



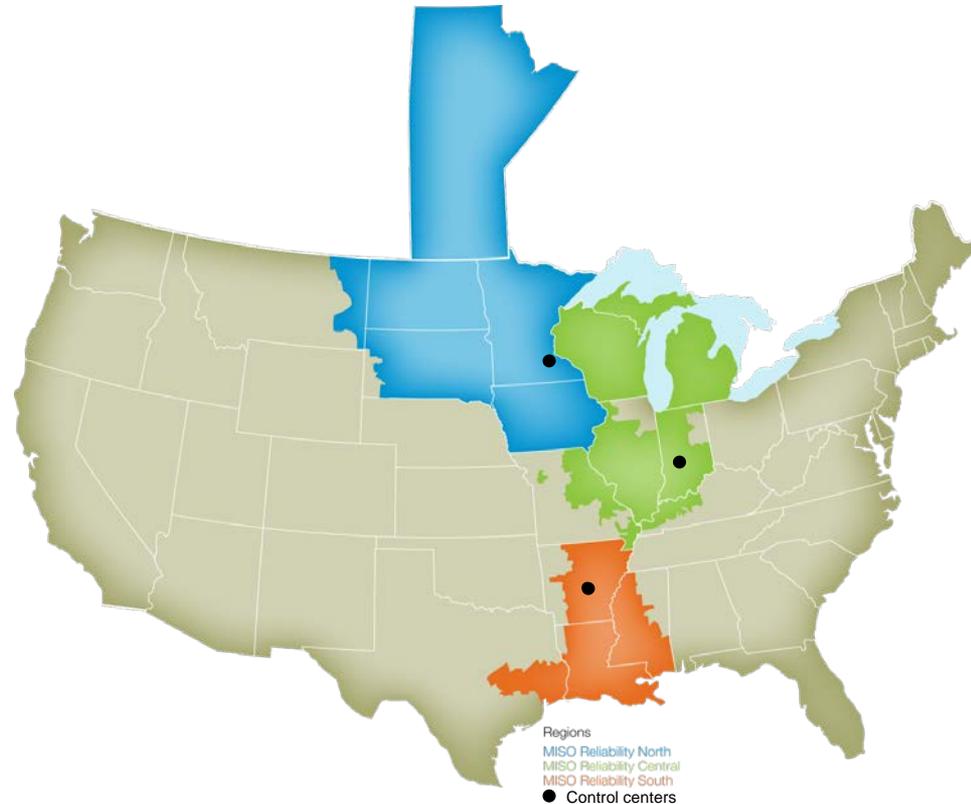
Centralized Energy & Operating Reserves Markets: A MISO perspective

1st International Conference on Large-Scale Grid
Integration of Renewable Energy in India

