Manual No. 002

Business Practices Manual

Energy and Operating Reserve Markets

Attachment B

Day-Ahead Energy and Operating Reserve Market Software Formulations and Business Logic

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1. Introduction

This introduction to the Midcontinent Independent System Operator, Inc. (MISO) *Business Practices Manual (BPM) for Energy and Operating Reserve Markets* includes basic information about this BPM and the other MISO BPMs. The first section (Section 1.1) of this Introduction provides information about MISO's BPMs. The second section (Section 1.2) is an introduction to this BPM. The third section (Section 0) identifies other documents in addition to the BPMs, which can be used by the reader as references when reading this BPM.

1.1 Purpose of the MISO Business Practices Manuals

The BPMs developed by MISO provide background information, guidelines, business rules, and processes established by MISO for the operation and administration of the MISO markets, provisions of transmission reliability services, and compliance with MISO settlements, billing, and accounting requirements. A complete list of MISO BPMs is available for reference through MISO's website. All definitions in this document are as provided in the MISO Tariff, the NERC Glossary of Terms Used in Reliability Standards, or are as defined by this document.

1.2 Purpose of this Business Practices Manual

This Attachment B to the *BPM for Energy and Operating Reserve Markets* covers the rules, design, and operational elements of MISO's Day-Ahead Energy and Operating Reserve Market.

This BPM Attachment conforms and complies with MISO's Open Access Transmission and Energy Markets Tariff (Tariff), the North American Electric Reliability Council (NERC), also known as the Electric Reliability Organization (ERO), operating policies, and the applicable Regional Reliability Organization (RRO) reliability principles, guidelines, and standards and is designed to facilitate administration of efficient Energy and Operating Reserve Markets.
This BPM benefits readers who want answers to the following questions:

- What are the roles of MISO and the Market Participants (MPs) in the Energy the Energy and Operating Reserve Markets?
- What are the basic concepts that one needs to know to interact with the Energy and Operating Reserve Markets?
- What MP activities must be performed to engage in the Energy and Operating Reserve Markets?

1.3 References

Other reference information related to this BPM includes:

- Tariff of MISO, Inc.
- Agreement of Transmission Facilities Owners to Organize the Midcontinent Independent System Operator, Inc., a Delaware Non-Stock Corporation (referred to as “T.O. Agreement” or “TOA”)

2. General Information

The Day-Ahead Energy and Operating Reserve Market software consists of the following processes:

- Pre-SCUC Processing
- SCUC Engine
- Pre-SCED Processing
- SCED Engine
- SCED-Pricing Engine
- Transmission Contingency Analysis
- Post-SCED Processing

Attachment B outlines the software formulation and business requirements for the Day-Ahead Energy and Operating Reserve Market.

3. Pre-SCUC Processing

Pre-SCUC processing includes the data calculations and data processing performed just after the Day-Ahead Energy and Operating Reserve Market closes but prior to execution of the SCUC or SCED engines. The results of pre-SCUC processing may be used by the SCUC algorithm, the SCED algorithm, or both. Pre-SCUC processing establishes the following:

3.1 Commitment Availability

The commitment availability is determined for each resource and hour prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available for commitment in a specific hour. A resource must be available for commitment in a specific hour in order to be considered for commitment by SCUC for that hour. The commitment availability is designated in the formulations as **CommitAvailability(r,h)** and will be set to 1 whenever a specific resource is available for commitment in a specific hour.

3.1.1 Commitment Availability – Conventional Generation Resources and Demand Response Resources – Type II

Generation Resources (other than combined-cycle Generation Resources) and Demand Response Resources - Type II will be available for commitment in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Commitment Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Not Participating***.

  NOTE: If a Resource is designated as a Network Resource, the Commitment Status in the Day-Ahead Energy and Operating Reserve Market cannot be set to ***Not Participating***.
- The Commitment Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Outage***.
- The Commitment Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
- The Outage Scheduler outage type listed for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Out of Service***.

3.1.2 Commitment Availability – Aggregate Combined-Cycle Generation Resources

An aggregate combined-cycle Generation Resource will be available for commitment in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Commitment Status for the aggregate combined-cycle Generation Resource during the hour is not set to ***Not Participating***.

  NOTE: If a Resource is designated as a Network Resource, the Commitment Status in the Day-Ahead Energy and Operating Reserve Market cannot be set to ***Not Participating***.
- The Commitment Status for the aggregate combined-cycle Generation Resource during the hour is not set to ***Outage***.
- The Commitment Status for the aggregate combined-cycle Generation Resource during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
- The Outage Scheduler outage type listed for at least one of the individual Generation Resources that make up the aggregate combined-cycle Generation Resource during the hour is not set to ***Out of Service***.
- The Combined Cycle Status for the resource is set to ***Aggregate*** for the day.

3.1.3 Commitment Availability – Individual Combined-Cycle Generation Resources

An individual Generation Resource that is part of an aggregate combined-cycle resource will be available for commitment in the Day-Ahead Energy and Operating Reserve Market as an individual Generation Resource during a specific hour as long as the following conditions apply:

- The Commitment Status for the individual Generation Resource during the hour is not set to ***Not Participating***.

  NOTE: If a Resource is designated as a Network Resource, the Commitment Status in the Day-Ahead Energy and Operating Reserve Market cannot be set to ***Not Participating***.
- The Commitment Status for the individual Generation Resource during the hour is not set to ***Outage***.

- The Commitment Status for the individual Generation Resource during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
- The Outage Scheduler outage type listed for the individual Generation Resource during the hour is not set to ***Out of Service***.
- The Combined Cycle Status for the parent aggregate combined-cycle Generation Resource is set to ***Individual*** for the day.

3.1.4 Commitment Availability – Demand Response Resources – Type I

A Demand Response Resource - Type I will be available for commitment for energy only in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Commitment Status for the Demand Response Resource - Type I during the hour is not set to ***Not Participating***.
- The Commitment Status for the Demand Response Resource - Type I during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.

3.1.5 Commitment Availability – External Asynchronous Resources

An External Asynchronous Resource will be available in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following apply:

- The resource Availability Status is set to ***Available***.
- The External Asynchronous Resource has an active, non-zero Fixed Dynamic Interchange Schedule Import Schedule for the hour and/or a non-zero Fixed Dynamic Interchange Schedule Export Schedule for the hour.

3.1.6 Commitment Availability – Electric Storage Resources

Electric Storage Resources will be committed in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Commitment Status for the Electric Storage Resource during the commitment interval is set to ***Charge, Discharge, Continuous, EmergencyCharge (***in Emergency mode surplus condition***) or EmergencyDischarge*** (in Emergency mode shortage condition***)***

- The Outage Scheduler outage type listed for the Electric Storage Resource during the hour is not set to ***Out of Service***.

3.2 Off-Line Supplemental Reserve Availability

The off-line Supplemental Reserve availability is determined for each and hour prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available for off-line Supplemental Reserve in a specific hour. Demand Response Resources - Type I and External Asynchronous Resources are not available to provide off-line Supplemental Reserve. A resource must be available to provide off-line Supplemental Reserve in a specific hour in order to be dispatched for off-line Supplemental Reserve by SCUC or cleared for off-line Supplemental Reserve by SCED for that hour. The off-line Supplemental Reserve availability is designated in the formulations as **OffLineSupAvailability(r,h)** and will be set to 1 whenever a specific resource is available to clear off-line supplemental reserve in a specific hour.

3.2.1 Off-line Supplemental Reserve Availability – Conventional Generation Resources and Demand Response Resources – Type II

Generation Resources (other than combined-cycle Generation Resources) and Demand Response Resources - Type II will be available to provide off-line Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Off-Line Supplemental Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Not Participating***.
  NOTE: If a Resource is designated as a Network Resource, the Off-Line Supplemental Reserve Dispatch Status in the Day-Ahead Energy and Operating Reserve Market cannot be set to ***Not Participating***.
- The Off-Line Supplemental Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Emergency***.
  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
- The Off-Line Supplemental Reserve Dispatch Status for the Generation Resource or Demand Response Resource- Type II during the hour is not set to ***Not Qualified***.
- The Commitment Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Outage***.
- The Outage Scheduler outage type listed for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Out of Service***.

- The Generation Resource or Demand Response Resource - Type II is qualified during the asset registration process as a Quick-Start Resource capable of supplying off-line Supplemental Reserve.
- The Minimum Run Time of the Generation Resource or the Minimum Interruption Duration of the Demand Response Resource – Type II is set to 180 minutes or less.

3.2.2 Off-line Supplemental Reserve Availability – Aggregate Combined-Cycle Generation Resources

An aggregate combined-cycle Generation Resource will be available to provide off-line Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Off-Line Supplemental Reserve Dispatch Status for the aggregate combined-cycle Generation Resource during the hour is not set to ***Not Participating***.

  NOTE: If a Resource is designated as a Network Resource, the Off-Line Supplemental Reserve Dispatch Status in the Day-Ahead Energy and Operating Reserve Market cannot be set to ***Not Participating***.
- The Off-Line Supplemental Reserve Dispatch Status for the aggregate combined-cycle Generation Resource during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
- The Off-Line Supplemental Reserve Dispatch Status for the aggregate combined-cycle Generation Resource during the hour is not set to ***Not Qualified***.
- The Commitment Status for the aggregate combined-cycle Generation Resource during the hour is not set to ***Outag***e.
- The Outage Scheduler outage type listed for at least one of the individual Generation Resources that make up the aggregate combined-cycle Generation Resource during the hour is not set to ***Out of Service***.
- The aggregate combined-cycle Generation Resource is qualified during the asset registration process as a Quick-Start Resource capable of supplying off-line Supplemental Reserve.
- The Combined Cycle Status for the resource is set to ***Aggregate*** for the day.
- The Minimum Run Time of the Aggregate Combined Cycle Generation Resource is set to 180 minutes or less.

3.2.3 Off-line Supplemental Reserve Availability – Individual Combined-Cycle Generation Resources

An individual Generation Resource that is part of an aggregate combined-cycle Generation Resource will be available to provide off-line Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market as an individual Generation Resource during a specific hour as long as the following conditions apply:

- The Off-Line Supplemental Reserve Dispatch Status for the individual Generation Resource during the hour is not set to ***Not Participating***.

  NOTE: If a Resource is designated as a Network Resource, the Off-Line Supplemental Reserve Dispatch Status in the Day-Ahead Energy and Operating Reserve Market cannot be set to ***Not Participating***.
- The Off-Line Supplemental Reserve Dispatch Status for the individual Generation Resource during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
- The Off-Line Supplemental Reserve Dispatch Status for the individual Generation Resource during the hour is not set to ***Not Qualified***.
- The Commitment Status for the individual Generation Resource during the hour is not set to ***Outage***.
- The Outage Scheduler outage type listed for the individual Generation Resource during the hour is not set to ***Out of Service***.
- The individual Generation Resource is qualified during the asset registration process as a Quick-Start Resource capable of supplying off-line Supplemental Reserve.
- The Combined Cycle Status for the parent aggregate combined-cycle Generation Resource is set to ***Individual*** for the day.
- The Minimum Run Time of the individual Generation Resource is set to 180 minutes or less.

