Market Implications of Reserve Deliverability Enhancement with the Application to Short-term Reserve

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Outline

- Overview of MISO 30-minute short-term reserve (STR)
- Zonal and nodal STR models
- Market implications of zonal and nodal STR models
- Penalty function design

30-Minute Short-Term Reserves Produce Price Signals and Improve Commitment Process

Background

- MISO has load pockets with limited importing capability and insufficient quick start units
- MISO has a requirement to restore import flow violation within limit under the largest contingency event in 30 minutes
- System-wide 30-minute flexibility needs

Motivation

- To improve commitment and dispatch process related to load pockets, regional dispatch transfer (RDT), and market-wide reliability needs
- Improve transparency of costs associated with short-term reserve needs
- Enhance reliability by aligning operational needs and market models

STR constraints reflect resource and system requirements

Resource Level Constraints

- Resource capacity
- Maximum cleared STR from single resource
- 30-minute ramp rate

System-wide Constraints

- System-wide requirement
- Post-event power balance constraint
- Post-event reserve deliverability constraints

Zonal and Nodal Short-term Reserve Models

Reserve Deliverability Can Be Improved by Post-event Constraints

Post-event power balance constraint

- Zonal / nodal STR deployment
- Ensure post-event power balance

Post-event reserve deliverability constraints

- Capture post-event power flow with the consideration of loss of generation and co-optimized zonal / nodal STR deployment
- Improve reserve deliverability with consideration of post-deployment transmission constraints for each of the largest zonal contingency events

Post-STR Deployment Deliverability Constraints

Zonal model

$$Baseflow_i + \mathrm{Event_e} * Sens_{i,e} - \sum_{\mathrm{z}} \mathrm{STRResponse_{z,e}} * Sens_{i,z}^{STR} \le Limit(SP\_SC_{i,e}^{ZSTR})$$

Event Impact

Post-Event STR Deployment Impact
Based on Zonal Sensitivities

Nodal model

$$Baseflow_i + \mathrm{Event_e} * Sens_{i,e} - \sum_{\mathrm{z}} \mathrm{STRResponse_{n,e}} * Sens_{i,n}^{STR} \le Limit(SP\_SC_{i,e}^{NSTR})$$

Event Impact

Post-Event STR Deployment Impact
Based on Nodal Sensitivities

- Index *n* represent node *n,* index *z* represents reserve zone *z,* index *r* represents generating resource *r,* index *i* represents post STR deployment deliverability constraint *r*
- $Baseflow_i$ is the pre-contingency flow

Optimal Deployment Constraints

Constraints	Zonal Model	Nodal Model
Post-STR deployment power balance constraint	$\sum_{z} \text{STRResponse}_{z,e} = \text{Event}_e$ (SP_PB_e)	$\sum_{n} \text{STRResponse}_{n,e} = \text{Event}_e$ (SP_PB_e)
Maximum STR deployment constraint	$\text{STRResponse}_{z,e} \leq \text{ZonalSTR}_z$	$\text{STRResponse}_{n,e} \leq \text{NodalSTR}_n$
System wide STR requirement	$\sum_{z} \text{ZonalSTR}_{z,t} \geq \text{Systemwide } STRReq$ (ω)	$\sum_{n} \text{NodalSTR}_z \geq \text{Systemwide } STRReq$ (ω)
Dynamic Requirements	$\sum_{r \in z} (\text{OnlineSTR}_r + \text{OfflineSTR}_r) \geq \text{ZonalSTR}_{z,t}$ (φ_z)	$\sum_{r \in n} (\text{OnlineSTR}_r + \text{OfflineSTR}_r) \geq \text{NodalSTR}_z$ (φ_n)

