

## **SCHEDULE 29**

### **Energy and Operating Reserve Market Simultaneous Co-optimized Formulations**

#### **I. INTRODUCTION**

The Transmission Provider utilizes a simultaneously co-optimized Security Constrained Economic Dispatch (SCED) algorithm to clear, dispatch and price Energy, Operating Reserves, Up Ramp Capability, Down Ramp Capability, and Short-Term Reserve. The simultaneously co-optimized SCED algorithm utilizes a linear programming solver to minimize objective costs represented by a linear objective function subject to linear or linearized physical, reliability and Good Utility Practice constraints. The simultaneously co-optimized SCED objective function includes total Energy costs, Regulating Reserve costs, Spinning Reserve costs, Supplemental Reserve costs, Short-Term Reserve costs, Market-Wide Operating Reserve value, Market-Wide Regulating and Spinning Reserve value, Market-Wide Regulating Reserve value, Up Ramp Capability value, Down Ramp Capability value, and Market-Wide Short-Term Reserve value. The simultaneously co-optimized SCED algorithm is solved on an Hourly basis for the Day-Ahead Energy and Operating Reserve Market and for each five (5) minute Dispatch Interval for the Real-Time Energy and Operating Reserve Market.

#### **II. DAY-AHEAD FORMULATIONS**

##### **Objective Function:**

Minimize {Total Hourly Energy Costs

- + Total Hourly Regulating Reserve Costs
- + Total Hourly Spinning Reserve Costs
- + Total Hourly Supplemental Reserve Costs

- + Total Hourly Short-Term Reserve Costs
- Total Hourly Market-Wide Operating Reserve Value
- Total Hourly Market-Wide Regulating and Spinning Reserve Value
- Total Hourly Market-Wide Regulating Reserve Value
- Total Hourly Market-Wide Up Ramp Capability Value
- Total Hourly Market-Wide Down Ramp Capability Value
- Total Hourly Market-Wide Short-Term Reserve Value}

Where

Total Hourly Energy Costs

= The sum of the hourly Energy costs incurred by all Resources, based on the Energy offer curves, supplying dispatchable Energy in the Day-Ahead Energy and Operating Reserve Market for the given Hour based on the submitted Energy Offer curves.

Total Hourly Regulating Reserve Costs

= The sum of the hourly Regulating Reserve costs, which is based on the Regulating Total Cost, incurred by all Resources supplying dispatchable Regulating Reserve in the Day-Ahead Energy and Operating Reserve Market for the given Hour, based on the submitted Regulating Capacity Offers and Regulating Mileage Offers.

Total Hourly Spinning Reserve Costs

= The sum of the hourly Spinning Reserve costs, based on the Spinning Reserve offer prices, incurred by all Resources supplying dispatchable Spinning Reserve in the Day-Ahead Energy and Operating Reserve Market for the given Hour based on the submitted Spinning Reserve Offers.

Total Hourly Supplemental Reserve Availability Costs

= The sum of the hourly Supplemental Reserve availability costs, based on the Supplemental Reserve offer prices, incurred by all Resources supplying dispatchable Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market for the given Hour based on the submitted Supplemental Reserve Offers.

Total Hourly Short-Term Reserve Availability Costs

= The sum of the hourly Short-Term Reserve availability costs, based on the Off-Line Short-Term Reserve Offer prices, incurred by all off-line Resources supplying Short-Term Reserve in the Day-Ahead Energy and Operating Reserve Market for the given Hour based on the submitted Off-Line Short-Term Reserve Offers.

Total Hourly Market-Wide Operating Reserve Value

= The hourly value of the cleared Market-Wide Operating Reserve to the Load Serving Entities and Market Participant with Exports on whose behalf the Transmission Provider is procuring Operating

Reserves based on the Market-Wide Operating Reserve Demand Curve.

Total Hourly Market-Wide Regulating and Spinning Reserve Value

= The hourly value of the cleared Market-Wide Regulating and Spinning Reserve to the Load Serving Entities and Market Participant with Exports on whose behalf the Transmission Provider is procuring Regulating and Spinning Reserves based on the Market-Wide Regulating and Spinning Reserve Demand Curve.