3.2.4 Off-line Supplemental Reserve Availability – Electric Storage Resources

Electric Storage Resources will be available to provide off-line Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the Commitment Status is Available.

3.3 Regulating Reserve Availability

The Regulating Reserve availability is determined for each resource and hour prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available to provide regulating reserve. Demand Response Resources - Type I are not available to provide Regulating Reserve. A resource must be available to provide Regulating Reserve in a specific hour in order to be dispatched for Regulating Reserve by SCUC or cleared for Regulating Reserve by SCED for that hour. The Regulating Reserve availability is designated in the formulations as **RegAvailability(r,h)** and will be set to 1 whenever a specific resource is available to provide Regulating Reserve in a specific hour.

3.3.1 Regulating Reserve Availability – Generation Resources and Demand Response Resources – Type II

Generation Resources and Demand Response Resources - Type II will be available to provide Regulating Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Generation Resource or Demand Response Resource - Type II is available for commitment during the hour per Section 3.1 above.
- The Generation Resource or Demand Response Resource - Type II is registered during the asset registration process as a Regulation Qualified Resource capable of supplying Regulating Reserve.
- The Regulating Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Not Participating***.
- The Regulating Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Not Qualified***.

3.3.2 Regulating Reserve Availability – External Asynchronous Resources

External Asynchronous Resources will be available to provide Regulating Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The External Asynchronous Resource **CommitAvailability** flag is set to 1 during the hour per Section 3.1.5 above.
- The External Asynchronous Resource is registered during the asset registration process as a Regulation Qualified Resource capable of supplying Regulating Reserve.
- The Regulating Reserve Dispatch Status for the External Asynchronous Resource during the hour is not set to ***Not Participating***.

- The Regulating Reserve Dispatch Status for the External Asynchronous Resource during the hour is not set to ***Not Qualified***.

3.3.3 Regulating Reserve Availability – Electric Storage Resource

Electric Storage Resources will be available to provide Regulating Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Electric Storage Resource **CommitAvailability** flag is set to 1 during the hour per Section 3.1.5 above.
- The Electric Storage Resource is registered during the asset registration process as a Regulation Qualified Resource capable of supplying Regulating Reserve.
- The Regulating Reserve Dispatch Status for Electric Storage Resource during the hour is not set to ***Not Participating***.
- The Regulating Reserve Dispatch Status for the Electric Storage Resource during the hour is not set to ***Not Qualified***.

3.4 Spinning Reserve Availability

The Spinning Reserve availability is determined for each resource and hour prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available to provide Spinning Reserve. A resource must be available to provide Spinning Reserve in a specific hour in order to be dispatched for Spinning Reserve by SCUC or cleared for Spinning Reserve by SCED for that hour. The Spinning Reserve availability is designated in the formulations as **SpinAvailability(r,h)** and will be set to 1 whenever a specific resource is available to provide Spinning Reserve in a specific hour.

3.4.1 Spinning Reserve Availability – Generation Resources and Demand Response Resources - Type II

Generation Resources and Demand Response Resources - Type II will be available to provide Spinning Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Generation Resource or Demand Response Resource - Type II is available for commitment during the hour per Section 3.1 above.
- The Generation Resource or Demand Response Resource - Type II is registered during the asset registration process as a Spin Qualified Resource capable of supplying Spinning Reserve.

- The Spinning Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Not Qualified***.

3.4.2 Spinning Reserve Availability – External Asynchronous Resources

External Asynchronous Resources will be available to provide Spinning Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The External Asynchronous Resource CommitAvailability flag is set to 1 during the hour per Section 3.1.5 above.
- The External Asynchronous Resource is registered during the asset registration process as a Spin Qualified Resource capable of supplying Spinning Reserve.
- The Spinning Reserve Dispatch Status for the External Asynchronous Resource during the hour is not set to ***Not Qualified***.

3.4.3 Spinning Reserve Availability – Demand Response Resources – Type I

Demand Response Resources - Type I will be available to provide Spinning Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Demand Response Resource - Type I is registered during the asset registration process as a Spin Qualified Resource capable of supplying Spinning Reserve.
- The Spinning Reserve Dispatch Status for the Demand Response Resource - Type I during the hour is not set to ***Not Qualified***.
- The Spinning Reserve Dispatch Status for the Demand Response Resource - Type I during the hour is not set to ***Not Participating***.
- The Contingency Reserve Status for the Demand Response Resource – Type I during the day is set to “online”.
- The Spinning Reserve Dispatch Status for the Demand Response Resource - Type I during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.

3.4.4 Spinning Reserve Availability – Electric Storage Resource

Electric Storage Resrouces will be available to provide Spinning Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Electric Storage Resource CommitAvailability flag is set to 1 during the hour per Section 3.1.5 above.
- The Electric Storage Resrouce is registered during the asset registration process as a Spin Qualified Resource capable of supplying Spinning Reserve.
- The Spinning Reserve Dispatch Status for the Electric Storage Resrouce during the hour is not set to ***Not Qualified***.

3.5 Supplemental Reserve Availability

The Supplemental Reserve availability is determined for each resourceand hour prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available to provide Supplemental Reserve. A resource must be available to provide Supplemental Reserve in a specific hour in order to be dispatched for Supplemental Reserve by SCUC or cleared for Supplemental Reserve by SCED for that hour. The Supplemental Reserve availability is designated in the formulations as **SupAvailability(r,h)** and will be set to 1 whenever a specific resource is available to provide Supplemental Reserve in a specific hour.

3.5.1 Supplemental Reserve Availability – Generation Resources and Demand Response Resources – Type II

Generation Resources and Demand Response Resources - Type II will be available to provide Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Generation Resource or Demand Response Resource - Type II is available for commitment during the hour per Section 3.1 above.
- The Generation Resource or Demand Response Resource - Type II is registered during the asset registration process as a Supplemental Qualified Resource capable of supplying Supplemental Reserve.
- The On-Line Supplemental Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour is not set to ***Not Qualified***.

3.5.2 Supplemental Reserve Availability – External Asynchronous Resources

External Asynchronous Resources will be available to provide Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The External Asynchronous Resource **CommitAvailability** flag is set to 1 during the hour per Section 3.1.5above.

- The External Asynchronous Resource is registered during the asset registration process as a Supplemental Qualified Resource capable of supplying Supplemental Reserve.
- The Supplemental Reserve Dispatch Status for the External Asynchronous Resource during the hour is not set to ***Not Qualified***.

3.5.3 Supplemental Reserve Availability – Demand Response Resources – Type I

Demand Response Resources - Type I will be available to provide Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Demand Response Resource - Type I is registered during the asset registration process as a Supplemental Qualified Resource capable of supplying Supplemental Reserve.
- The Supplemental Reserve Dispatch Status for the Demand Response Resource - Type I during the hour is not set to ***Not Qualified***.
- The Supplemental Reserve Dispatch Status for the Demand Response Resource - Type I during the hour is not set to ***Not Participating***.
- The Contingency Reserve Status for the Demand Response Resource – Type I during the day is set to “offline”.
- The Contingency Reserve Status for the Demand Response Resource – Type I during the day is set to “online”, and the following is true: the Demand Response Resource – Type I is not registered as a Spin Qualified Resource, or its Spinning Reserve Dispatch Status is set to either Not Qualified or Not Participating
- The Supplemental Reserve Dispatch Status for the Demand Response Resource - Type I during the hour is not set to ***Emergency***.

  NOTE: This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.

3.5.4 Supplemental Reserve Availability – Electric Storage Resource

Electric Storage Resources will be available to provide Supplemental Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Electric Storage Resource **CommitAvailability** flag is set to 1 during the hour per Section 3.1.5 above.
- The Electric Storage Resource is registered during the asset registration process as a Supplemental Qualified Resource capable of supplying Supplemental Reserve.

- The Supplemental Reserve Dispatch Status for the Electric Storage Resource during the hour is not set to ***Not Qualified***.

3.6 On-line Short Term Reserve Availability

The online Short Term Reserve availability is determined for each resource and hour prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available to provide online Short Term Reserve. Demand Response Resources – Type I are not eligible to provide Short Term Reserve. A resource must be available to provide online Short Term Reserve in a specific hour in order to be dispatched for Short Term Reserve by SCUC or cleared for Short Term Reserve by SCED for that hour. The online Short Term Reserve availability is designated in the formulations as **onlineSTRAvailability(r,h)** and will be set to 1 whenever a specific resource is available to provide online Short Term Reserve in a specific hour.

3.6.1 On-line Short Term Reserve Availability – Generation Resources and Demand Response Resources – Type II

Generation Resources (that are not Intermittent Resources and Dispatchable Intermittent Resources) and Demand Response Resources - Type II will be available to provide Short Term Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Generation Resource or DRR-Type II Resource is available for commitment during the commitment interval per Section **Error! Reference source not found.** above.
- The On-Line Short Term Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour must be set to ***Economic***.

3.6.2 On-line Short Term Reserve Availability – External Asynchronous Resources

External Asynchronous Resources will be available to provide on-line Short Term Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The External Asynchronous Resource CommitAvailability flag is set to 1 during the hour per Section 3.1.5 above.
- The On-Line Short Term Reserve Dispatch Status for the External Asynchronous Resource during the hour must set to ***Economic***.

3.6.3 On-line Short Term Reserve Availability – Electric Storage Resource

Electric Storage Resources will be available to provide on-line Short Term Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Electric Storage Resource CommitAvailability flag is set to 1 during the hour per Section 3.1.5 above.
- The On-Line Short Term Reserve Dispatch Status for the Electric Storage Resource during the hour must set to ***Economic***.

3.7 Off-line Short Term Reserve Availability

The offline Short Term Reserve availability is determined for each resource and hour prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available to provide off-line Short Term Reserve. External Asynchronous ResourcesIntermittent Resources and Dispatchable Intermittent Resources are not eligible to provide Short Term Reserve. A resource must be available to provide off-line Short Term Reserve in a specific hour in order to be dispatched for Short Term Reserve by SCUC or cleared for off-line Short Term Reserve by SCED for that hour. The off-line Short Term Reserve availability is designated in the formulations as **offlineSTRAvailability(r,h)** and will be set to 1 whenever a specific resource is available to provide online Short Term Reserve in a specific hour.

3.7.1 Off-line Short Term Reserve Availability – Generation Resources and Demand Response Resources – Type II

Generation Resources (that are not Intermittent Resources and Dispatchable Intermittent Resources) and Demand Response Resources - Type II will be available to provide Short Term Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Generation Resource or Demand Response Resource - Type II is registered during the asset registration process as an Off-Line Short Term Reserve Qualified Resource capable of supplying Short Term Reserve.
    - The Commitment Status for the individual Generation Resource during the hour is not set to ***Outage***.
    - The Outage Scheduler outage type listed for the individual Generation Resource during the hour is not set to ***Out of Service***.