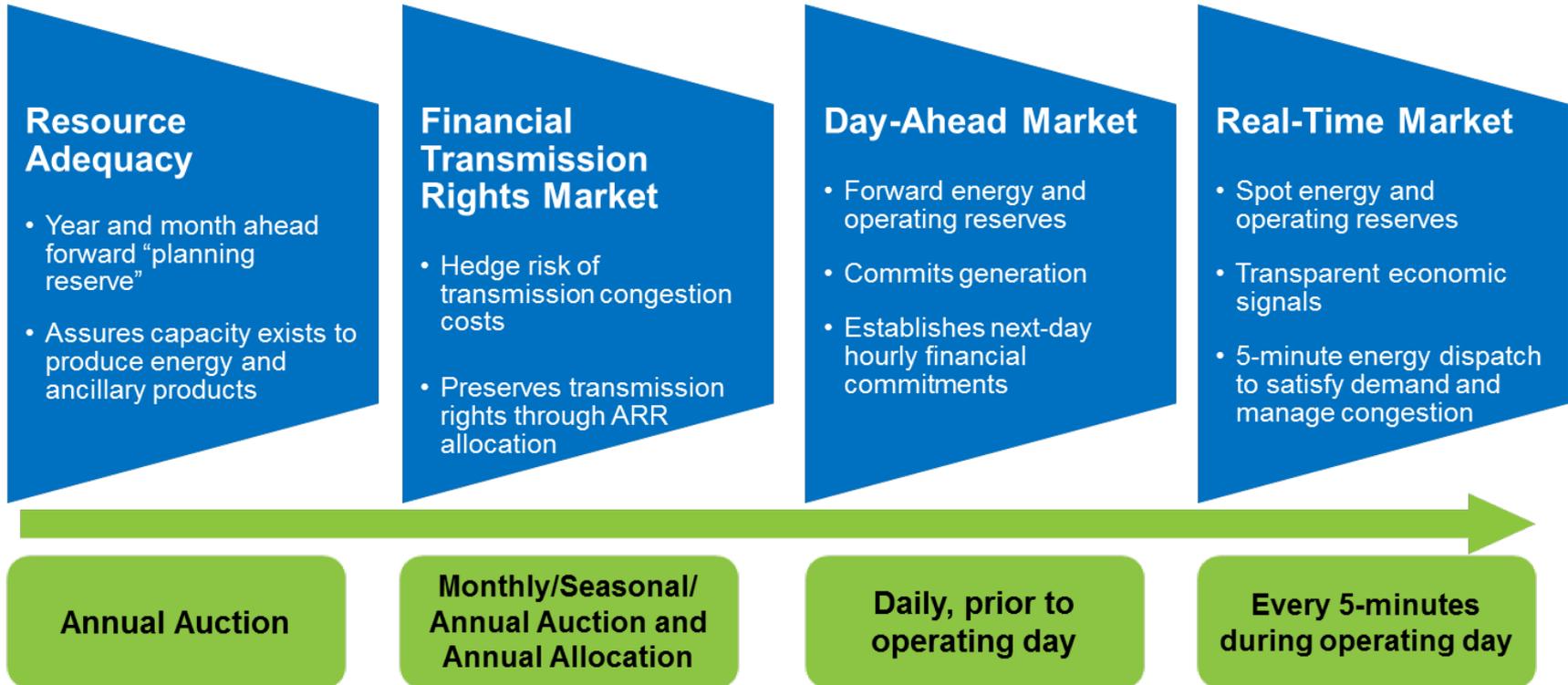
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MISO manages one of the world's largest energy markets

- Scope of Market Operations
 - US \$25.3 billion gross market charges
 - 437 market participants, 42 million customers
 - 5-minute security constrained economic dispatch
- Generation Capacity: 191,062 MW
- Historic Peak Load: 130,917 MW
- Wind generation capacity: 16,326 MW
- Instantaneous Wind Peak: 13,731 MW
- 65,800 miles of transmission
- Footprint: 15 US States, 1 Canadian Province



Markets span a broad time continuum to ensure reliable and efficient operations



Evolution of DA & RT market operations at MISO

Pre- Energy Market (prior to April 2005)

- Decentralized bi-lateral market and unit-commitment & dispatch
- Sub-optimal dispatch and congestion management
- Individual BAs carried own regulation and spin reserves
- Regulation requirement: ~1600 MW
- Spin requirement: ~1500 MW

Post-Energy market, pre-ASM

- Centralized, optimal unit commitment and dispatch
- Transmission congestion managed through SCED
- Individual BAs still carried their own regulation and spin reserves
- Regulation requirement: ~1600 MW
- Spin requirement: ~1500 MW