Total Hourly Market-Wide Regulating Reserve Value

= The hourly value of the cleared Market-Wide Regulating Reserve to the Load Serving Entities on whose behalf the Transmission Provider is procuring Regulating Reserves based on the Market-Wide Regulating Reserve Demand Curve.

Total Hourly Market-Wide Up Ramp Capability Value

= The hourly value of the cleared Market-Wide Up Ramp Capability to the Load Serving Entities and Market Participant with Exports on whose behalf the Transmission Provider is procuring Up Ramp Capability based on the Market-Wide Up Ramp Capability Demand Curve.

Total Hourly Market-Wide Down Ramp Capability Value

= The hourly value of the cleared Market-Wide Down Ramp Capability to the Load Serving Entities and Market Participant with Exports on whose behalf the Transmission Provider is procuring Down Ramp Capability based on the Market-Wide Down Ramp Capability Demand Curve.

Total Hourly Market-Wide Short-Term Reserve Capability Value

= The hourly value of the cleared Market-Wide Short-Term Reserve to the Load Serving Entities and Market Participant with Exports on whose behalf the Transmission Provider is procuring Short-Term Reserve based on the Market-Wide Short-Term Reserve Demand Curve.

**Constraints:**

Subject to

Global Power Balance Constraint

Market-Wide Operating Reserve Constraint

Market-Wide Regulating and Spinning Reserve Constraint

Market-Wide Regulating Reserve Constraint

Market-Wide Non-DRR1 Operating Reserve Constraint

Market-Wide Non-DRR1 Regulating and Spinning Reserve Constraint

Market-Wide Up Ramp Capability Constraint

Ramp Procurement Minimum Reserve Zone Up Ramp Capability Requirement  
Constraint

Market-Wide Down Ramp Capability Constraint

Ramp Procurement Minimum Reserve Zone Down Ramp Capability Requirement  
Constraint

Market-Wide Short-Term Reserve Constraint

Resource Limit Constraints

Resource Ramping Constraints

Transmission Constraints

Sub-Regional Power Balance Constraints

Post Reserve Deployment Constraints

Co-optimized Reserve Zone Operating Reserve constraints

Co-optimized Reserve Zone Regulating and Spinning Reserve constraints

Co-optimized Reserve Zone Regulating Reserve constraint

Co-optimized Reserve Zone Short-Term Reserve constraints

Electric Storage Resource Energy Storage Level constraints

Where:

The Global Power Balance Constraint is a constraint that requires the net Energy injected into the Network Model to equal the net withdrawn from the Network Model plus losses.

The Market-Wide Operating Reserve Constraint ensures the supply of Market-Wide Operating Reserve is greater than or equal to the cleared Market-Wide Operating Reserve.

The Market-Wide Regulating and Spinning Reserve Constraint ensure that the supply of Market-Wide Regulating and Spinning Reserve is greater than or equal to the Market-Wide Regulating and Spinning Reserve requirement.

The Market-Wide Regulating Reserve Constraint ensures the supply of Market-Wide Regulating Reserve is greater than or equal to the cleared Market-Wide Regulating Reserve.

The Market-Wide Non-DRR1 Operating Reserve Constraint ensures the percentage of Market-Wide Operating Reserve that is cleared on Generation Resources, Demand Response Resources – Type II, Electric Storage Resources, External Asynchronous Resources, and/or Distributed Energy Aggregated Resources complies with Applicable Reliability Standards.

The Market-Wide Non-DRR1 Regulating and Spinning Reserve Constraint ensures the percentage of Market-Wide Regulating and Spinning Reserve that is cleared on Generation Resources, Demand Response Resources – Type II, Electric Storage Resources, External Asynchronous Resources, and/or Distributed Energy Aggregated Resources complies with Applicable Reliability Standards.

The Market-Wide Up Ramp Capability Constraint ensures the supply of Market-Wide Up Ramp Capability is greater than or equal to the cleared demand for Market-Wide Up Ramp Capability.