- The Off-Line Short Term Reserve Dispatch Status for the Generation Resource or Demand Response Resource - Type II during the hour must be set to ***Economic***.
- Minimum run time must be less than 4 hours
- Minimum down time constraint is met.

3.7.2 Off-line Short Term Reserve Availability – Demand Response Resources – Type I

Demand Response Resources – Type I will be available to provide off-line Short Term Reserve in the Day-Ahead Energy and Operating Reserve Market during a specific hour as long as the following conditions apply:

- The Demand Response Resource - Type I is registered during the asset registration process as an Off-Line Short Term Reserve Qualified Resource capable of supplying Short Term Reserve.
- The Off-Line Short Term Reserve Dispatch Status for the Demand Response Resource - Type I during the hour must be set to ***Economic***.
- Minimum Non-Interruption Interval constrant is met.

3.8 Must Run Status

The Must Run Status, which is designated in the formulations as **MustRunStatus(r,h)**, is determined as follows for each resource (except for External Asynchronous Resources and Demand Response Resources - Type I) and hour based on the submitted Commitment Status and prior commitment processes for that resource and hour:

- If the Commitment Status for a specific resource and hour is set to ***Must Run***, or, if a prior commitment process (such as Multi-Day Reliability Assessment Commitment), has committed the resource for the hour, then the Must Run Status is set to 1 for that resource and hour.
- Else, the Must Run Status is set to 0 for that resource and hour.

The Must Run Status is used in the commitment constraints in SCUC.

3.9 Emergency Status

The Emergency Status, which is designated in the formulations as **EmerStatus(r,h)**, is determined as follows for each resource (except for External Asynchronous Resources) and hour based on the submitted Commitment Status for that resource and hour:

- If the Commitment Status for a specific resource and hour is set to ***Emergency***, then the Emergency Status is set to 1 for that resource and hour.

If the Commitment Status for a specific resource and hour is not set to ***Emergency***, then the Emergency Status is set to 0 for that resource and hour.

The Emergency Status is used in the commitment constraints in SCUC.

3.10 Intermittent Resource Status

The Intermittent Resource Status, which is designated in the formulations as **IF(r)**, is determined based on the quarterly-model parameter determined during the Asset Registration period for each Resource.

3.11 Self-Scheduled Energy Status

The Self-Scheduled Energy Status, which is designated in the formulations as **SSEnergyStatus(r,h)**, is determined as follows for each resource (except for Demand Response Resources - Type I) and hour based on the submitted Energy Dispatch Status for that resource and hour:

- If the Energy Dispatch Status for a specific resource and hour is set to ***Self Schedule***, then the Self-Scheduled Energy Status is set to 1 for that resource and hour.
- If the Energy Dispatch Status for a specific resource and hour is not set to ***Self Schedule***, then the Self-Scheduled Energy Status is set to 0 for that resource and hour.

The Self-Scheduled Energy status is used in the self-schedule energy constraints in SCUC and SCED.

3.12 Self-Scheduled Regulating Reserve Status

The Self-Scheduled Regulating Reserve Status, which is designated in the formulations as **SSRegResStatus(r,h)**, is determined as follows for each resource (except Demand Response Resources - Type I hour based on the submitted Regulating Reserve Dispatch Status for that resource and hour:

- If the Regulating Reserve Dispatch Status for a specific resource and hour is set to ***Self Schedule***, then the Self-Scheduled Regulating Reserve Status is set to 1 for that resource and hour.
- If the Regulating Reserve Dispatch Status for a specific resource and hour is not set to ***Self Schedule***, then the Self-Scheduled Regulating Reserve Status is set to 0 for that resource and hour.

The Self-Scheduled Regulating Reserve Status is used in the self-schedule Regulating Reserve constraints in SCUC and SCED.

3.13 Self-Scheduled Spinning Reserve Status

The Self-Scheduled Spinning Reserve Status, which is designated in the formulations as **SSSpinResStatus(r,h)**, is determined as follows for each resource and hour based on the submitted Spinning Reserve Dispatch Status for that resource and hour:

- If the Spinning Reserve Dispatch Status for a specific resource and hour is set to ***Self Schedule***, then the Self-Scheduled Spinning Reserve Status is set to 1 for that resource and hour.
- If the Spinning Reserve Dispatch Status for a specific resource and hour is not set to ***Self Schedule***, then the Self-Scheduled Spinning Reserve Status is set to 0 for that resource and hour.

The Self-Scheduled Spinning Reserve Status is used in the self-schedule Contingency Reserve constraints in SCUC and SCED.

3.14 Self-Scheduled Supplemental Reserve Status

The Self-Scheduled Supplemental Reserve Status, which is designated in the formulations as **SSSupResStatus(r,h)**, is determined as follows for each External Asynchronous Resource and Demand Response Resource - Type I and for each hour based on the submitted Supplemental Reserve Dispatch Status for that resource and hour:

- If the Supplemental Reserve Dispatch Status for a specific resource and hour is set to ***Self Schedule***, then the Self-Scheduled Supplemental Reserve Status is set to 1 for that resource and hour.
- If the Supplemental Reserve Dispatch Status for a specific resource and hour is not set to ***Self Schedule***, then the Self-Scheduled Supplemental Reserve Status is set to 0 for that resource and hour.

The Self-Scheduled Supplemental Reserve Status is used in the self-schedule Contingency Reserve constraints in SCUC and SCED.

3.15 Self-Scheduled On-Line Supplemental Reserve Status

The Self-Scheduled On-Line Supplemental Reserve Status, which is designated in the formulations as **SSOnLineSupResStatus(r,h)**, is determined as follows for each Generation Resource, Demand Response Resource - Type II and Electric Storage Resrouce and for each hour based on the submitted On-Line Supplemental Reserve Dispatch Status for that resource and hour:

- If the On-Line Supplemental Reserve Dispatch Status for a specific resource and hour is set to ***Self Schedule***, then the Self-Scheduled On-Line Supplemental Reserve Status is set to 1 for that resource and hour.
- If the On-Line Supplemental Reserve Dispatch Status for a specific resource and hour is not set to ***Self Schedule***, then the Self-Scheduled On-Line Supplemental Reserve Status is set to 0 for that resource and hour.

The Self-Scheduled On-Line Supplemental Reserve Status is used in the self-schedule Contingency Reserve constraints in SCUC and SCED.

3.16 Self-Scheduled Off-Line Supplemental Reserve Status

The Self-Scheduled Off-Line Supplemental Reserve Status, which is designated in the formulations as **SSOffLineSupResStatus(r,h)**, is determined as follows for each Generation Resource, Demand Response Resource - Type II and Electric Storage Resource and for each hour based on the submitted Off-Line Supplemental Reserve Dispatch Status for that resource and hour:

- If the Off-Line Supplemental Reserve Dispatch Status for a specific resource and hour is set to ***Self Schedule***, then the Self-Scheduled Off-Line Supplemental Reserve Status is set to 1 for that resource and hour.
- If the Off-Line Supplemental Reserve Dispatch Status for a specific resource and hour is not set to ***Self Schedule***, then the Self-Scheduled Off-Line Supplemental Reserve Status is set to 0 for that resource and hour.

The Self-Scheduled Off-Line Supplemental Reserve Status is used in the self-schedule Contingency Reserve constraints in SCUC and SCED.

3.17 Day-Ahead Market Resource Limit Set

A Day-Ahead Market Resource Limit Set is determined for each Generation Resource, Demand Response Resource - Type II, Electric Storage Resource and External Asynchronous Resource for each hour prior to executing the SCUC and SCED algorithm. If the resource is registered as a Regulation Qualified Resource during the asset registration process, and is not an Electric Storage Resource, the Day-Ahead Market Resource Limit Set must include the following limits:

- Emergency Maximum Limit
- Emergency Minimum Limit
- Economic Maximum Limit
- Economic Minimum Limit
- Regulation Maximum Limit
- Regulation Minimum Limit

-

If the resource is an Electric Storage Resource, the Day-Ahead Market Resource Limit Set must include the following limits:

- Emergency Maximum Discharge Limit
- Emergency Minimum Discharge Limit
- Economic Maximum Discharge Limit

- Economic Minimum Discharge Limit
- Regulation Maximum Discharge Limit
- Regulation Minimum Discharge Limit
- Emergency Maximum Charge Limit
- Emergency Minimum Charge Limit
- Economic Maximum Charge Limit
- Economic Minimum Charge Limit
- Regulation Maximum Charge Limit
- Regulation Minimum Charge Limit

The 12 ESR limits will be mapped to the existing common set of limits (Emergency Maximum Limit, Emergency Minimum Limit, Economic Maximum Limit, Econonic Minimum Limit, Regulation Maximum Limit, Regulation Minimum Limit) as determined by Commitment Status. General mapping is as follows:

Unit Limit	**ESR Charge/Emergency Charge** **(Assume Charge Limits are Non-Positive values)**	**ESR Discharge/Emergency Discharge/Available** **(Assume Discharge Limits are Non-Negative values)**	**ESR Continuous/NP/Outage**
EcoMin	EcoMaxCharge	EcoMinDischarge	EcoMaxCharge (likely a negative value)
EcoMax	EcoMinCharge	EcoMaxDischarge	EcoMaxDischarge
EmerMin	EmerMaxCharge	EmerMinDischarge	EmerMaxCharge (likely a negative value)
EmerMax	EmerMinCharge	EmerMaxDischarge	EmerMaxDischarge
RegMin	RegMaxCharge	RegMinDischarge	RegMaxCharge (likely a negative value)
RegMax	RegMinCharge	RegMaxDischarge	RegMaxDischarge

If the resource is not registered as a Regulation Qualified Resource during the asset registration process, the Day-Ahead Market Resource Limit Set must include the following limits:

- Emergency Maximum Limit
- Emergency Minimum Limit
- Economic Maximum Limit
- Economic Minimum Limit

3.17.1 Day-Ahead Market Resource Limit Sets – Generation Resources and Demand Response Resources – Type II

If a valid hourly Day-Ahead Resource Limit Set has been submitted by the market participant for a specific resource and hour, that limit set is used for that resource during that hour in the Day-Ahead Energy and Operating Reserve Market. If a valid hourly Day-Ahead Resource Limit Set has not been submitted by the market participant for a specific resource and hour (e.g., a null value has been submitted for one or more of the hourly limits or the limit set does not pass the portal validation tests, etc.), the default Day-Ahead Resource Limit Set is used for that resource during that hour. The processed limit set is denoted as EmerMinLimit(r,h), EcoMinLimit(r,h), RegMinLimit(r,h) (if applicable), RegMaxLimit(r,h) (if applicable), EcoMaxLimit(r,h) and EmerMaxLimit(r,h).

