define events for which spinning or supplemental reserves (jointly contingency reserves) would be deployed.
  - Define zones and a single largest event in each zone.
    - $P^{MaxEvent}(z)$ is the largest event anticipated in zone z.
    - $P^{MaxEvent}(z)$ is spread over nodes in zone z using fixed factors.
- **Regulation Reserve Events**
  - Event requiring deployment of regulation reserves is assumed to occur at reference node.
  - Two regulation events are modeled:
    - One to deploy regulating reserve up.
    - A second to deploy regulating reserve down.
    - Requirement spread over nodes in reference node using fixed factors.

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Model Impact of Reserve Deployment

- **Constants:**
  - GlobalRegRequirement: Requirement for regulating reserve
  - GlobalSpinRequirement: Requirement for spinning reserve
  - GlobalSuppRequirement: Requirement for supplemental reserve
  - SensDem(k,z): Distribution factor for flow on transmission constraint k for the demand for deployed reserves sinking in zone z
  - SensSpin(k,z): Distribution factor for flow on transmission constraint k for spinning reserves deployed in zone z
  - SensSupp(k,z): Distribution factor for flow on transmission constraint k for supplemental reserves deployed in zone z
  - Limit(k): Flow limit on transmission constraint k
- **Variables from SCED without Reserve Transmission Model:**
  - *"Flow_from_energy_dispatch(k)":* Flow on constraint k from energy dispatch
  - *ClearedReg(r):* Cleared regulating reserve on resource r
  - *ClearedCR(r):* Cleared contingency reserve on resource r

Model Impact of Reserve Deployment

- **Reserve deployment model in SCED attempts to mimic current AGC deployment logic.**
  - Spinning reserves and on-line supplemental reserves are deployed proportionally by AGC following a contingency reserve deployment event.
    - Spinning reserves are deployed first.
    - Supplemental reserves are called if deployment of spinning reserve is not sufficient.
- **Aggregate reserves by zone:**
  - *ZonalReg(z):* Regulating reserve cleared in zone z
  - *ZonalSpin(z):* Spinning reserve cleared in zone z
  - *ZonalSupp(z):* Supplemental reserve cleared in zone z

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Model Impact of Reserve Deployment

$$\sum_{\text{r in zone z}} Cleared\,Reg(r) \geq Zonal\,Reg(z)$$

$$\sum_{\text{r in zone z}} Cleared\,Reg(r) + \sum_{\substack{\text{r in zone z} \\ \text{and r Spin Qualified}}} ClearedCR(r) \geq Zonal\,Reg(z) + ZonalSpin(z)$$

$$\sum_{\text{r in zone z}} Cleared\,Reg(r) + \sum_{\text{r in zone z}} ClearedCR(r) \geq Zonal\,Reg(z) + ZonalSpin(z) + ZonalSupp(z)$$

$$\sum_{\forall \text{ zones z}} Zonal\,Reg(z) \geq Global\,Reg\,Requirement$$

$$\sum_{\forall \text{ zones z}} \left(Zonal\,Reg(z) + ZonalSpin(z)\right) \geq \begin{pmatrix} Global\,Reg\,Requirement \\ +GlobalSpin\,Requirement \end{pmatrix}$$

$$\sum_{\forall \text{ zones z}} \left(Zonal\,Reg(z) + ZonalSpin(z) + ZonalSupp(z)\right) \geq \begin{pmatrix} Global\,Reg\,Requirement \\ +GlobalSpin\,Requirement \\ +GlobalSupp\,Requirement \end{pmatrix}$$

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Modeling Current Deployment Logic