The Ramp Procurement Minimum Reserve Zone Up Ramp Capability Requirement Constraint ensure that the cleared Up Ramp Capability in a zone can be converted to Energy when needed while respecting transmission constraints.

The Market-Wide Down Ramp Capability Constraint ensures the supply of Market-Wide Down Ramp Capability is greater than or equal to the cleared demand for Market-Wide Down Ramp Capability.

The Ramp Procurement Minimum Reserve Zone Down Ramp Capability Requirement Constraint ensure that the cleared Down Ramp Capability in a zone can be converted to Energy when needed while respecting transmission constraints.

The Market-Wide Short-Term Reserve Constraint ensures the supply of Market-Wide Short-Term Reserve is greater than or equal to the cleared demand for Market-Wide Short-Term Reserve.

The Resource Limit Constraints ensure that each Resource has the Capacity, based on submitted limits, to simultaneously supply cleared Energy, deploy one hundred percent (100%) of cleared Regulating Reserve in the upward direction, deploy one hundred percent (100%) of cleared Spinning Reserve, deploy one hundred percent (100%) of cleared Supplemental Reserve, and change output in the upward direction one hundred percent (100%) of cleared Up Ramp Capability. The Resource Limit Constraints ensure that each Resource has the Capacity, based on submitted limits, to simultaneously supply cleared Energy and deploy one hundred percent (100%) of cleared Short-Term Reserve. In addition,



the Resource Limit Constraints ensure that each Resource has the ability to simultaneously supply cleared Energy, deploy one hundred percent (100%) of the cleared Regulating Reserve in the downward direction, and change output in the downward direction one hundred percent (100%) of cleared Down Ramp Capability with no Spinning Reserve, Supplemental Reserve, or Short-Term Reserve deployment.

The Resource Ramping Constraints ensure that each Resource is cleared in a manner to follow load based on cleared Energy levels in adjacent dispatch intervals, to deploy Regulating Reserve and Contingency Reserve in a manner that will comply with Applicable Reliability Standards, to support the cleared level of Up Ramp Capability and Down Ramp Capability and to support the deployment cleared level of Short-Term Reserve.

The Transmission Constraints ensure that Energy is cleared on Resources and Loads in such a way as to prevent flows on transmission flowgates and branches from exceeding normal operating limits under basecase conditions or Emergency operating limits under a first contingency loss of a Resource or transmission facility. In addition, the Transmission Constraints ensure that Operating Reserves can be deployed, Up Ramp Capability and Down Ramp Capability can be supplied, and Short-Term Reserve can be supplied in such a way as to prevent flows on transmission flowgates and branches from exceeding normal operating limits under basecase conditions or Emergency operating limits under a first contingency loss of a Resource or transmission facility.

The Sub-Regional Power Balance Constraints ensure that Energy flows within the Transmission Provider Region are managed consistent with applicable seams agreements, coordination agreements, transmission service agreements, or operating procedures. The Sub-Regional Power Balance Constraints also ensure that Operating Reserves can be deployed, Up Ramp Capability and Down Ramp Capability can be supplied, and Short-Term Reserve can be supplied in such a way as to prevent flows on Sub-Regional Power Balance Constraints from exceeding the appropriate limits.

The Post Reserve Deployment Constraints ensure that Operating Reserves and Short-Term Reserve can be deployed in such a way as to prevent flows on identified Transmission Constraints from exceeding the appropriate limits.

The Co-optimized Reserve Zone Operating Reserve constraints ensure the supply of Operating Reserve within a specific Reserve Zone is greater than or equal to the Co-optimized Zonal Operating Reserve Requirement.

The Co-optimized Reserve Zone Regulating and Spinning Reserve constraints ensure the supply of Regulating Reserve and Spinning Reserve within a specific Reserve Zone is greater than or equal to the Co-optimized Zonal Spinning Reserve Requirement plus the Co-optimized Zonal Regulating Reserve Requirement.

The Co-optimized Reserve Zone Regulating Reserve constraints ensure the supply of Regulating Reserve within a specific Reserve Zone is greater than or equal to the Co-optimized Zonal Regulating Reserve Requirement.