3.17.2 Day-Ahead Market Resource Limit Sets – External Asynchronous Resources

If a valid hourly Day-Ahead Resource Limit Set has been submitted by the market participant for a specific External Asynchronous Resource and hour, that limit set is used for that resource during that hour in the Day-Ahead Energy and Operating Reserve Market. If a valid hourly Day-Ahead Resource Limit Set has not been submitted by the market participant for a specific External Asynchronous Resource and hour (e.g., a null value has been submitted for one or more of the hourly limits or the limit set does not pass the portal validation tests, etc.), the default Day-Ahead Resource Limit Set is used for that External Asynchronous Resource during that hour. In any event, all limits for an External Asynchronous Resource will be capped by a maximum value determined by the associated tag that is used to schedule energy from the External Asynchronous Resource into or out of the MISO Balancing Authority Area. The processed limit set is denoted as EmerMinLimit(r,h), EcoMinLimit(r,h), RegMinLimit(r,h) (if applicable), RegMaxLimit(r,h) (if applicable), EcoMaxLimit(r,h) and EmerMaxLimit(r,h).

3.17.3 Day-Ahead Market Resource Limit Sets – Electric Storage Resource

If a valid hourly Day-Ahead Resource Limit Set has been submitted by the market participant for a specific resource and hour, that limit set is used for that resource during that hour in the Day-Ahead Energy and Operating Reserve Market. If a valid hourly Day-Ahead Resource Limit Set has not been submitted by the market participant for a specific resource and hour (e.g., a null value has been submitted for one or more of the hourly limits or the limit set does not pass the portal validation tests, etc.), the default Day-Ahead Resource Limit Set is used for that resource during that hour. The processed limit set is denoted as EmerMinCH(r,h), EcoMinCH(r,h), RegMinCH(r,h), RegMaxCH(r,h), EcoMaxCH(r,h), EmerMaxCH(r,h), EmerMinDS(r,h), EcoMinDS(r,h), RegMinDS(r,h), RegMaxDS(r,h), EcoMaxCH(r,h) and EmerMaxCH(r,h).

3.18 Day-Ahead Market Input Ramp Rates

An input ramp rate is determined for each Generation Resource, Demand Response Resource - Type IIand External Asynchronous Resource for each hour prior to executing the SCUC and SCED algorithm. Both input Charge Ramp Rate and Discharge Ramp Rate are determined for each Electric Storage Resource for each hour prior to executing the SCUC and SCED algorithm

3.18.1 Day-Ahead Market Ramp Rates – Generation Resources, External Asynchronous Resources and Demand Response Resources – Type II

If a valid Day-Ahead Hourly Ramp Rate has been submitted by the market participant for a specific resource and hour that ramp rate is used for that resource during that hour in the Day-Ahead Energy and Operating Reserve Market. If a valid Day-Ahead Hourly Ramp Rate has not been submitted by the market participant for a specific resource and hour (e.g., a null value has been submitted for the Day-Ahead Hourly Ramp Rate, etc.), the Day-Ahead Default Ramp Rate is used for that resource during that hour.

3.18.2 Day-Ahead Market Ramp Rates – Electric Storage Resource

If a valid Day-Ahead Hourly Charge Ramp Rate and Discharge Ramp Rate have been submitted by the market participant for a specific resource and hour the ramp rates are used for that resource during that hour in the Day-Ahead Energy and Operating Reserve Market. If either a valid Day-Ahead Hourly Charge Ramp Rate or Discharge Ramp Rate has not been submitted by the market participant for a specific resource and hour (e.g., a null value has been submitted for the Day-Ahead Hourly Charge Ramp Rate, etc.), the Day-Ahead Default Charge Ramp Rate or Discharge Ramp Rate will be used for that resource during that hour.

3.19 SCUC Day-Ahead Market Ramp Rate Set

The following ramp rates are determined for each Generation Resource, Demand Response Resource - Type II and External Asynchronous Resource for use in the SCUC algorithm:

3.19.1 Long-Term SCUC Ramp-Up Rates

Long-term SCUC ramp-up rates, which are designated in the formulations as **LTSCUCRampUpRate(r,h)**, are used in the long-term ramp-up constraints in the SCUC algorithm. Long-term SCUC ramp-up rates are calculated for each resource and hour (except for the first hour of the SCUC period). The long-term SCUC ramp-up rate is set equal to the input ramp rate for the hour, subject to relaxation if necessary, to enforce Resource limit constraints. Calculating the long-term SCUC ramp-up rate in this manner avoids a situation where changes in hourly limits do not allow for the long-term SCUC ramp-up constraints to be enforced based on the input ramp rate for the hour.

3.19.2 Long-Term SCUC Ramp-Down Rates

Long-term SCUC ramp-down rates, which are designated in the formulations as **LTSCUCRampDownRate(r,h)**, are used in the long-term ramp-down constraints in the SCUC algorithm. Long-term SCUC ramp-down rates are calculated for each resource and hour (except for the first hour of the SCUC period). The long-term SCUC ramp-down rate is set equal to the input ramp rate for the hour, subject to relaxation if necessary, to enforce Resource limit constraints.

3.19.3 Long-Term SCUC Start-Up Ramp Rates

Long-term SCUC start-up ramp rates, which are designated in the formulations as **LTSCUCSURampRate(r,h)**, are used in the long-term ramp-up constraints in the SCUC algorithm. Long-term SCUC start-up ramp rates are calculated for each resource and hour. The long-term SCUC start-up ramp rate is set such that it can achieve, during the startup hour, the Economic Minimum Limit plus 30 minutes of ramping capability based on the **LTSCUCRampUpRate(r,h)**.

3.19.4 Long-Term SCUC Shut-Down Ramp Rates

Long-term SCUC shut-down ramp rates, which are designated in the formulations as **LTSCUCSDRampRate(r,h)**, are used in the long-term ramp-down constraints in the SCUC algorithm. Long-term SCUC shut-down ramp rates are calculated for each resource and hour (except for the first hour of the SCUC period).

The long-term SCUC shut-down ramp rate is set to the Economic Maximum Limit of the Resource for the previous hour divided by 60.

3.20 Initial On Status

The Initial On Status, which is designated in the formulations as **InitialOnStatus(r)**, is determined as follows for each resource:

- If the resource is scheduled to be on-line during the last hour of the day prior to the operating day, the Initial On Status for the resource is set to 1.
- If the resource is not scheduled to be on-line during the last hour of the day prior to the operating day, the initial on status for the resource is set to 0.

The Initial On Status is simply an indication as to whether or not a resource is initially on-line or initially off-line at the beginning of the operating day and is used in the start-up constraints.

3.21 Certain Must-Run Start-Up Flag

The Certain Must-Run Start-Up flag, which is designated in the formulations as **CertainMustRunStartup(r,h)**, captures the condition such that if a resource r starts up in hour h, it initiates a contiguous commitment period during which the resource has offered at least one of the hours with a Must-Run Commitment Status. During the study period, the CertainMustRunStartup(r,h) will be set to one for the first hour where the resource r offers the Must-Run Commitment Status, as well as the hour immediately preceding it.

This flag and the Possible Must-Run Start-Up flag are used to define the domain condition of constraints that cause the startup cost of a resource to be ignored in the objective function if the startup initiates a commitment period in which the resource offers the Must-Run Commitment Status; that is, it acknowledges that the system does not incur commitment costs for Must-Run commitment periods.

3.22 Possible Must-Run Start-Up Flag

The Possible Must-Run Startup flag, which is designated in the formulations as **PossibleMustRunStartup(r,h)**, captures the condition such that if a resource r starts up in hour h, it *may* initiate a contiguous commitment period during which the resource has offered at least one of the hours with a Must-Run Commitment Status. During the study period, the PossibleMustRunStartup(r,h) will be set to one for sequential hours with offered Commitment Status of Economic, that immediately precede an hour with offered Commitment Status of Must-Run.

If the SCUC starts a resource during an hour where PossibleMustRunStartupPeriod(r,h) = 1 and, and if the startup initiates a commitment period contiguous to an hour with the Must-Run Commitment Status, then the startup cost of the commitment is ignored in the objective cost function; that is, it acknowledges that the system does not incur commitment costs for Must-Run commitment periods.

3.23 Next Must-Run Startup Period

The next Must-Run period of a resource r in hour h describes the hour in which the resource next has a Must Run status, after hour h, and is referred to as **NextMustRunPeriod(r,h)**

NextMustRunPeriod(r,h) = first h1 such that

h1 >= h and MustRunStatus(r,h1)]

3.24 Minimum Commitment Time

The minimum commitment time, which is designated in the formulations as **MinCommitTime(r,h)**, represents the minimum amount of time a resource must be committed if started in hour h. The minimum commitment time is the lesser of the minimum run time for resource r or the amount of time remaining in the SCUC period starting with hour h. Mathematically, the minimum commitment time is determined as follows:

MinCommitTime(r,h) = **MINIMUM {** MinRunTime(r), H+1-h **}**

where H = SCUC Period Duration (typically 48 hours)

3.25 Minimum Decommitment Time

The minimum decommitment time, which is designated in the formulations as **MinDecommitTime(r,h)**, represents the minimum amount of time a resource must be decommitted if shut down in hour h. The minimum decommitment time is the lesser of the minimum down time for resource r or the amount of time remaining in the SCUC period starting with hour h. Mathematically, the minimum decommitment time is determined as follows:

MinDecommitTime(r,h) = **MINIMUM {** MinDownTime(r), H+1-h **}**

where H = SCUC Period Duration (typically 48 hours)

3.26 SCUC Resource Regulating Reserve Total Offer Price

The Regulating Reserve total offer price, designated in the formulations as **RegResOfferPrice(r,h)** is determined for each resource prior to executing the SCUC algorithm. The Regulating Reserve total offer price is equal to the sum of the resource's Regulation Capacity offer (in $/MWh), and the Resource's Regulation Mileage Offer (in $/MW) multiplied by the Regulation Deployment Factor (in units of deployments/hour). The Regulation Deployment Factor is needed to convert the mileage offer per MW of movement into an hourly offer. The Regulation Deployment Factor is updated for each calendar Operating Month, based on analysis performed for a one month period ending on the fifteenth of the month prior to the Operating Month. The factor is determined by first calculating the average ratio of deployed Regulating Mileage to cleared Regulating Capacity, averaged across all Resources providing Regulation, for each

Dispatch Interval. This average is then multiplied by 12 to convert from average deployments per interval to average deployments per hour.

3.27 SCUC Contingency Reserve Offer Price

The Contingency Reserve offer price is determined for each resource prior to executing the SCUC algorithm. The Contingency Reserve offer price is used to determine the cost of Spinning Reserve and Supplemental Reserve in SCUC on the following types of resources:

- Committed Generation Resources
- Committed Demand Response Resources - Type II
- *Uncommitted Demand Response Resources - Type I
- Available External Asynchronous Resources
- Committed Electric Storage Resources

  ***NOTE:** Demand Response Resources - Type I cannot supply Contingency Reserve when committed for Energy due to the two-state characteristic of these resources.