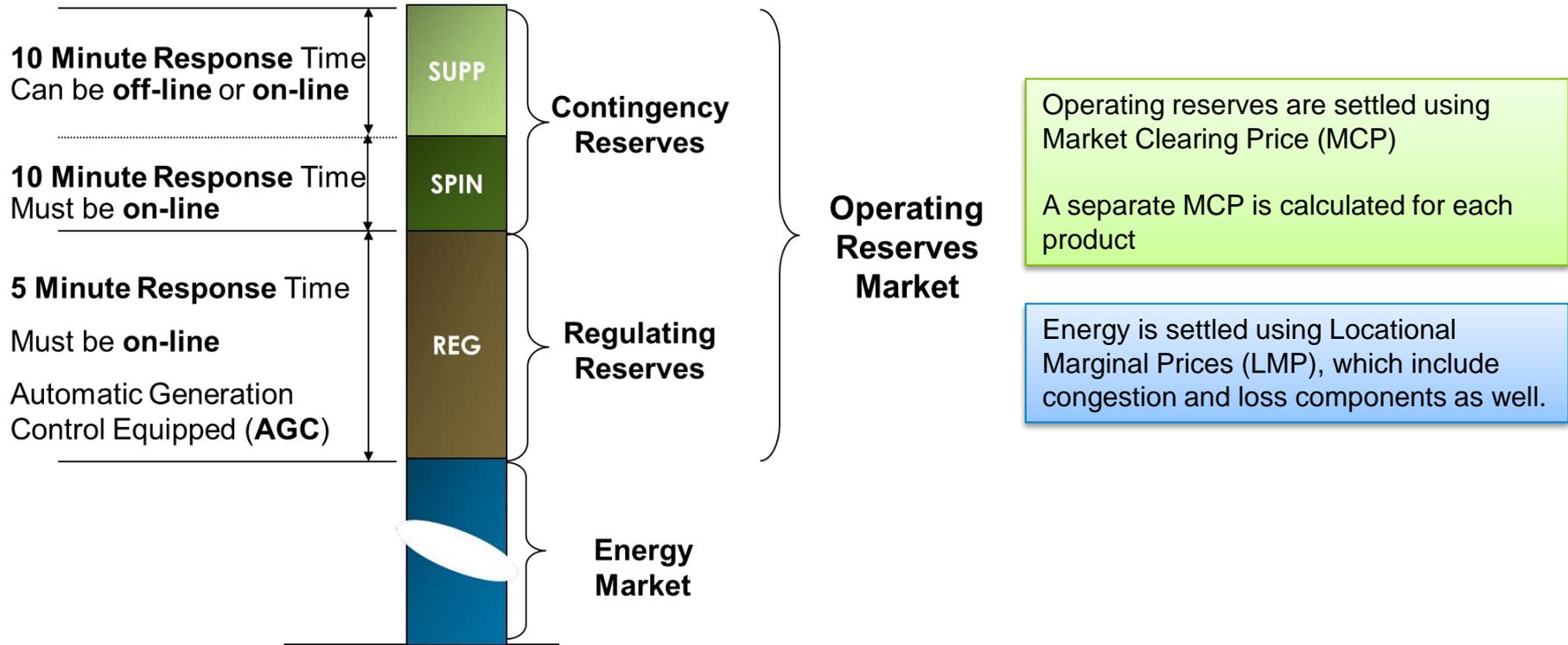
Post-ASM (January 2009)

- Centralized, co-optimized energy and operating reserves dispatch
- One centralized regulation target
- Pricing mechanism for regulation moved to market pricing
- Regulation requirement: ~400 MW
- Spin requirement: ~935 MW

Enhancements for renewable integration

- Dispatchable Intermittent Resource product
- Ramping product
- Under consideration
- Requirements for variable resources to provide ancillary service (efforts through MISO stakeholders, FERC and NERC)
- Market enhancements