Nomenclature

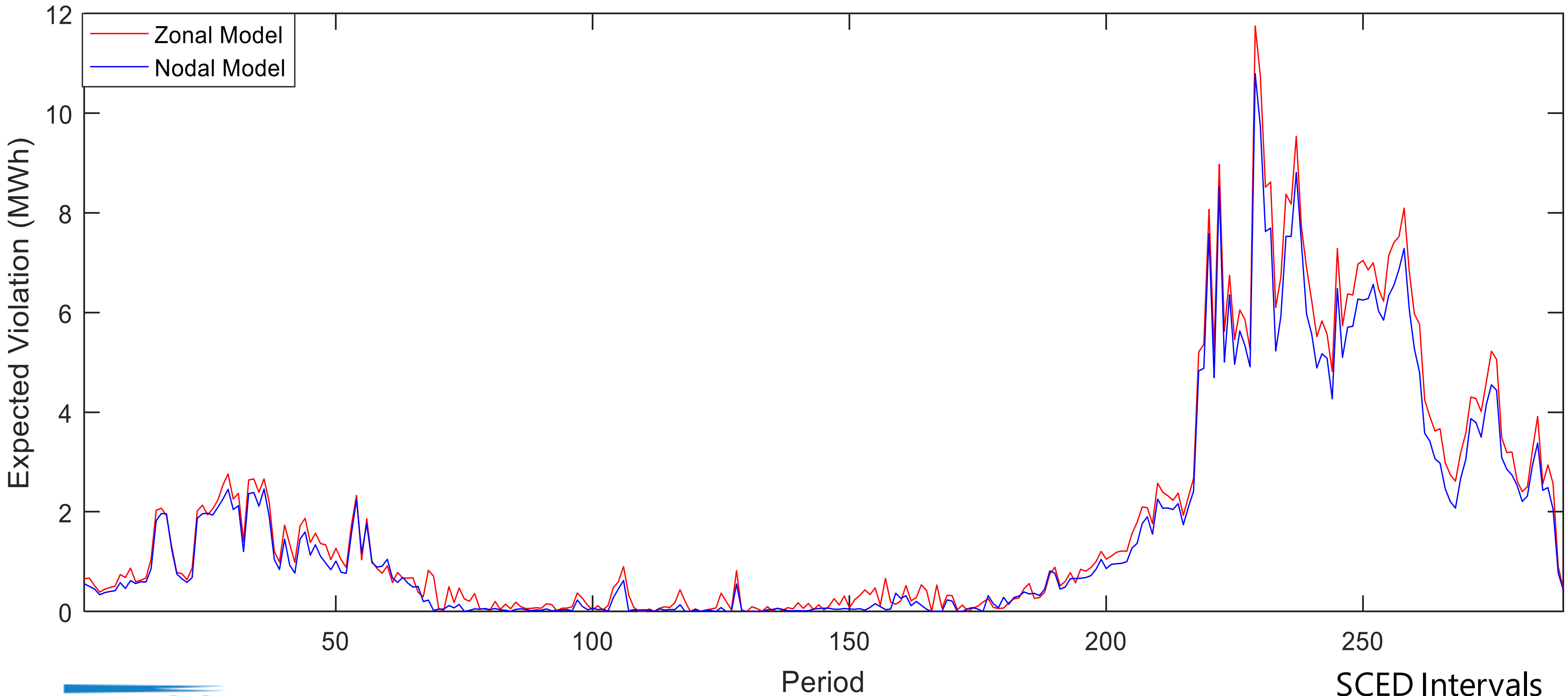
Index *n* represent node *n*, index *z* represents reserve zone *z*, index *r* represents generating resource *r*

$\text{STRResponse}_{z,e,t}$ is the reserve deployment in response to event e from zone z

$\text{STRResponse}_{n,e,t}$ is the reserve deployment in response to event e from node *n*

Contingency Analysis- Nodal Model Has Less Violation

On average, the nodal model improves reserve deliverability by 12.6% for constraints across zones. Nodal modal can also address deliverability for constraints within a zone.



SCED Intervals

Market Implications of Zonal and Nodal STR Models

Market Clearing Prices

Zonal Model

$$MCP_{z}^{STR} = \varphi_{z} = \omega + \sum_{e \in E} SP\_PB_{e} + \sum_{i \in I^{STR}} \sum_{e \in \mathcal{E}^{STR}} SP\_SC_{i,e}^{ZSTR} Sens_{i,z}^{STR}$$

Congestion component

$$LMP_{n,t}^{ZSTR} = \lambda + \sum_{i \in I} SP\_SC_{i}^{ENERGY} Sens_{i,n} + \sum_{i \in I^{STR}} \sum_{e \in \mathcal{E}^{STR}} SP\_SC_{i,e}^{ZSTR} Sens_{i,n}$$

System-wide component

Energy congestion component

STR congestion component

Nodal Model

$$MCP_{n}^{STR} = \varphi_{n} = \omega + \sum_{e \in E} SP\_PB_{e} + \sum_{i \in I^{STR}} \sum_{e \in \mathcal{E}^{STR}} SP\_SC_{i,e}^{NSTR} Sens_{i,n}$$