The Contingency Reserve offer price will not be used to determine the cost of Supplemental Reserve supplied by uncommitted Generation Resources or uncommitted Demand Response Resources - Type II in the SCUC algorithm. Instead, the Off-Line Supplemental Reserve price will be used to determine the cost of Supplemental Reserve supplied by these resources. The Contingency Reserve Offer Price is designated in the formulations as **ContResOfferPrice(r,h)**.

3.27.1 Contingency Reserve Offer Price – Generation Resources and Demand Response Resources – Type II

The following logic is used to set the Contingency Reserve offer price for Generation Resources and Demand Response Resources - Type II for use in the SCUC algorithm.

- If a Generation Resources or Demand Response Resources - Type II is available to provide Spinning Reserve per Section 3.4.1, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price for the hour.
- If a Generation Resource or Demand Response Resource - Type II is available to provide Supplemental Reserve per Section 3.5.1 but is not available to provide Spinning Reserve per Section 3.4.1, then the Contingency Reserve offer price is set equal to the On-Line Supplemental Reserve offer price for the hour.

3.27.2 Contingency Reserve Offer Price – External Asynchronous Resources

The following logic is used to set the contingency reserve offer price for External Asynchronous Resources for use in the SCUC algorithm.

- If an External Asynchronous Resource is available to provide Spinning Reserve per Section 3.4.2, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price for the hour.
- If an External Asynchronous Resource is available to provide Supplemental Reserve per Section 3.5.2 but is not available to provide Spinning Reserve per Section 3.4.2, then the Contingency Reserve offer price is set equal to the Supplemental Reserve offer price for the hour.

3.27.3 Contingency Reserve Offer Price – Demand Response Resources – Type I

The following logic is used to set the contingency reserve offer price for Demand Response Resources - Type I for use in the SCUC algorithm.

- If a Demand Response Resource - Type I is available to provide Spinning Reserve per Section 3.4.3, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price for the hour.
- If a Demand Response Resource - Type I is available to provide Supplemental Reserve per Section 3.5.3 but is not available to provide Spinning Reserve per Section 3.4.3, then the Contingency Reserve offer price is set equal to the Supplemental Reserve offer price for the hour.

3.27.4 Contingency Reserve Offer Price – Electric Storage Resources

The following logic is used to set the Contingency Reserve offer price for Electric Storage Resources for use in the SCUC algorithm.

- If an Electric Storage Resource is available to provide Spinning Reserve per Section 3.4.2, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price for the hour.
- If an Electric Storage Resource is available to provide Supplemental Reserve per Section 3.5.2 but is not available to provide Spinning Reserve per Section 3.4.2, then the Contingency Reserve offer price is set equal to the Supplemental Reserve offer price for the hour.

3.28 SCUC Off-Line Short Term Reserve Offer Price

The Off-Line Short Term Reserve offer price is determined for each resource (that is not an External Asynchronous Resource, prior to executing the SCUC algorithm. The Off-Line Short

Term offer price is used to determine the cost of Off-Line Short Term Reserve in the SCUC on the following types of resources:

- Uncommitted Generation Resources and Demand Response Resources - Type II
- *Uncommitted Demand Response Resources - Type I

  ***NOTE:** Demand Response Resources - Type I cannot supply Off-Line Short Term Reserve when committed for Energy due to the two-state characteristic of these resources.

The Short Term Reserve Offer Price is designated in the formulations as **OfflineSTROfferPrice(r,h)**.

3.29 Market-Wide Operating Reserve Requirement

The Market-Wide Operating Reserve Requirement is calculated for each hour prior to executing the SCUC and SCED algorithm. The Market-Wide Operating Reserve Requirement for a specific hour is set equal to the sum of the Market-Wide Regulating Reserve Requirement for that hour plus the Market-Wide Contingency Reserve Requirement for that hour. The Market-Wide Operating Reserve Requirement for a specific hour is designated in the formulations as **MWORReq(h)**. For SCUC, this requirement may be scaled up by MWRegReqFactor and MWCRReqFactor to ensure an adequate commitment.

3.30 Market-Wide Regulating Reserve Requirement

The Market-Wide Regulating Reserve Requirement is calculated for each hour prior to executing the SCUC and SCED algorithm. The Market-Wide Regulating Reserve Requirement for a specific hour is designated in the formulations as **MWRegReq(h)**. For SCUC, this requirement may be scaled up by MWRegReqFactor to ensure an adequate commitment.

3.31 Market-Wide Regulating plus Spinning Reserve Requirement

The Market-Wide Regulating plus Spinning Reserve Requirement is calculated for each hour prior to executing the SCUC and SCED algorithm. The Market-Wide Regulating plus Spinning Reserve Requirement for a specific hour is set equal to the sum of the Market-Wide Regulating Reserve Requirement for that hour plus the Market-Wide Spinning Reserve Requirement for that hour. The Market-Wide Regulating plus Spinning Reserve Requirement for a specific hour is designated in the formulations as **MWRegSpinReq(h)**. For SCUC, this requirement may be scaled up by MWRegReqFactor and MWSpinReqFactor to ensure an adequate commitment.

3.32 Market-Wide Short Term Reserve Requirement

The Market-Wide Short Term Reserve Requirement is calculated for each hour prior to executing the SCUC and SCED algorithm. The Market-Wide Short Term Reserve Requirement for a specific hour is designated in the formulations as **MWSTRReq(h)**.

3.33 Market-Wide Hourly Ramp-Up Capacity Requirement

The Market-Wide Hourly Ramp-Up Capacity Requirement is calculated for each hour prior to executing the SCUC algorithm. The Market-Wide Hourly Ramp-Up Capacity Requirement for a specific hour is set equal to the following:

MWRampUpReq(h)=

MAX { BaseRampUpReq,
[NetLoadForecastChange(h)
+ (NetFixedNSIChange(h) * NSIMultiplier(h))
- NetWindGenerationChange(h)]
* NetLoadVariationFactor
*(RampMinutes/60)
+ NetLoadUncertaintyUp(h)**}**

The Market-Wide Hourly Ramp-Up Capacity Requirement for a specific hour is designated in the formulations as **MWRampUpReq(h)**. This requirement may be scaled by MWRampUpReqScaleFactor to ensure an adequate commitment. BaseRampUpReq represents the minimum ramp up requirement for any hour.

3.34 Market-Wide Hourly Ramp-Down Capacity Requirement

The Market-Wide Hourly Ramp-Down Capacity Requirement is calculated for each hour prior to executing the SCUC algorithm. The Market-Wide Hourly Ramp-Down Capacity Requirement for a specific hour is set equal to the following:

MWRampDnReq(h)=

MAX { BaseRampDownReq,
[- NetLoadForecastChange(h)
- (NetFixedNSIChange(h) * NSIMultiplier(h))
+ NetWindGenerationChange(h)]

* NetLoadVariationFactor(h)
*(RampMinutes/60)
\- NetLoadUncertaintyDown(h)**}**

The Market-Wide Hourly Ramp-Dn Capacity Requirement for a specific hour is designated in the formulations as **MWRampDnReq(h)**. This requirement may be scaled by MWRampDnReqScaleFactor to ensure an adequate commitment. BaseRampDnReq represents the minimum ramp down requirement for any hour.

3.35 Method to Establish Minimum Co-Optimized Zonal Operating Reserve and Other Reserve Requirements

MISO identifies the minimum Co-Optimized Zonal Operating Reserve, Ramp Capability and Short Term Reserve Requirements as the minimum amount of Reserves needed within a Reserve Zone as determined by co-optimization with Post Reserve Deployment Constraints. The Post Reserve Deployment Constraints are the post zonal Reserve deployment flows on the transmission constraints, used to determine the Co-optimized Zonal Regulating Reserve Requirement, Co-optimized Zonal Contingency Reserve Requirement, Co-optimized Zonal Spinning Reserve Requirement, Co-optimized Zonal Ramp Capability Requirement and Co-optimized Zonal Short Term Reserve Requirement for each Reserve Zone.

3.36 Generation-Based Operating Reserve Requirement Factor

The Generation-Based Operating Reserve Requirement Factor, designated in the formulations as **GenORReqFactor(h)**, represents the minimum percentage of the Market-Wide Operating Reserve Requirement that must be satisfied by Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources based on reliability standards. Currently, the amount of Spinning Reserves that may be supplied by interruptible load is 40% of the Spinning Reserve Requirement, and the amount of Supplemental Reserve that may be supplied by interruptible load is 50% of the Supplemental Reserve requirement. The Generation-Based Operating Reserve Requirement Factor will be calculated for each hour as follows:

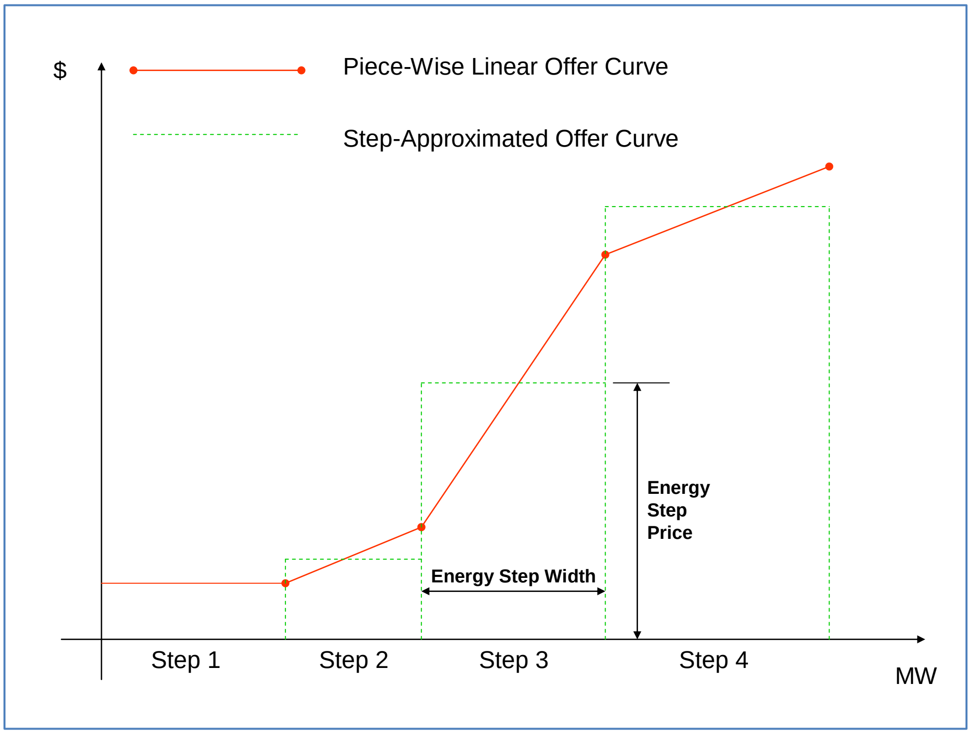
GenORReqFactor(h)
= 0.6 * [MWRegSpinReq(h) – MWRegReq(h)] / MWORReq(h)
\+ 0.5 * [MWORReq(h) - MWRegSpinReq(h)] / MWORReq(h)

3.37 SCUC Energy Offer Curve Linearization

- For each resource, and each hour, if the energy offer curve is modeled as a piece-wise linear curve, it is converted to an approximated step offer curve for use in the SCUC algorithm by replacing each piece-wise linear segment with an equivalent step segment where the step segment price is equal to the average price of the piece-wise linear segment. The upper and lower MW bounds for each step segment will be the same as the upper and lower MW bounds of each piece-wise linear segment.