Day-Ahead and Real-Time Markets Include Four Products



Energy and ancillary service products are cleared using co-optimized dispatch

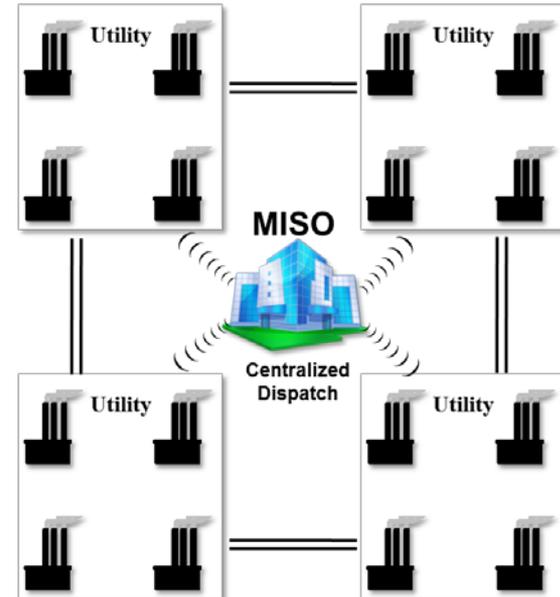
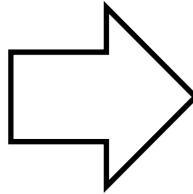
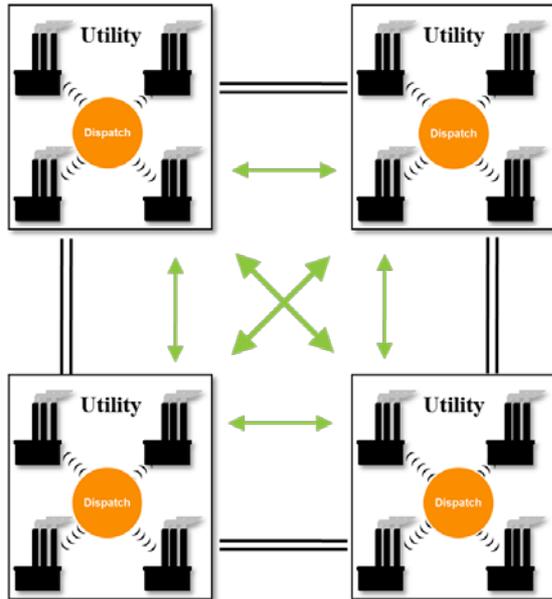
- Co-optimization ensures that there is enough energy online and available for the system demands
- Energy and Operating Reserves clear in a manner that maximizes margin (payment above offered costs) to the resources

Market	Product	Description	Product Highlights	
Energy Market	Energy	Ensures there is enough capacity to meet demand for the operating day	<ul style="list-style-type: none"> • Based on demand bids and resource offers in DA • Based on offers and system demand in RT 	
Operating Reserves Market	Regulating Reserve	Allows MISO to physically balance supply and demand on real-time basis	<ul style="list-style-type: none"> • 5 Minute Response Time • Must be on-line • Automatic Generation Control Equipped (AGC) 	
	Contingency Reserves	Spinning Reserve	Provides energy to meet demand in the event of an unexpected loss of a generation or transmission resource	<ul style="list-style-type: none"> • 10-Minute Response Time • Must be on-line
		Supplemental Reserve	Similar to Spinning Reserve, but can be supplied by offline Resources	<ul style="list-style-type: none"> • 10 Minute Response Time • Can be off-line or on-line

Centralized energy market provides over \$150 million in annual benefits to MISO's members¹

Before MISO market, the region operated as a decentralized, bilateral market resulting in limited transmission utilization, pancaked transmission rates and low market transparency.

MISO's energy markets use centralized security-constrained unit commitment and economic dispatch to optimize resource use based on market participant provided bids and offers.



Bilateral transaction

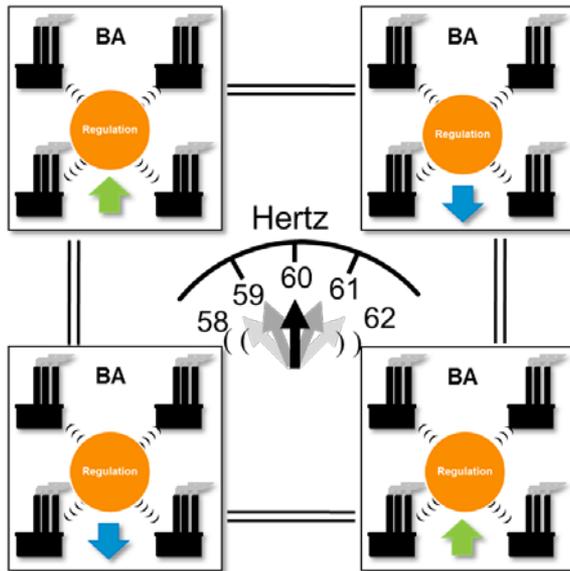


Transmission Lines

1: Based on MISO's [2016 Value proposition study](#)

Regulating and spin reserves market provides annual benefits of around \$75 million to MISO's members¹