- **If a contingency reserve event of size $P^{MaxEvent}(z)$ occurred in zone z, AGC would deploy contingency reserves roughly as follows:**

$$\text{If } P^{MaxEvent}(z) \leq \sum_{\forall \text{ zones } y} ZonalSpin(y)$$

$$\text{then deploy } \frac{P^{MaxEvent}(z)}{\sum_{\forall \text{ zones } y} ZonalSpin(y)} \times ZonalSpin(x)$$

in each zone x with cleared spinning reserves

Modeling Current Deployment Logic

Else deploy $ZonalSpin(x)$ in each zone x with cleared spinning reserves and

$$min\left[1, \frac{\left(P^{MaxEvent}(z) - \sum_{\forall \text{ zones } y} ZonalSpin(y)\right)}{\sum_{\forall \text{ zones } y} ZonalSupp(y)}\right] \times ZonalSupp(x)$$

in each zone x with cleared supplemental reserves

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Linear Approximation of Deployment Logic

If $P^{MaxEvent}(z) \leq GlobalSpin\,Requirement$ then deploy

$$\frac{P^{MaxEvent}(z)}{GlobalSpin\,Requirement} \times ZonalSpin(x)$$

in each zone x with spinning reserves

Else

deploy $\mathrm{ZonalSpin}(y)$ in all zones y with cleared spin and

$$\frac{P^{MaxEvent}(z) - GlobalSpin\,Requirement}{GlobalSupp\,Requirement} \times ZonalSupp(x)$$

in each zone x with supplemental reserves

Xmission Constraints for Event in Zone z

If $P^{MaxEvent}(z) \le GlobalSpin\,Requirement$ then

$$Flow\_from\_energy\_dispatch(k) - P^{MaxEvent}(z) \cdot SensDem(k,z)$$
$$+ \frac{P^{MaxEvent}(z)}{GlobalSpin\,Requirement} \cdot \left(\sum_{\forall \text{ zones } x} ZonalSpin(x) \times SensSpin(k,x) \right) \le Limit(k)$$

Else

$$Flow\_from\_energy\_dispatch(k) - P^{MaxEvent}(z) \times SensDem(k,z)$$
$$+ \left(\sum_{\forall \text{ zones } x} ZonalSpin(x) \times SensSupp(k,x) \right)$$
$$+ \left[\frac{P^{MaxEvent}(z) - GlobalSpin\,Requirement}{GlobalSupp\,Requirement} \times \left(\sum_{\forall \text{ zones } x} ZonalSupp(x) \times SensSupp(k,x) \right) \right]$$
$$\le Limit(k)$$