Exhibit 3-1 below provides a graphical illustration of the SCUC offer curve linearization:

Exhibit 3-1: SCUC Energy Offer Curve Linearization Illustration



The energy step width and energy step price of each approximated energy offer curve step are designated in the formulations as **EnergyStepWidth(r,h,st)** and **EnergyStepPrice(r,h,st)** respectively.

3.38 Topology Processing

A topology processor executes for each hour of the Day-Ahead Energy and Operating Reserve Market. The topology uses an hourly network model (based on outage scheduler data applied to the quarterly Network Model) to develop an hourly bus admittance matrix for use in the SCED algorithm's optimal power flow constraints and to calculate hourly shift factors for use in the watch list set of transmission constraints to be enforced in the SCUC algorithm. The topology processor also supplies series line admittance (susceptance) information for use in formulating the base-case SCED transmission constraints. The bus admittance matrix terms are designated in the formulation as **B(i,j,h)**, the series line admittance values are designated in the formulations as **BranchB(k,h)** and the shift factors are designated in the formulations as **∂Flow(k,h)/∂P(i, h)**.

3.39 Marginal Loss Penalty Factor Calculation

Marginal Loss Penalty Factors are calculated for each resource and energy transaction and for each hour for use in the SCUC algorithm only. The marginal loss penalty factors are designated in the formulations as **PF(i,h)**. The marginal loss penalty factors are calculated as follows:

$$PF(i,h) = 1 / [1 - \partial Loss(h)/\partial P(i,h)]$$

4. SCUC Formulations

The SCUC algorithm is used to:

- Commit resources on an hourly basis.
- Schedule resources for regulation on an hourly basis.
- Detect a shortage condition or surplus condition on an hourly basis.
- Release emergency maximum operating ranges on selected resources on an hourly basis if a shortage condition exists.
- Release emergency minimum operating ranges on selected resources on an hourly basis if a surplus condition exists.

The SCUC algorithm uses a Mixed Integer Programming (MIP) solver. A MIP solver is a special type of LP (Linear Programming) solver that allows primal variables (i.e., output variables) to be a mixture of continuous variables and integer variables. In the SCUC algorithm, the use of integer variables is restricted to the special case of Boolean variables that can only take on values of 0 and 1. In the formulations that follow, continuous primal variables are shown in a red font, integer (or Boolean) primal variables are shown in a green font, and constraint violation variables are shown in a blue font. See Attachment A on Market Optimization Techniques for background information on MIP solvers.

The SCUC algorithm is designed to operate in two basic modes: ***Normal Mode*** and ***Emergency Mode***. In ***Normal Mode***, the SCUC algorithm will not:

- Utilize capacity above the Economic Maximum Limit of a committed resource to supply Energy, Regulating Reserve or Contingency Reserve.
- Unload capacity below the Economic Minimum Limit for the purpose of supplying Energy or Regulating Reserve.
- Commit a Generation Resource, Demand Response Resource - Type I or Demand Response Resource - Type II when the Commitment Status is set to ***Emergency***.
- Utilize capacity from an uncommitted Generation Resource or Demand Response Resource - Type II to supply Supplemental Reserve when the Off-Line Supplemental Reserve Dispatch Status is set to ***Emergency***.
- Utilize capacity from an uncommitted Demand Response Resource - Type I to supply Spinning Reserve when the Spinning Reserve Dispatch Status is set to ***Emergency***.

- Utilize capacity from an uncommitted Demand Response Resource - Type I to supply Supplemental Reserve when the Supplemental Reserve Dispatch Status is set to ***Emergency***.

*** NOTE:** Electric Storage Resources are selfcommitted units. They will be cleared at Economic Minimum Limit in DisCharge mode(Economic Maximum Limit in Charge mode and 0 in Continuous mode) unless self scheduled. Electric Storage Resourcs will clear reserve at 0 unless self scheduled.

In ***Emergency Mode***, the SCUC algorithm <u>may</u>:

- Utilize capacity above the Economic Maximum Limit of a committed resource to supply Energy, Regulating Reserve or Contingency Reserve.
- Unload capacity below the Economic Minimum Limit for the purpose of supplying Energy or Regulating Reserve.
- Commit a Generation Resource, Demand Response Resource - Type I or Demand Response Resource - Type II when the Commitment Status is set to ***Emergency***.
- Utilize capacity from an uncommitted Generation Resource or Demand Response Resource - Type II to supply Supplemental Reserve when the Off-Line Supplemental Reserve Dispatch Status is set to ***Emergency***.
- Utilize capacity from an uncommitted Demand Response Resource - Type I to supply Spinning Reserve when the Spinning Reserve Dispatch Status is set to ***Emergency***.
- Utilize capacity from an uncommitted Demand Response Resource - Type I to supply Supplemental Reserve when the Supplemental Reserve Dispatch Status is set to ***Emergency***.

*** NOTE:** Electric Storage Resources with emergency offer will be committed in Emergency mode.

The SCUC algorithm will always attempt to operate in the ***Normal Mode*** first. If a shortage and/or surplus condition is detected in one or more hours during the ***Normal Mode*** execution, the SCUC algorithm will re-execute in the ***Emergency Mode***. When operating in ***Emergency Mode***, the goal of the SCUC algorithm is to utilize only the amount of emergency capacity that is required to address the shortage or surplus condition so that appropriate price signals will be maintained during the emergency condition. The selection of which emergency capacity is to be utilized during an emergency condition will based on overall economics.

4.1 SCUC Objective Function

The overall objective function of the SCUC algorithm is to minimize the following cost function over the entire SCUC period:

MINIMIZE { Start Up Costs
+ DRRI Shut Down Costs
+ No Load Costs
+ DRRI Hourly Curtailment Costs
+ Resource Energy Costs
- Price Sensitive Demand Value
+ Dispatchable Import Costs
- Dispatchable Export Value
+ Virtual Supply Costs
- Virtual Demand Value
- Up to TUC Transaction Costs
+ Regulating Reserve Costs
+ Contingency Reserve Costs
+ Off-Line Supplemental Reserve Costs
+ Off-Line Short Term Reserve Costs
+ Emergency Maximum Release Penalty Costs*
+ Emergency Minimum Release Penalty Costs*
+ Emergency Commitment Penalty Costs*
+ Emergency Contingency Reserve Penalty Costs*
+ Constraint Violation Penalty Costs**
- Up Ramp Capability Demand Curve Value
- Down Ramp Capability Demand Curve Value}

NOTE:** Applies only in ***Emergency Mode

****NOTE:** Applies only when there are opposing constraints

The cost terms in the objective function above are described as follows:

4.1.1 Start-Up Costs

Start-up costs apply to Generation Resources and Demand Response Resources - Type II. The start-up costs are expressed mathematically in the SCUC objective function as follows:

Start-Up Costs

$$= \sum_{r}\sum_{h} \{ SUH(r,h) * SUHOfferPrice(r,d) + SUI(r,h) * SUIOfferPrice(r,d) + SUC(r,h) * ColdSUOffer(r,d) \}$$

4.1.2 DRR Type – I Shut-Down Costs

Shut-Down costs apply only to Demand Response Resources - Type I. The shut-down costs are expressed mathematically in the SCUC objective function as follows:

Shut-Down Costs

$$= \sum_{r}\sum_{h} \{ SU(r,h) * SDOfferPrice(r,d) \}$$

4.1.3 No-Load Costs

No-load costs apply only to Generation Resources and Demand Response Resources - Type II. The no-load costs are expressed mathematically in the SCUC objective function as follows:

No-Load Costs

$$= \sum_{r}\sum_{h} \{ CF(r,h) * NLOfferPrice(r,h) \}$$

4.1.4 DRR Type – Hourly Curtailment Costs

Hourly curtailment costs apply only to Demand Response Resources - Type I. The curtailment costs are expressed mathematically in the SCUC objective function as follows:

CurtailmentCosts

$$= \sum_{r}\sum_{h} \{ CF(r,h) * [HourCurtOffer(r,h) + TargetDemRedLevel(r,h) * EnergyOffer(r,h)]\}$$

4.1.5 Resource Energy Costs

Resource energy costs apply only to Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources. Energy costs are expressed mathematically in the SCUC objective function as follows:

Resource Energy Costs

$$= \sum_{r}\sum_{h} \{ \int_{0}^{EnergyDispatch(r,h)} PF(r,h) * EnergyOfferCurve(r,h,MW)dMW\}$$

NOTE: The energy offer curve must be converted to an approximated stepped curve in order to linearize the SCUC optimization problem. Each step of the approximated offer curve is then treated as a separate offer and the amount of dispatch within each step is treated as a separate continuous primal variable in the SCUC optimization problem. Therefore, the following mathematical expression for Energy Costs is incorporated into the actual SCUC objective function:

Energy Costs

$$= \sum_{r}\sum_{h}\sum_{st} \{ PF(r,h) * EnergyStepPrice(r,h,st) * EnergyStepDispatch(r,h,st)\}$$

where

EnergyDispatch(r,h)

$$= \sum_{st} \{ EnergyStepDispatch(r,h,st)\}$$

4.1.6 Price Sensitive Demand Value

Price sensitive demand value is expressed mathematically in the SCUC objective function as follows:

Price Sensitive Demand Value

$$= \sum_{tr} \sum_{h} \sum_{sg} \{ PF(tr,h) * DemSegPrice(tr,h,sg) * DemSegDispatch(tr,h,sg) \}$$

4.1.7 Dispatchable Import Cost

Dispatchable import cost is expressed mathematically in the SCUC objective function as follows:

Dispatchable Import Cost

$$= \sum_{tr} \sum_{h} \sum_{sg} \{ PF(tr,h) * ImportSegPrice(tr,h,sg) * ImportSegDispatch(tr,h,sg) \}$$

4.1.8 Dispatchable Export Value

Dispatchable export value is expressed mathematically in the SCUC objective function as follows:

Dispatchable Export Value

$$= \sum_{tr} \sum_{h} \sum_{sg} \{ PF(tr,h) * ExportSegPrice(tr,h,sg) * ExportSegDispatch(tr,h,sg) \}$$

4.1.9 Virtual Supply Cost

Virtual supply cost is expressed mathematically in the SCUC objective function as follows:

Virtual Supply Cost

$$= \sum_{tr} \sum_{h} \sum_{sg} \{ PF(tr, h) * VirtualSupSegPrice(tr, h, sg) * VirtualSupSegDispatch(tr, h, sg) \}$$

4.1.10 Virtual Demand Value

Virtual demand value is expressed mathematically in the SCUC objective function as follows:

Virtual Demand Value

$$= \sum_{tr} \sum_{h} \sum_{sg} \{ PF(tr,h) * VirtualDemSegPrice(tr,h,sg) * VirtualDemSegDispatch(tr,h,sg) \}$$

4.1.11 Up-to-TUC Transaction Value

Up-to-TUC transaction value is expressed mathematically in the SCUC objective function as follows:

Up-to-TUC Transaction Value

$$= \sum_{tr} \sum_{h} \sum_{sg} \{ PF(tr,h) * UpToTUCSegPrice(tr,h,sg) * UpToTUCSegDispatch(tr,h,sg) \}$$

4.1.12 Regulating Reserve Costs

Regulating Reserve costs apply only to Generation Resources Demand Response Resources - Type II and External Asynchronous Resources. Regulating Reserve costs are expressed mathematically in the SCUC objective function as follows:

$$\text{Regulating Reserve Costs} = \sum_{r} \sum_{h} \{RegResOfferPrice(r,h) * RegResDispatch1(r,h) + RegCapOfferPrice(r,h) * RegResDispatch2(r,h)\}$$

> **NOTE:** Regulation-qualified DRR-Type II resources may submit a Regulating Reserve offer curve. This curve would then be treated similar to an Energy offer curve as described in the Resource Energy Costs Section 4.1.5.