The Co-optimized Reserve Zone Short-Term Reserve constraints ensure the supply of Short-Term Reserve within a specific Reserve Zone is greater than or equal to the Co-optimized Zonal Short-Term Reserve Requirement.

Electric Storage Resource Energy Storage Level constraints ensure the Electric Storage Resource units have sufficient Energy Storage Level to supply Energy, Operating Reserves, Up Ramp Capability, Down Ramp Capability, and Short-Term Reserve reliably.

### **III. REAL-TIME FORMULATIONS**

#### **Objective Function:**

Minimize {Total Dispatch Interval Energy Costs

- + Total Dispatch Interval Regulating Reserve Costs
- + Total Dispatch Interval Spinning Reserve Costs
- + Total Dispatch Interval Supplemental Reserve Costs
- + Total Dispatch Interval Short-Term Reserve Costs
- Total Dispatch Interval Market-Wide Operating Reserve Value
- Total Dispatch Interval Market-Wide Regulating and Spinning Reserve Value
- Total Dispatch Interval Market-Wide Regulating Reserve Value
- Total Dispatch Interval Market-Wide Up Ramp Capability Value
- Total Dispatch Interval Market-Wide Down Ramp Capability Value
- Total Dispatch Interval Market-Wide Short-Term Reserve Value}

Where

Total Dispatch Interval Energy Costs

= The sum of the Dispatch Interval Energy costs incurred by all Resources, based on the Energy offer curves, supplying dispatchable Energy in the Real-Time Energy and Operating Reserve Market for the given Dispatch Interval based on the submitted Energy Offers curves.

Total Dispatch Interval Regulating Reserve Costs

= The sum of the Dispatch Interval Regulating Reserve costs, which is based on the Regulating Total Cost prices, incurred by all Resources supplying dispatchable Regulating Reserve in the Real-Time Energy and Operating Reserve Market for the given Dispatch Interval, based on the submitted Regulating Capacity Offers and Regulating Mileage Offers.

Total Dispatch Interval Spinning Reserve Costs

= The sum of the Dispatch Interval Spinning Reserve costs, based on the Spinning Reserve offer prices, incurred by all Resources supplying dispatchable Spinning Reserve in the Real-Time Energy and Operating Reserve Market for the given Dispatch Interval based on the submitted Spinning Reserve Offers.

Total Dispatch Interval Supplemental Reserve Availability Costs

= The sum of the Dispatch Interval Supplemental Reserve costs, based on the Supplemental Reserve offer prices, incurred by all

Resources supplying dispatchable Supplemental Reserve in the Real-Time Energy and Operating Reserve Market for the given Dispatch Interval based on the submitted Supplemental Reserve Offers.

Total Dispatch Interval Short-Term Reserve Costs

= The sum of the Dispatch Interval Short-Term Reserve availability costs, based on the Off-line Short-Term Reserve Offer prices, incurred by all off-line Resources supplying Short-Term Reserve in the Real-Time Energy and Operating Reserve Market for the given Dispatch Interval based on the submitted Off-line Short-Term Reserve Offers.

Total Dispatch Interval Market-Wide Operating Reserve Value

= The Dispatch Interval value of the cleared Market-Wide Operating Reserve to the Load Serving Entities and Market Participants with Exports on whose behalf the Transmission Provider is procuring Operating Reserve based on the Market-Wide Operating Reserve Demand Curve.

Total Dispatch Interval Market-Wide Regulating and Spinning Reserve Value

= The Dispatch Interval value of the cleared Market-Wide Regulating and Spinning Reserve to the Load Serving Entities and Market Participants with Exports on whose behalf the Transmission Provider is procuring Regulating and Spinning

Reserve based on the Market-Wide Regulating and Spinning  
Reserve Demand Curve.

Total Dispatch Interval Market-Wide Regulating Reserve Value

= The Dispatch Interval value of the cleared Market-Wide  
Regulating Reserve to the Load Serving Entities on whose behalf  
the Transmission Provider is procuring Regulating Reserve based  
on the Market-Wide Regulating Reserve Demand Curve.