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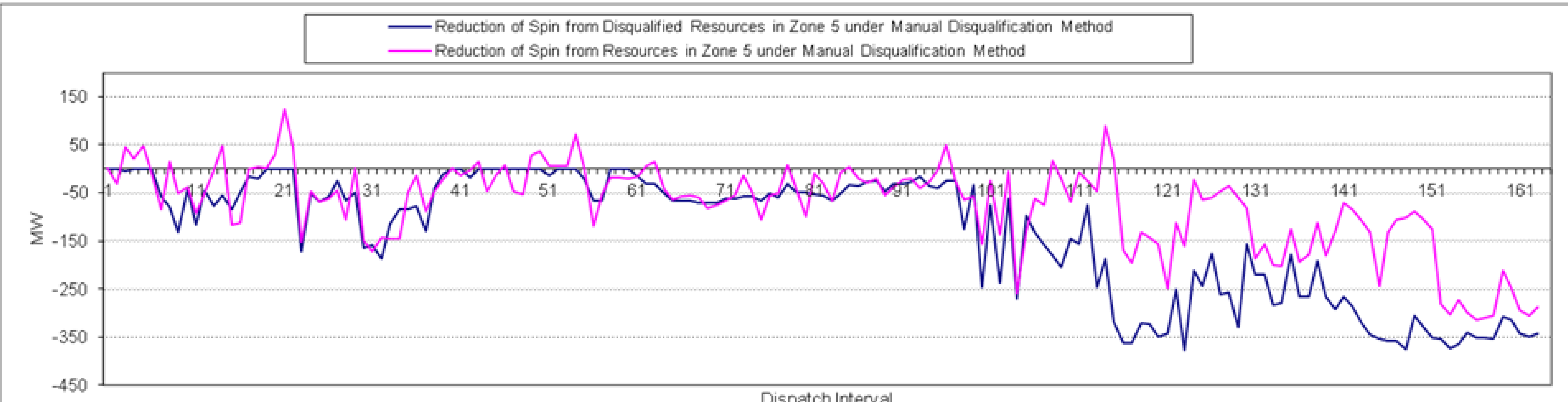
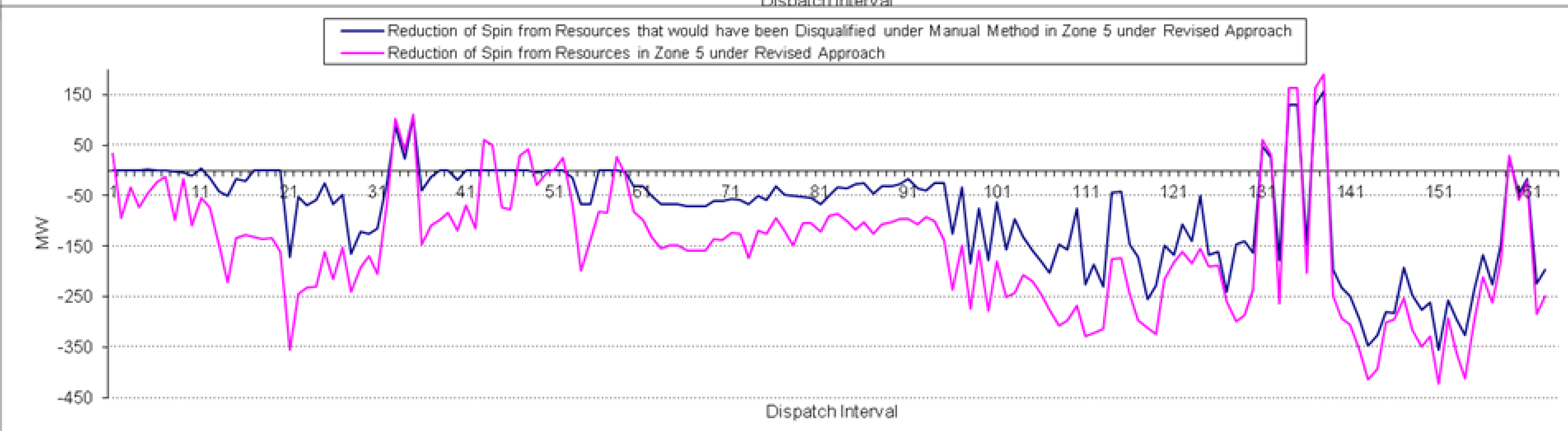
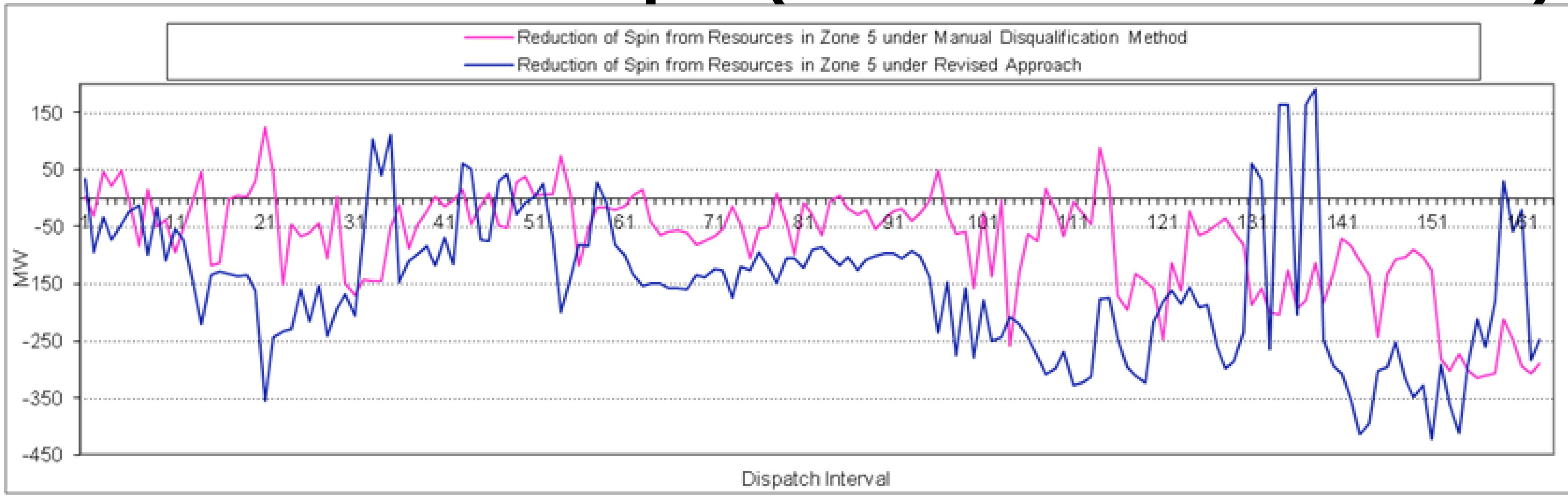
Performance Example (~13.5 hours on 7/26/11)