4.1.13 Contingency Reserve Costs

Contingency Reserve costs apply to all resources . Contingency Reserve costs are expressed mathematically in the SCUC objective function as follows:

Contingency Reserve Costs

$$= \sum_{r} \sum_{h} \{ ContResOfferPrice(r,h) * ContResDispatch(r,h) \}$$

NOTE: DRR-Type I, DRR-Type II Resources may submit Contingency Reserve offer curves. These curves would then be treated similar to an Energy offer curve as described in the Resource Energy Costs 4.1.5.

4.1.14 Off-Line Supplemental Reserve Costs

Off-Line Supplemental Reserve costs apply to uncommitted Generation, Demand Response Resources - Type II. Off-Line Supplemental Reserve costs are expressed mathematically in the SCUC objective function as follows:

Off-Line Supplemental Reserve Costs

$$= \sum_{r} \sum_{h} \{ \text{OffLineSupResOfferPrice}(r,h) * \text{OffLineSupResDispatch}(r,h) \}$$

4.1.15 Off-Line Short Term Reserve Costs

Off-Line Short-Term Reserve costs apply to uncommitted Generation Resources and Demand Response Resources - Type I and II. Off-Line Short Term Reserve costs are expressed mathematically in the SCUC objective function as follows:

Off-Line Short Term Reserve Costs

$$= \sum_{r} \sum_{h} \{ \text{OffLineSTROfferPrice}(r,h) * \text{OffLineSTRResDispatch}(r,h) \}$$

4.1.16 Emergency Maximum Release Penalty Costs

Emergency maximum release penalty costs are included in the SCUC cost minimization objective function in ***Emergency Mode*** only. The purpose of the emergency maximum release penalty costs is to restrict the amount of emergency capacity released from committed resources to the amount necessary to address a shortage condition.

In ***Emergency Mode***, the following emergency maximum release penalty cost terms will be included in the objective function for each specific hour where there was a shortage condition in the initial normal mode SCUC iteration:

Emergency Maximum Release Penalty Cost

$$= \sum_{r} \sum_{\substack{h \\ h \in H}} \{[EmerMaxLimit(r,h) - EcoMaxLimit(r,h)] * EmerPenPrice * EmerMaxRelease(r,h)\}$$

Where

H is the set of hours with a shortage condition in the initial ***Normal Mode*** SCUC execution

4.1.17 Emergency Minimum Release Penalty Costs

Emergency minimum release penalty costs are included in the SCUC cost minimization objective function in ***Emergency Mode*** only. The purpose of the emergency minimum release penalty costs is to restrict the amount of emergency minimum capability released from committed resource to the amount necessary to address a surplus condition.

In the ***Emergency Mode***, the following emergency minimum release penalty cost terms will be included in the objective function for each specific hour where there was a surplus condition in the initial normal mode SCUC iteration:

Emergency Minimum Release Penalty Cost

$$= \sum_{r} \sum_{\substack{h \\ h \in H'}} \{[EcoMinLimit(r,h) - EmerMinLimit(r,h)] * EmerPenPrice * EmerMinRelease(r,h)\}$$

Where

H' is the set of hours with a surplus condition in the initial ***Normal Mode*** SCUC execution

4.1.18 Emergency Commitment Penalty Costs

Emergency commitment penalty costs are included in the SCUC cost minimization objective function in ***Emergency Mode*** only. The purpose of the emergency commitment penalty costs is to ensure a level playing field for all emergency capacity.

In ***Emergency Mode***, the following emergency commitment penalty cost terms will be included in the objective function for all resources that have a Commitment Status set to ***Emergency*** in at least one hour of the SCUC period.

4.1.18.1 Generation Resources and Demand Response Resources – Type II

Emergency Commitment Penalty Cost

$$= \sum_{r} \sum_{h} \{ EmerStatus(r,h) * EcoMaxLimit(r,h) * EmerPenPrice * CF(r,h) \}$$

4.1.18.2 Demand Response Resources – Type I

Emergency Commitment Penalty Cost

$$= \sum_{r} \sum_{h} \{ EmerStatus(r,h) * TargetDemRedLevel(r,h) * EmerPenPrice * CF(r,h) \}$$

4.1.19 Emergency Contingency Reserve Penalty Costs

Emergency contingency reserve penalty costs are included in the SCUC cost minimization objective function in ***Emergency Mode*** only. The purpose of the emergency contingency reserve penalty costs is to ensure a level playing field for all emergency capacity.

In the ***Emergency Mode***, the following emergency contingency reserve penalty cost terms will be included in the objective function in applicable hours for all of the following resources:

- Quick-start Generation Resources and Demand Response Resources - Type II with an Off-Line Supplemental Reserve Dispatch Status set to ***Emergency.***
- Demand Response Resources - Type I with a Spinning Reserve Dispatch Status set to ***Emergency*** that are otherwise available to provide Spinning Reserve.
- Demand Response Resources- Type I unavailable to supply Spinning Reserve with a Supplemental Reserve Dispatch Status set to ***Emergency*** that are otherwise available to supply Supplemental Reserve.

4.1.19.1 Generation Resources and Demand Response Resources – Type II

Emergency Contingency Reserve Penalty Cost

$$= \sum_{r} \sum_{h} \{ EmerStatus(r,h) * EmerPenPrice * OffLineSupResDispatch(r,h) \}$$

4.1.19.2 Demand Response Resources – Type I

Emergency Contingency Reserve Penalty Cost

$$= \sum_{r} \sum_{h} \{ EmerStatus(r,h) * EmerPenPrice * ConResDispatch(r,h) \}$$

4.1.20 Opposing Constraint Violation Penalty Costs

Opposing constraint violation penalty costs are included in the SCUC objective function to avoid infeasible solutions when opposing constraints exists (see Attachment A on Market Optimization Techniques for more information on addressing infeasible solutions). Constraint violation variables are introduced into the cost minimization objective function with penalty price coefficients. The opposing constraint violation penalty terms are used to ensure the solution satisfies all constraints if possible and/or to prioritize the constraints to determine which constraints are violated under an opposing constraint scenario. The following opposing constraint violation penalty terms are included in the cost minimization objective function of the SCUC algorithm:

4.1.20.1 Resource Maximum Limit Violation Cost:

Applies to Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources:

Resource Maximum Limit Violation Cost

$$= \sum_{r} \sum_{h} \{ LimitPenPrice * MaxLimitViolation(r,h) \}$$

4.1.20.2 Resource Minimum Limit Violation Cost:

Applies to Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources:

Resource Minimum Limit Violation Cost

$$= \sum_{r} \sum_{h} \{ LimitPenPrice * MinLimitViolation(r,h) \}$$

4.1.20.3 Resource Ramp Rate Violation Cost:

Applies to Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources:

Resource Ramp Rate Violation Cost

$$= \sum_{r}\sum_{h} \{ \text{RampPenPrice} * \text{ContResRampViolation}(r,h)\}$$

$$+ \sum_{r}\sum_{h} \{ \text{RampPenPrice} * \text{RegRampViolation}(r,h)\}$$

4.1.20.4 Global Power Balance Violation Cost:

Applies to the entire market.

Global Power Balance Violation Cost

$$= \sum_{h} \{[\text{EnergyShortagePenPrice} * \text{GlobalEnergyShortage}(h)] + [\text{EnergySurplusPenPrice} * \text{GlobalEnergySurplus}(h)]\}$$

4.1.20.5 Market-Wide Regulating Reserve Violation Cost:

Applies to the entire market

Market Wide Regulating Reserve Violation Cost

$$= \sum_{h} \{[\text{RegShortagePenPrice} * \text{MWRegShortage}(h)]\}$$

4.1.20.6 Market-Wide Regulating plus Spinning Reserve Violation Cost:

Applies to the entire market

Market Wide Regulating plus Spinning Reserve Violation Cost

$$= \sum \{[\text{RegSpinShortagePenPrice} * \text{MWRegSpinShortage}(h)]\}$$

h

4.1.20.7 Market-Wide Operating Reserve Violation Cost:

Applies to the entire market

Market Wide Operating Reserve Violation Cost

$$= \sum_{h} \{[\text{OpResShortagePenPrice} * \text{MWOpResShortage(h)}]\}$$

4.1.20.8 Market-Wide Short Term Reserve Violation Cost:

Applies to the entire market

Market Wide Short Term Reserve Violation Cost

$$= \sum_{h} \{[\text{STRShortagePenPrice} * \text{MWSTRShortage(h)}]\}$$

4.1.20.9 Market-Wide Ramp-Up Violation Cost:

Applies to the entire market

Market Wide Ramp-Up Violation Cost

$$= \sum_{h} \{[\text{RampUpPenPrice} * \text{MWHourlyRampUpViolation(h)}]\}$$

4.1.20.10 Market-Wide Ramp-Down Violation Cost:

Applies to the entire market

Market Wide Ramp-Down Violation Cost

$$= \sum_{h} \{[\text{RampDnPenPrice} * \text{MWHourlyRampDnViolation(h)}]\}$$

4.1.20.11 Short Term Reserve Post-Deployment Power Balance Constraint Violation Cost:

Applies to each reserve zone

Short Term Reserve Post-Deployment Power Balance Constraint Violation Cost

$$= \sum_{z} \sum_{h} \{[ZneedSTRPenPrice * (ZNeedViolSTRPos(z,h) + ZNeedViolSTRNeg(z,h))]\}$$

4.1.20.12 Generation-Based Operating Reserve Violation Cost:

Applies to the entire market

Generation Based Operating Reserve Violation Cost

$$= \sum_{h} \{[GenOpResShortagePenPrice * GenOpResShortage(h)]\}$$

4.1.20.13 Transmission Demand Curve Violation Cost:

Applies to each transmission constraint. Each Transmission Constraint consists of a step curve with one or more steps.