Congestion component

$$LMP_{n,t}^{ZSTR} = \lambda + \sum_{i \in I} SP\_SC_{i}^{ENERGY} Sens_{i,n} + \sum_{i \in I^{STR}} \sum_{e \in \mathcal{E}^{STR}} SP\_SC_{i,e}^{NSTR} Sens_{i,n}$$

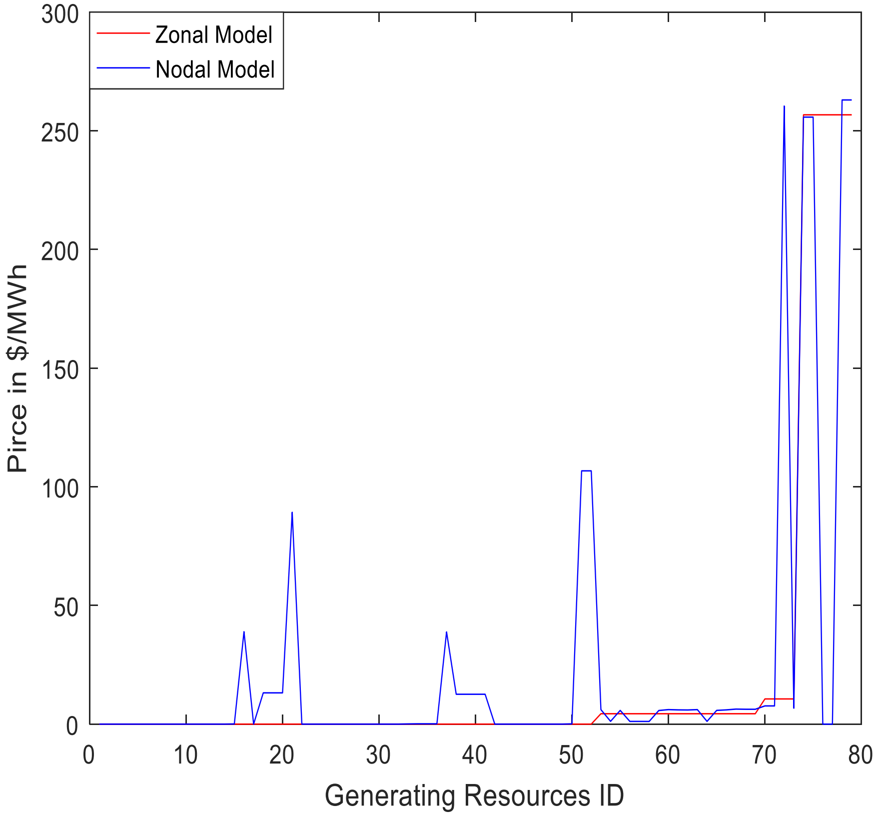
System-wide component

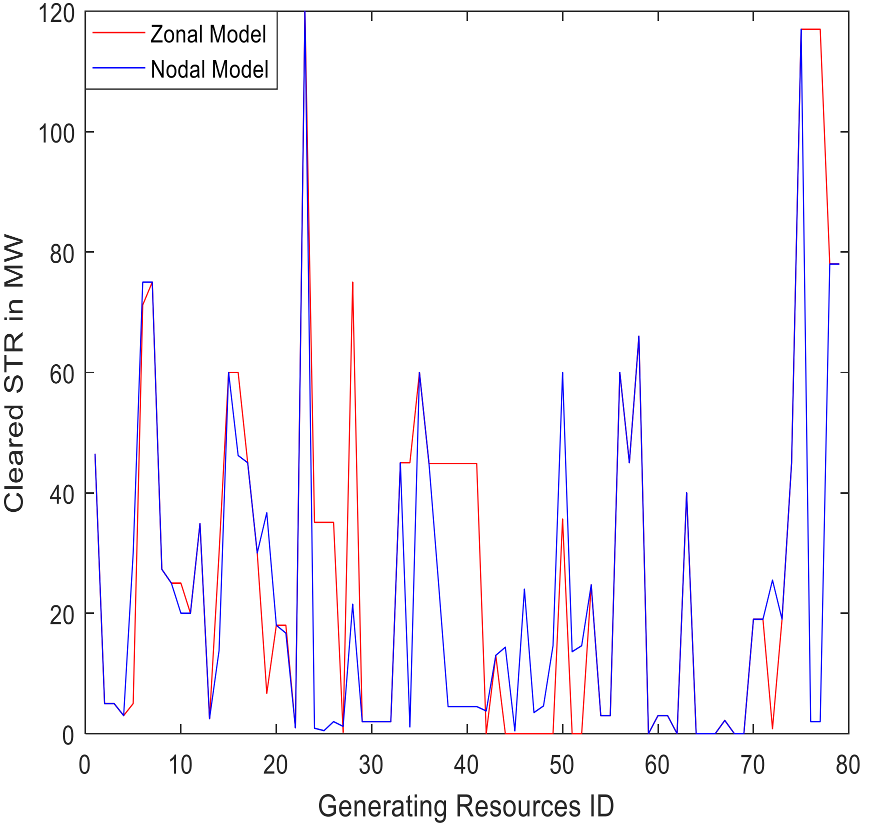
Energy congestion component

STR congestion component

Nodal model produces nodal

Example Result: the period that has the most STR payment





Units 76 and 77 receive $0/MWh and are cleared with 0MW in nodal model. Their nodal sensitivities are 0.13.

Units 76 and 77 are cleared with 117MW each and received $257/MWh in zonal model. There zonal sensitivity is -0.23.

Penalty Function Design

Penalty Function Can Significantly Impact STR Prices

$$Baseflow_i + \mathrm{Event_e} * Sens_{i,e} - \sum_{\mathrm{z}} \mathrm{STRResponse_{z,e}} * Sens_{i,z}^{STR} \le s_{i,e}^{PED} + Limit \qquad SP\_SC_{i,e}^{STR}$$