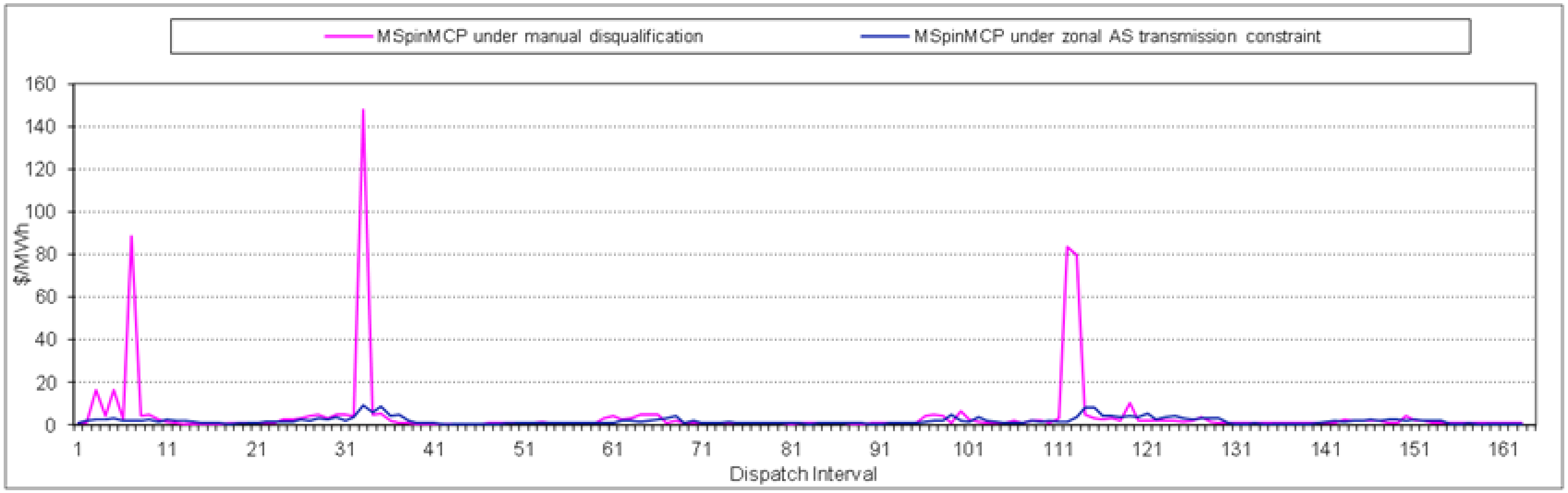
- Spinning reserves cleared in Zone with transmission constraint binding





Performance Example (~13.5 hours on 7/26/11)





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Performance

- **Experience shows that the new approach to enforcing post deployment transmission constraints does a better job than manually disqualifying resources.**
- **However, there are some problems with the current approach.**
  - The linearization method used may result in the market clearing more reserves than are needed for an event if deploying the excess reserves and sinking the excess at the reference bus would reduce flow on a violated or binding constraint.
  - Requiring pro-rata deployment of reserves increases the difficulty of enforcing some transmission constraints.
    - This is often the case for transmission constraints located within a zone rather than crossing zones.