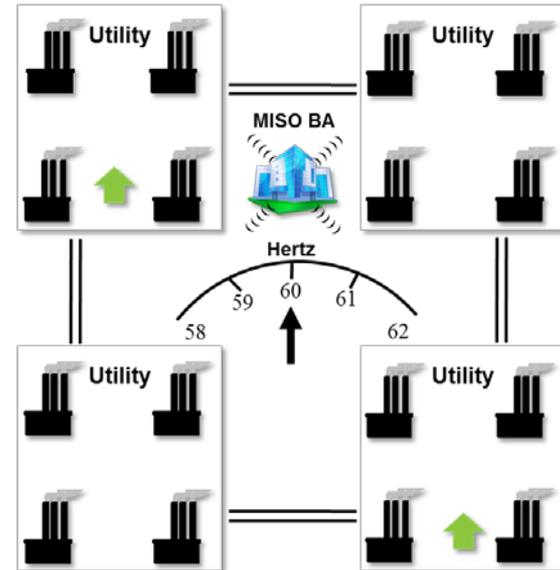
Prior to MISO's reserves market each BA maintained their own regulation & spin reserves



Individual regulating needs often resulted in BAs working *against* each other

With the reserves market the MISO BA as a whole has a common regulation & spin reserves target

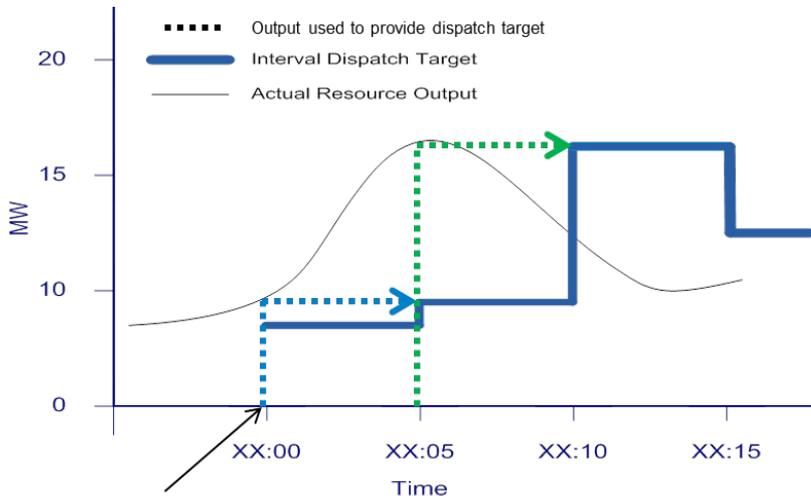
The amount of regulation & spinning reserves required within the footprint have reduced significantly



Reduction in regulation and spinning reserves frees up generation to serve the energy needs more economically

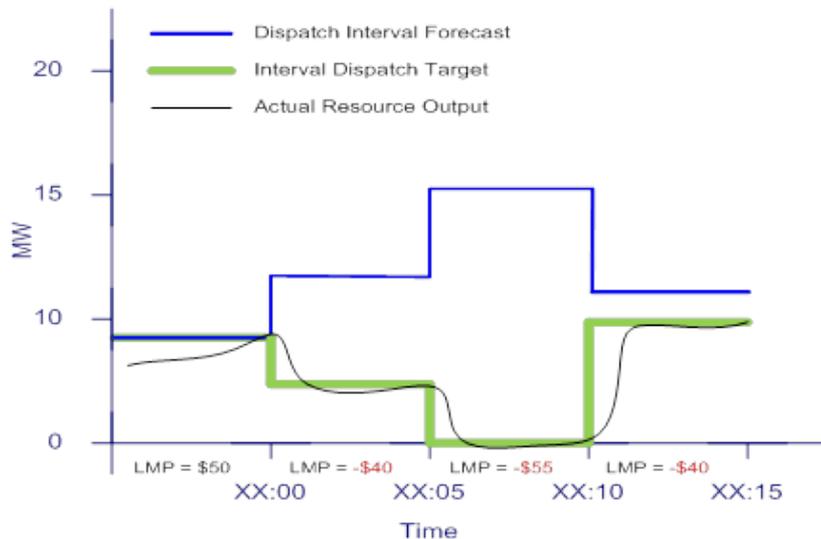
Wind and solar generation are dispatchable in MISO's market, just like traditional generation

Pre-DIR, dispatch target equal to observed output in previous state estimator snapshot – which could be ineffective, as shown below