$$\textstyle\sum_{\mathrm{z}} \mathrm{STRResponse_{z,e}} = s_{i,e}^{PB+} - s_{i,e}^{PB-} + \mathrm{Event_e} \qquad SP\_PB_e$$

Penalty function design 1: Penalize the total violations from all events. May overstate the value of the constraints given reliability requirement only requires covering single event.

$$\mathrm{pf} = \sum_i \sum_e \Psi_{i,\mathrm{e}}^{PED} s_{i,e}^{PED} + \sum_e \Psi^{PB}\left(s_e^{PB+} + s_e^{PB-}\right) \qquad \mathrm{SP\_PF}^{STR}$$

Penalty function design 2: Penalize the worst violations from all events. Align the value of the constraint with the reliability requirement

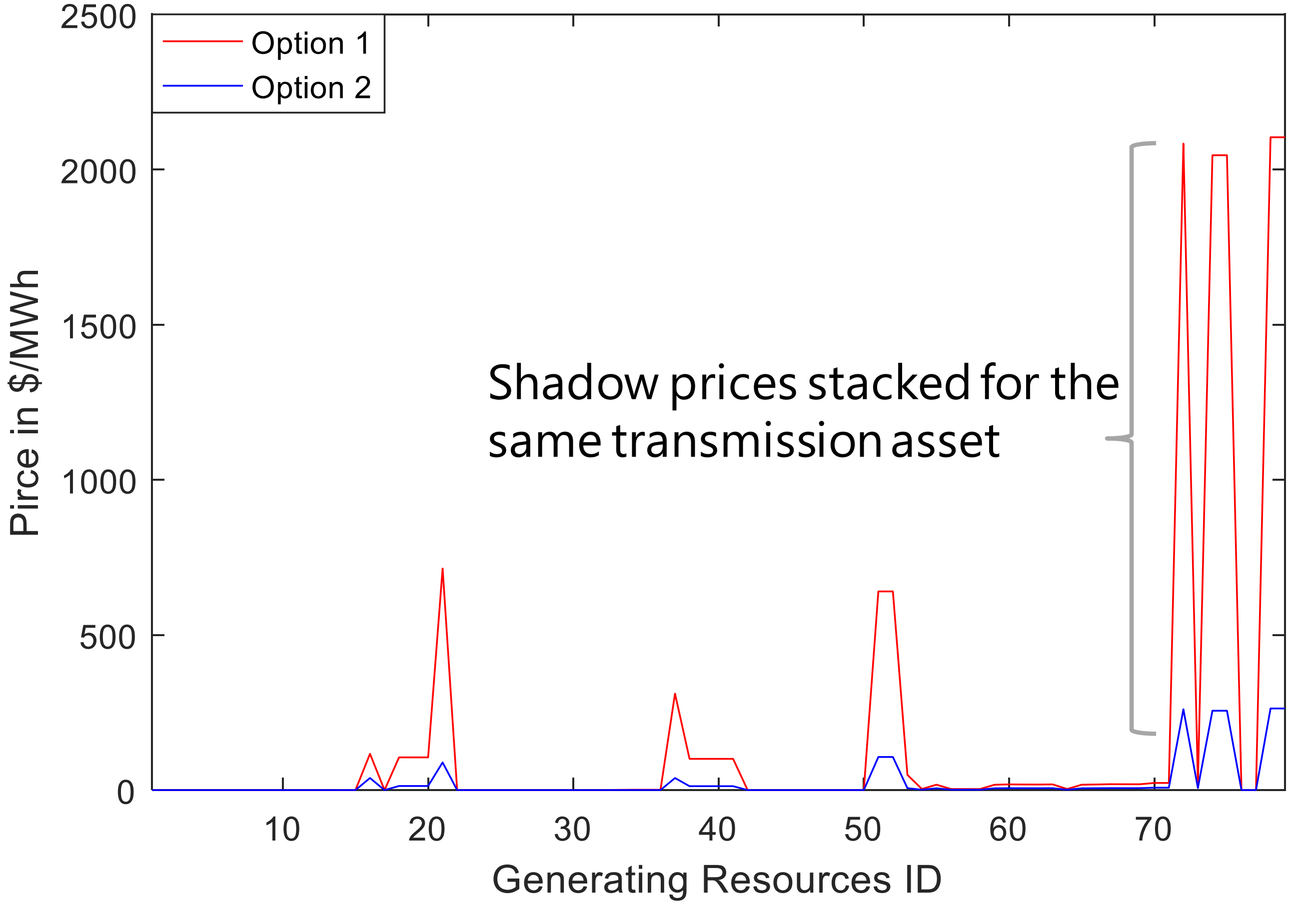
$$\mathrm{pf} \ge \sum_i \Psi_{i,\mathrm{e}}^{PED} s_{i,e}^{PED} + \Psi^{PB}\left(s_e^{PB+} + s_e^{PB-}\right) \qquad \mathrm{SP\_PF}_e^{STR}$$