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Improving Deployment of Reserves

- **MISO is investigating approaches to increase flexibility in modeling reserve deployment.**
  - Model deployment of reserves by incorporating nodal deployment variables in the co-optimized SCED.
    - Treat these as independent decision variables; do not require pro-rata deployment.
  - This would require modifications to the AGC logic used to deploy reserves in practice to keep models in sync.

Enhanced Reserve Deployment Model

- **Spinning and Contingency Reserve Events**
  - For each zone, define a largest event to be met by spinning reserves.
    - $P^{MaxSpinEvent}(z)$ is the largest spinning reserve event anticipated in zone z.
  - For each zone, define a largest event to be met by contingency reserves (spinning and supplemental).
    - $P^{MaxCREvent}(z)$ is the largest contingency reserve event anticipated in zone z.

Enhanced Reserve Deployment Model

- **Constants:**
  - GlobalRegRequirement: Global regulation reserve target to be met
  - GlobalRegSpinRequirement: Global reg plus spinning reserve target to be met
  - GlobalORRequirement: Global reg plus contingency reserve target to be met
  - SensDem(k,z): Distribution factor for flow on transmission constraint k for the demand for deployed reserves sinking in zone z
  - SensRes(k,r): Distribution factor for flow on transmission constraint k for deploying reserves on resource r
  - Limit(k): Flow limit on transmission constraint k
- **Variables:**
  - *"Flow_from_energy_dispatch(k)":* Flow on transmission constraint k from energy dispatch
  - *ClearedReg(r):* Cleared regulating reserve on resource r
  - *ClearedCR(r):* Cleared contingency reserve on resource r

Enhanced Reserve Deployment Model

- **Variables:**
  - *RegSpinShortage:* Shortfall in cleared regulation reserve and cleared spinning reserves for GlobalRegSpinRequirement
  - *ORShortage:* Shortfall in cleared regulation reserve and cleared contingency reserves for GlobalORRequirement
  - *DeployedReg(r,up):* Deployed regulating reserve on resource r for reg requirement in upward direction
  - *DeployedReg(r,down):* Deployed regulating reserve on resource r for reg requirement in downward direction
  - *DeployedSpin(r,z):* Deployed ClearedCR on Spin qualified resource r for maximum spinning reserve event in zone z
  - *DeployedCR(r,z):* Deployed ClearedCR on resource r for maximum contingency reserve event in zone z
  - *SpinShortage(z):* Shortfall in deployed spinning reserves for maximum spinning reserve event in zone z
  - *CRShortage(z):* Shortfall in deployed contingency reserves for maximum contingency reserve event in zone z

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Constraints for Spinning Reserve Deployment

$$DeployedSpin(r,z) \geq 0$$

$$DeployedSpin(r,z) \leq ClearedCR(r) \text{ for all spin qualified resources r}$$

$$\sum_{\text{r spin qualified}} DeployedSpin(r,z) + SpinShortage(z) = P^{MaxSpinEvent}(z)$$

$$SpinShortage(z) \geq 0$$

$$Flow\_from\_energy\_dispatch(k)$$
$$-\left[P^{MaxSpinEvent}(z) - SpinShortage(z)\right] \times SensDem(k,z)$$
$$+ \sum_{r \text{ spin qualified}} DeployedSpin(r,z) \times SensRes(k,r) \leq Limit(k)$$

Constraints for Contingency Reserve Deployment

$$DeployedCR(r,z) \geq 0$$

$$DeployedCR(r,z) \leq ClearedCR(r) \text{ for all resources r, spin qualified or not}$$

$$\sum_r DeployedCR(r,z) + CRShortage(z) = P^{MaxCREvent}(z)$$

$$CRShortage(z) \geq 0$$

$$\begin{aligned} &Flow\_from\_energy\_dispatch(k) \\ &-\left[P^{MaxCREvent}(z) - CRShortage(z)\right] \times SensDem(k,z) \\ &+\sum_r DeployedCR(r,z) \times SensRes(k,r) \leq Limit(k) \end{aligned}$$