SE snapshot and dispatch target for next 5-min interval

DIR adjusts dispatch target based on real-time forecast and recognizing transmission limitations, as illustrated below

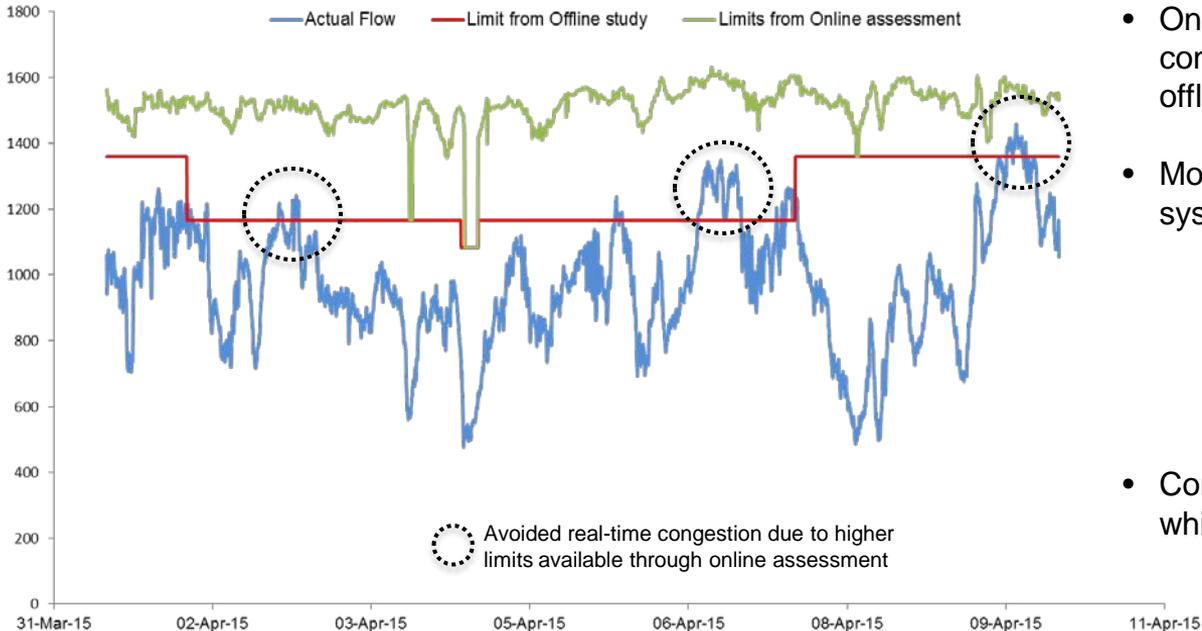


The blue trace is what the wind resource is capable of producing, and the green trace is what the transmission system can accommodate.

Optimal dispatch in the MISO market considers system ramping capability needs

- Ramp-capability product considers system ramping needs while optimally dispatching generation in real-time
- Market dispatch is fine-tuned by withholding faster ramping resources even though they may be more economic, to ensure that the system isn't ramp-constrained during times of need
- These generators are then paid their opportunity cost as compensation for the duration that they are withheld.
- There is no offer price for the ramp product – when the ramp product is binding it is cleared at a price which is equal to the opportunity cost of the marginal resource
- Participation in the ramp product is voluntary and resources can opt out

Real-time stability assessments maximize utilization of renewables while minimizing market congestion costs



- Online assessment (green) provides consistently higher limits compared to offline studies (red).
- More efficient utilization of the transmission system by:
 - minimizing real-time congestion and reducing costs
 - accommodating higher wind generation by minimizing curtailments
- Contributes to overall market efficiency while ensuring reliable operations

Online stability assessment reduced congestion costs by ~\$31 million in 2016!

In Summary...

- MISO manages one of the world's largest energy markets with over 190,000 MW of generation and over US \$25 billion in gross market charges
- Day-ahead and real-time markets for energy and ancillary services cumulatively save the MISO membership ~US \$225 million annually
- Need for efficient and reliable integration of bulk quantities of renewable resources has driven enhancements to the MISO market such as dispatchable intermittent resources, ramp-capability product and online stability assessment



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