Total Dispatch Interval Market-Wide Up Ramp Capability Value

= The Dispatch Interval value of the cleared Market-Wide Up Ramp  
Capability to the Load Serving Entities and Market Participant  
with Exports on whose behalf the Transmission Provider is  
procuring Up Ramp Capability based on the Market-Wide Up  
Ramp Capability Demand Curve.

Total Dispatch Interval Market-Wide Down Ramp Capability Value

= The Dispatch Interval value of the cleared Market-Wide Down  
Ramp Capability to the Load Serving Entities and Market  
Participant with Exports on whose behalf the Transmission  
Provider is procuring Down Ramp Capability based on the Market-  
Wide Down Ramp Capability Demand Curve.

Total Dispatch Interval Market-Wide Short-Term Reserve Value

= The Dispatch Interval value of the cleared Market-Wide Short-  
Term Reserve to the Load Serving Entities and Market Participants

with Exports on whose behalf the Transmission Provider is  
procuring Short-Term Reserve based on the Market-Wide Short-  
Term Reserve Demand Curve.

**Constraints:**

Subject to

Global Power Balance Constraint

Market-Wide Operating Reserve Constraint

Market-Wide Regulating and Spinning Reserve Constraint

Market-Wide Regulating Reserve Constraint

Market-Wide Non-DRR1 Operating Reserve Constraint

Market-Wide Non-DRR 1 Regulating and Spinning Reserve Constraint

Market-Wide Up Ramp Capability Constraint

Ramp Procurement Minimum Reserve Zone Up Ramp Capability Requirement  
Constraint

Market-Wide Down Ramp Capability Constraint

Ramp Procurement Minimum Reserve Zone Down Ramp Capability Requirement  
Constraint

Market-Wide Short-Term Reserve Constraint

Resource Limit Constraints

Resource Ramping Constraints

Transmission Constraints

Sub-Regional Power Balance Constraints

Post Reserve Deployment Constraints

Co-optimized Reserve Zone Operating Reserve constraints

Co-optimized Reserve Zone Regulating and Spinning Reserve constraints

Co-optimized Reserve Zone Regulating Reserve constraints

Co-optimized Reserve Zone Short-Term Reserve constraints

Electric Storage Resource Energy Storage Level constraints

Where

The Global Power Balance Constraint is a constraint that requires the net Energy injected into the Network Model to equal the net Energy withdrawn from the Network Model plus losses.

The Market-Wide Operating Reserve Constraint ensures the supply of Market-Wide Operating Reserve is greater than or equal to the cleared Market-Wide Operating Reserve.

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The Market-Wide Regulating Reserve Constraint ensures the supply of Market-Wide Regulating Reserve is greater than or equal to the cleared Market-Wide Regulating Reserve.

The Market-Wide Non-DRR 1 Operating Reserve Constraint ensures the percentage of Market-Wide Operating Reserve that is cleared on Generation Resources, Demand Response Resources – Type II, Electric Storage Resources,



External Asynchronous Resources, and/or Distributed Energy Aggregated

Resources complies with Applicable Reliability Standards.

The Market-Wide Non-DRR1 Regulating and Spinning Reserve

Constraint ensures the percentage of Market-Wide Regulating and Spinning

Reserve that is cleared on Generation Resources, Demand Response Resources –

Type II, Electric Storage Resources, External Asynchronous Resources, and/or

Distributed Energy Aggregated Resources complies with Applicable Reliability

Standards.

The Market-Wide Up Ramp Capability Constraint ensures the supply of

Market-Wide Up Ramp Capability is greater than or equal to the cleared demand

for Market-Wide Up Ramp Capability.

The Ramp Procurement Minimum Reserve Zone Up Ramp Capability

Requirement Constraint ensure that the cleared Up Ramp Capability in a zone can

be converted to Energy when needed while respecting transmission constraints.

The Market-Wide Down Ramp Capability Constraint ensures the supply

of Market-Wide Down Ramp Capability is greater than or equal to the cleared

demand for Market-Wide Down Ramp Capability.