$\Psi_{i,\mathrm{e}}^{PED}$: the penalty cost for post-event STR deployment constraint

Ψ^{PB}: the penalty cost for power balance Constraint

Improper Penalty Function Design May Overvalue the STR Product

STR Price



Takeaways

- **Nodal STR model produces nodal STR prices while zonal STR model produces zonal STR prices.**
  - On average, the nodal model improves reserve deliverability by over 12 percent.
- **More research should be done in events selection.**
  - Currently model the largest event from each zone.
- **Post-event constraints are considered inter-zonal**
  - Nodal model should be able to bring more benefits with intra-zonal constraints
  - More intra-zonal constraints modeled may increase the computational complexity
- **Penalty function design can significantly impact the market clearing prices of STR.**
  - Proposed penalty function design to avoid overvaluing transmission constraints.

Questions?

Appendix

The STR Design

STR qualified resources

- Online generators
- Offline quick-start generators
- Demand response

Reserve offer

- Online resources: no offer (opportunity cost)
- Offline resources: offer cost

Ramp rate and capacity

- STR resource ramp rate is shared – full ramp rate available to all products
- STR capacity can overlap with ramp product and Contingency Reserves

Primal Variables	Dual Constraints	
	Design 1	Design 2
$s_{i,e}^{PED}$	$SP\_SC_{i,e}^{STR} - \Psi_i^{PED}\kappa^{STR} \le 0$	$SP\_SC_{i,e}^{STR} - \Psi_i^{PED}\kappa_e^{STR} \le 0$
s_e^{PB+}, s_e^{PB-}	$\lvert SP\_PB_e\rvert - \Psi^{PB}\kappa_t^{STR} \le 0$	$\lvert SP\_PB_e\rvert - \Psi^{PB}\kappa_{e,t}^{STR} \le 0$
pf	$\mathrm{SP\_PF}^{STR} = 1$	$\sum_e \mathrm{SP\_PF}_e^{STR} = 1$

Slack Variable and Dual Constraints

Design 1 $SP\_SC_{i,e}^{STR} \le \Psi_i^{PED}$ and $\lvert SP\_PB_e\rvert \le \Psi^{PB}$

Design 2 $\sum_e SP\_SC_{i,e}^{STR} \le \Psi_i^{PED}$ *and* $\sum_e \lvert SP\_PB_e\rvert \le \Psi^{PB}$