



Impacts of Higher Wind Penetration Levels on Operating Reserves: A MISO perspective

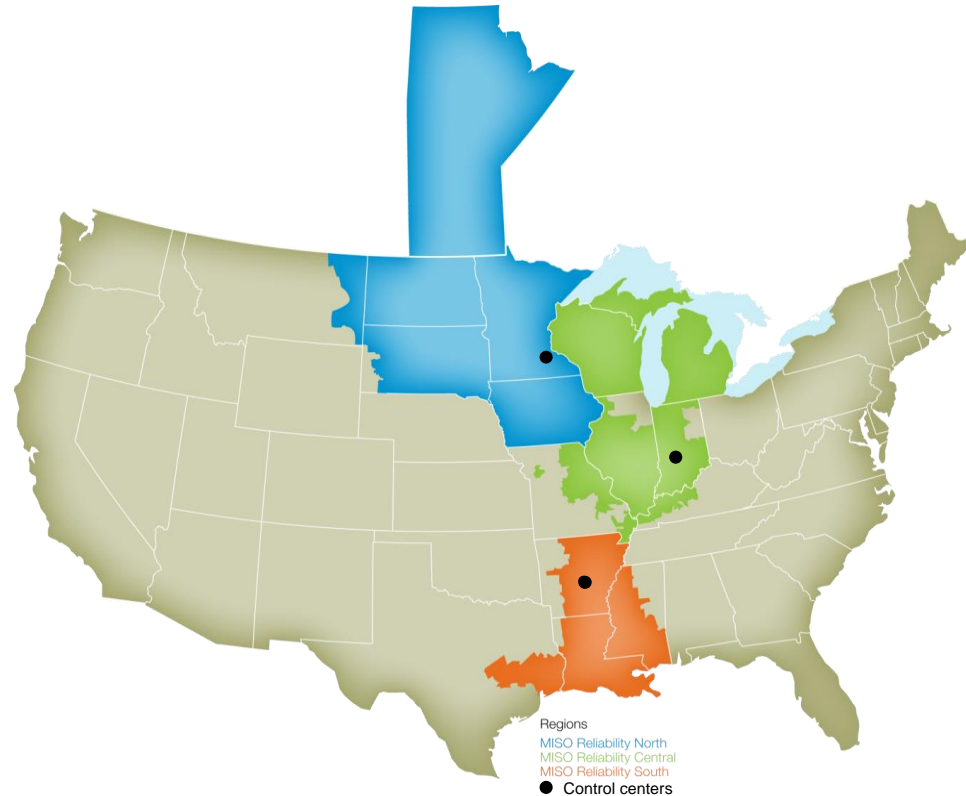
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MISO manages one of the world's largest energy markets

- 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



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

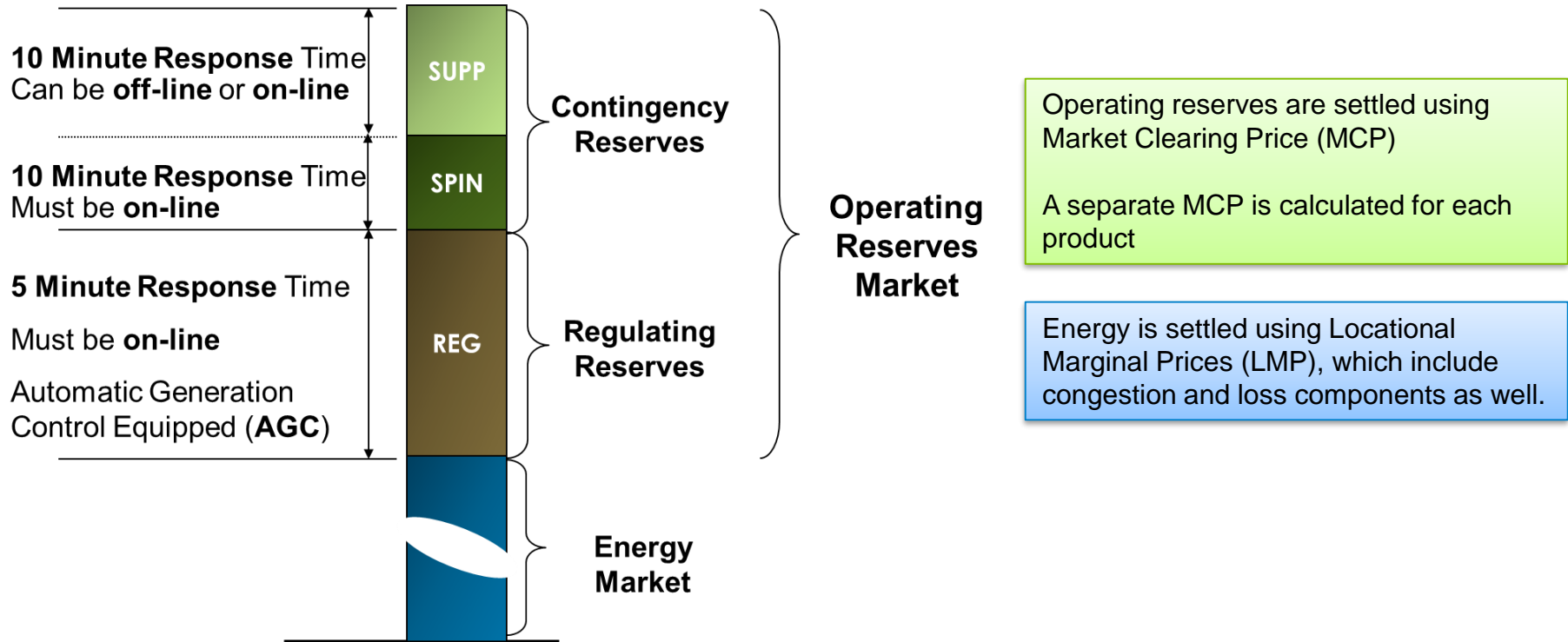
Post-ASM (January 2009)

- 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



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

Large balancing area, use of DIRs and ramp capability product help manage need for reserves

- MISO's large balancing area and geographic diversity help minimize the issue at current wind penetration levels
- Improved load and wind forecasting
 - 5 min for 6 hours and hourly for seven days at farm level
 - Persistence and numerical weather prediction models
- Current operational methods to manage ramp include
 - Pre-commitment of units
 - Use of fast-start units and spinning reserves to manage unexpected variability
 - Ramp capability product, new in 2016, procures and sets aside ramp
- Improved operational and market methods under development
 - 30-minute reserve products, storage, automatic generation control and others

MISO Renewable Roadmap - Will the continuation of these trends present problems to the resiliency of the grid?

Boundary conditions

- Is there a maximum level of renewable energy the grid can handle?
- How high can renewable penetration get before we need additional storage?

Timing

- Which physical area of the grid will face the greatest stress first?
- How much renewable energy can be deployed before fundamental changes are needed?

Reliability

- How large will the ramping requirements be?
- What is the frequency response of a renewable fleet?
- Is traditional inertia still needed?
- Will reserve requirements change? Operating? Planning?
- Is there a minimum amount of baseload that must remain online? 24/7?, seasonally?

Other

- How do conditions present outside of MISO change the answers?
- Can current planning processes deal with high levels of renewable penetration?

In Summary...

- Day-ahead and real-time markets for energy and ancillary services cumulatively save the MISO membership ~US \$225 million annually
 - Regulating and spin reserves market provides annual benefits of around \$75 million to MISO's members
 - Keeping Operating Reserves low enhances market benefits
- 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
- MISO continues to assess higher levels of renewable energy penetration to understand operational and planning impacts



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