The Ramp Procurement Minimum Reserve Zone Down Ramp Capability

Requirement Constraint ensure that the cleared Down Ramp Capability in a zone

can be converted to Energy when needed while respecting transmission

constraints.

The Market-Wide Short-Term Reserve Constraint ensures the supply of Market-Wide Short-Term Reserve is greater than or equal to the cleared demand for Market-Wide Short-Term Reserve.

The Resource Limit Constraints ensure that each Resource has the Capacity, based on submitted limits, to simultaneously supply cleared Energy, deploy one hundred percent (100%) of cleared Regulating Reserve in the upward direction, deploy one hundred percent (100%) of cleared Spinning Reserve, deploy one hundred percent (100%) of cleared Supplemental Reserve, and change output in the upward direction one hundred percent (100%) of cleared Up Ramp Capability. The Resource Limit Constraints ensure that each Resource has the Capacity, based on submitted limits, to simultaneously supply cleared Energy and deploy one hundred percent (100%) of cleared Short-Term Reserve. In addition, the Resource Limit Constraints ensure that each Resource has the ability to simultaneously supply cleared Energy, deploy one hundred percent (100%) of the cleared Regulating Reserve in the downward direction, and change output in the downward direction one hundred percent (100%) of cleared Down Ramp Capability with no Spinning Reserve, Supplemental Reserve, or Short-Term Reserve deployment.

The Resource Ramping Constraints ensure that each Resource is cleared in a manner to follow load based on cleared Energy levels in adjacent Dispatch Intervals to deploy Regulating Reserve and Contingency Reserve in a manner that will comply with Applicable Reliability Standards, to support the cleared level of

Up Ramp Capability and Down Ramp Capability, and to support the deployment of Short-Term Reserve.

The Transmission Constraints ensure that Energy is cleared on Resources and Loads in such a way as to prevent flows on transmission flowgates and branches from exceeding normal operating limits under basecase conditions or Emergency operating limits under a first contingency loss of a Resource or transmission facility. In addition, the Transmission Constraints also ensure that Operating Reserves can be deployed, Up Ramp Capability and Down Ramp Capability can be supplied, and Short-Term Reserve can be supplied in such a way as to prevent flows on transmission flowgates and branches from exceeding normal operating limits under basecase conditions or Emergency operating limits under a first contingency loss of a Resource or transmission facility. Moreover, the Transmission Constraints shall also ensure that Short-Term Reserve can be deployed in such a way as to prevent flows on transmission flowgates and branches from exceeding normal operating limits under basecase conditions or Emergency operating limits under a first contingency loss of a Resource or transmission facility.

The Sub-Regional Power Balance Constraints ensure that Energy flows within the Transmission Provider Region are managed consistent with applicable seams agreements, coordination agreements, transmission service agreements, or operating procedures. The Sub-Regional Power Balance Constraints also ensure that Operating Reserves can be deployed, Up Ramp Capability and Down Ramp

Capability can be supplied, and Short-Term Reserve can be supplied in such a way as to prevent flows on Sub-Regional Power Balance Constraints from exceeding the appropriate limits.

The Post Reserve Deployment Constraints ensure that Operating Reserves and Short-Term Reserves can be deployed in such a way as to prevent flows on identified Transmission Constraints from exceeding the appropriate limits.

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The Co-optimized Reserve Zone Regulating Reserve constraints ensure the supply of Regulating Reserve within a specific Reserve Zone is greater than or equal to the Co-optimized Zonal Regulating Reserve Requirement.

The Co-optimized Reserve Zone Short-Term Reserve constraints ensure the supply of Short-Term Reserve within a specific Reserve Zone is greater than or equal to the Co-optimized Zonal Short-Term Reserve Requirement.

Electric Storage Resource Energy Storage Level constraints ensure the Electric Storage Resource units have sufficient Energy Storage Level to supply

Energy, Operating Reserves, Up Ramp Capability, Down Ramp Capability, and  
Short-Term Reserve reliably.