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Pricing for Reserves: Spin Qualified

- **The dual variables for several constraints contribute to the prices that are paid to cleared CR that is spin qualified.**

Primal Constraint **Dual Variable**

$$\sum_{r \text{ Reg Qualified}} ClearedReg(r) + \sum_{r \text{ Spin Qualified}} ClearedCR(r) + RegSpinShortage \geq GlobalRegSpinRequirement \qquad \xi Mregspin$$

$$\sum_{r \text{ Reg Qualified}} ClearedReg(r) + \sum_{r} ClearedCR(r) + ORShortage \geq GlobalORRequirement \qquad \xi Mor$$

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Pricing for Reserves: Spin Qualified

Primal Constraint	Dual Variable
$DeployedSpin(r,z) \le ClearedCR(r)$ for r spin qualified	$\xi DeploySpin(r,z)$
$\sum_{\text{r spin qualified}} DeployedSpin(r,z) + SpinShortage(z) = P^{MaxSpinEvent}(z)$	$\xi BalanceSpin(z)$
$Flow\_from\_energy\_dispatch(k) - \left[P^{MaxSpinEvent}(z) - SpinShortage(z)\right] \times SensDem(k,z) + \sum_{r \text{ spin qualified}} DeployedSpin(r,z) \times SensRes(k,r) \le Limit(k)$	$\mu SpinFlow(k,z)$
$DeployedCR(r,z) \le ClearedCR(r)$	$\xi DeployCR(r,z)$
$\sum_{\text{r}} DeployedCR(r,z) + CRShortage(z) = P^{MaxCREvent}(z)$	$\xi BalanceCR(z)$
$Flow\_from\_energy\_dispatch(k) - \left[P^{MaxCREvent}(z) - CRShortage(z)\right] \times SensDem(k,z) + \sum_{r \text{ spin qualified}} DeployedCR(r,z) \times SensRes(k,r) \le Limit(k)$	$\mu CRFlow(k,z)$

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Pricing for Reserves: Spin Qualified

- **The dual variables can be combined to calculate the prices to be paid to resources cleared for reserves.**
- **A spin qualified resource providing CR would be paid**

$$\left[\xi Mregspin + \xi Mor - \sum_{z} \xi DeploySpin(r,z) - \sum_{z} \xi DeployCR(r,z)\right] \times ClearedCR(r)$$

- **Using complementary slackness, we can write this as**

$$[\xi Mregspin + \xi Mor] \times ClearedCR(r)$$
$$+ \sum_{z}\left(\left[\sum_{k} \mu SpinFlow(k,z) \times Sens\,Re\,s(k,r) + \xi BalanceSpin(z)\right] \times DeployedSpin(r,z)\right)$$
$$+ \sum_{z}\left(\left[\sum_{k} \mu CRFlow(k,z) \times Sens\,Re\,s(k,r) + \xi BalanceCR(z)\right] \times DeployedCR(r,z)\right)$$

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Deploying Contingency Reserves

- **The method used to actually deploy reserves should be modified to be consistent with the enhanced modeling of deployment of reserves in a revised SCED.**
  - We could use a simplified version of SCED to deploy CR (and other available resources) after an event.
    - Concerns exist regarding solution time.
  - We could use data from the existing SCED solution to deploy CR in a weighted pro-rata approach.
    - If spinning reserves only are to be deployed to meet an event in zone z, we could use DeployedSpin(r,z) as weights used in a pro-rata deployment of ClearedCR(r) on spin qualified resources.
    - If spinning and supplemental reserves are to be deployed to meet an event in zone z, we could use DeployedCR(r,z) as weights used in a pro-rata deployment of ClearedCR(r) on spin and supplemental qualified resources.