Transmission Constraint Demand Curve Violation Cost

$$= \sum_{st} \sum_{k} \sum_{h} \{[TransLimitPenPrice(st,k,h) * TransLimitStepViolation(st,k,h)]\}$$

4.1.20.14 Sub-Regional Demand Curve Violation Cost:

Applies to the Sub-Regional Demand Constraint. The Sub-Regional Demand Constraint consists of a step curve.

Sub-Regional Demand Curve Violation Cost

$$= \sum_{st} \sum_{k} \sum_{h} \{[SubRegLimitPenPrice(st,k,h) * SubRegLimitStepViolation(st,k,h)]\}$$

4.1.20.15 Reserve Procurement Transmission Limit Regulation Up Violation Cost:

Applies to each transmission constraint selected as a reserve procurement constraint.

Reserve Procurement Transmission Limit Regulation Up Violation Cost

$$= \sum_{k} \sum_{h} \{[TransLimitRegUpPenPrice * TransLimitViolationRegUp(k,h)]\}$$

4.1.20.16 Reserve Procurement Transmission Limit Regulation Down Violation Cost:

Applies to each transmission constraint selected as a reserve procurement constraint.

Reserve Procurement Transmission Limit Regulation Down Violation Cost

$$= \sum_{k} \sum_{h} \{[TransLimitRegDownPenPrice * TransLimitViolationRegDown(k,h)]\}$$

4.1.20.17 Reserve Procurement Transmission Limit Contingency Reserve Event Violation Cost:

Applies to each transmission constraint selected as a Contingency Reserve procurement constraint.

Reserve Procurement Transmission Limit Contingency Reserve Event Violation Cost

$$= \sum_{k} \sum_{h} \{[TransLimitCREventPenPrice * TransLimitViolationCREvent(k,h)]\}$$

4.1.20.18 Reserve Procurement Transmission Limit Short Term Reserve Event Violation Cost:

Applies to each transmission constraint selected as a Short Term Reserve procurement constraint.

Short Term Reserve Procurement Transmission Limit Short Term Reserve Event Violation Cost

$$=\Sigma \Sigma \text{ TotalSTRPenaltyCost}(k,h)$$

k h

,where

TotalSTRPenaltyCost(k,h)

>= TransLimitSTRPenPrice(k,h)*[TransLimitViolSTR(k,e,h) + TransLimitSurplusSTR(k,e,h)]

4.1.20.19 Ramp Procurement Transmission Limit Up Ramp Capability Violation Cost:

Applies to each transmission constraint selected as a ramp procurement constraint.

Ramp Procurement Up Ramp Capability post deployment transmission limit Violation Cost

= Σ {[TransLimitRCUpPenPrice * TransLimitViolationRCUp(k,h)]}

4.1.20.20 Ramp Procurement Transmission Limit Down Ramp Capability Violation Cost:

Applies to each transmission constraint selected as a ramp procurement constraint.

Ramp Procurement Down Ramp Capability post deployment transmission limit Violation Cost

= Σ {[TransLimitRCDownPenPrice * TransLimitViolationRCDown(k,h)]}

4.1.20.21 Maximum Resource Regulating Reserve Violation Cost:

Applies to each resource

Maximum Resource Regulating Reserve Violation Cost

= Σ Σ{[MaxResourceRegPenPrice* MaxResourceRegViolation(r,h)]}
r h

4.1.20.22 Maximum Resource Contingency Reserve Violation Cost:

Applies to each resource

Maximum Resource Contingency Reserve Violation Cost

$$= \sum_{r}\sum_{h}\{[MaxResourceContResPenPrice * MaxResourceContResViolation(r,h)]\}$$

4.1.20.23 Maximum Resource Up Ramp Capability Violation Cost:

Applies to each Resource.

Maximum Resource Down Ramp Capability Violation Cost

$$= \sum_{r}\{ MaxResourceRCUpPenPrice * MaxResourceRCUPViolation(r,di)\}$$

4.1.20.24 Maximum Resource Down Ramp Capability Violation Cost:

Applies to each Resource.

Maximum Resource Down Ramp Capability Violation Cost

$$= \sum_{r}\{ MaxResourceRCDownPenPrice * MaxResourceRCDownViolation(r,di)\}$$

4.1.20.25 Maximum Resource Short Term Reserve Violation Cost:

Applies to each resource

Maximum Resource Short Term Reserve Violation Cost

$$= \sum_{r}\sum_{h}\{[MaxResourceSTRPenPrice * MaxResourceSTRViolation(r,h)]\}$$

4.1.20.26 Resource Self-Scheduled Energy Violation Cost:

Applies to each resource

Resource Self Scheduled Energy Violation Cost

$$= \sum_{r}\sum_{h}\{[SSEnergyPenPrice * SSEnergyDeficit(r,h)]\}$$

4.1.20.27 Resource Self-Scheduled Regulating Reserve Violation Cost:

Applies to each resource

Resource Self Scheduled Regulating Reserve Violation Cost

$$= \sum_{r} \sum_{h} \{[SSRegPenPrice * SSRegDeficit(r,h)]\}$$

Resource Self-Scheduled Contingency Reserve Violation Cost:
Applies to each resource

Resource Self Scheduled Contingency Reserve Violation Cost

$$= \sum_{r} \sum_{h} \{[SSContResPenPrice * SSContResDeficit(r,h)]\}$$

4.2 SCUC Constraints

The overall objective function of the SCUC algorithm is minimized subject to the following constraints:

> **NOTE:** While the formal constraint representation includes all variables on the LHS and a single constant on the RHS, the SCUC constraints below have been arranged in a format that provides the most clarity as to the purpose and function of the constraint.

4.2.1 Generation Resource and Demand Response Resource – Type II Constraints

4.2.1.1 Commitment Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for commitment during a specific hour in order to be committed in that hour.

$$CF(r,h) \le CommitAvailability(r,h)$$

If the commitment availability of a specific resource is 0 during a specific hour, the commitment flag for that resource and hour must also be 0. If the commitment availability for a specific resource is 1 during a specific hour, the commitment flag for that resource and hour may be 0 or 1 based on economics and other constraints.

4.2.1.2 Regulation Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that an eligible resource be available for regulation a specific hour in order to be selected for regulation during that hour.

RF(r,h)
≤
RegAvailability(r,h)

If the regulation availability of a specific resource is 0 during a specific hour, the regulation flag for that resource and hour must also be 0. If the regulation availability for a specific resource is 1 during a specific hour, the regulation flag for that resource and hour may be 0 or 1 based on economics and other constraints.

4.2.1.3 Contingency Reserve Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that an eligible resource be available for Spinning Reserve or Supplemental Reserve in a specific hour in order to be dispatched for Contingency Reserve during that hour.

ContResDispatch(r,h)
≤
[EmerMaxLimit(r,h) - EmerMinLimit(,h)] *
SpinAvailability(r,h)

+ [EmerMaxLimit(r,h) - EmerMinLimit(,h)]
* [SupAvailability(r,h) - SpinAvailability(r,h)]

If the Spinning Reserve availability and the Supplemental Reserve availability of a specific resource are both 0 during a specific hour, the Contingency Reserve dispatched on that resource during that hour must also be 0. If either the Spinning Reserve availability or the Supplemental Reserve availability of a specific resource are 1 during a specific hour, the Contingency Reserve dispatched on that resource may be as high as the emergency maximum limit less the emergency minimum limit, based on economics and other constraints. It is important to note that the purpose of this constraint is to prevent Contingency Reserve from being dispatched on a resource during an hour when neither Spinning Reserve nor Supplemental Reserve is available from the resource. Other constraints will likely restrict the Contingency Reserve dispatch to levels well below what is allowed by this constraint during hours when Contingency Reserve is available from the resource.

Off-Line Supplemental Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for off-line Supplemental Reserve during a specific hour in order to be dispatched for off-line Supplemental Reserve during that hour.

OffLineSupResDispatch(r,h)
≤
MaxOffLineResponse(r,h) * OffLineSupAvailability(r,h)

If the off-line Supplemental Reserve availability of a specific resource is 0 during a specific hour, the off-line Supplemental Reserve dispatched on that resource during that hour must also be 0. If the Supplemental Reserve availability of a specific resource is 1 during a specific hour, the off-line Supplemental Reserve dispatched on that resource may be as high as the maximum off-line response of that resource for that hour based on economics and other constraints.

4.2.1.4 On-Line Short Term Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for on-line Short Term Reserve during a specific hour in order to be dispatched for on-line Short Term Reserve during that hour.

OnLineSTRDispatch(r,h)
≤
{ - EnergyDispatch(r,h) - RegResDispatch1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]}
* OnLineSTRAvailabity(r,h)

The following maximum limit constraints apply to resources during any hour of an emergency mode SCUC execution when there was a shortage detected for that hour during the initial normal mode SCUC iteration.

OnLineSTRDispatch(r,h)
≤
{ - EnergyDispatch(r,h) - RegResDispatch1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]
+ EmerMaxRelease(r,h) * [EmerMaxLimit(r,h) - EcoMaxLimit(r,h)] }
* OnLineSTRAvailabity(r,h)

4.2.1.5 On-line Short Term Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following on-line Short Term Reserve ramp constraints is used to quantify and limit the cleared on-line Short Term Reserve on each resource based on ramp rate.

[STRRampMult / STRDeployTime] * OnlineSTRResDispatch(r,h)
<=
[1 – CF(r,h)] * InputRampRate(r,h)

4.2.1.6 Off-Line Short Term Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for off-line Short Term Reserve during a specific hour in order to be dispatched for off-line Short Term Reserve during that hour.

OffLineSTRResDispatch(r,h)
≤
{[1 – CF(r,h)] * min[MaxOffLineSTR(r,h) , EcoMaxLimit (r,h)]}
 * OffLineSTRAvailabity(r,h)

4.2.1.7 Must-Run Commitment Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints require that a resource be committed during a specific hour if the resource is available for commitment during that hour and the Commitment Status is set to ***Must Run*** for that resource and hour.

CF(r,h)
≥
CommitAvailability(r,h) * MustRunStatus(r,h)

If the commitment availability and must run status of a resource during a specific hour are both set to 1, the resource commitment flag must also be 1 for that hour. Otherwise the resource commitment flag may be 0 or 1 based on economics and other constraints.

4.2.1.8 Regulation Commitment Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a specific resource be committed in a specific hour in order to be considered for regulation for that hour.

RF(r,h)
≤
CF(r,h)

If the commitment flag is 0 for a specific resource and hour, the regulation flag for that resource and hour must also be zero. If the commitment flag is 1 for a specific resource and hour, the regulation flag for that resource and hour may be 0 or 1 based on economics and other constraints.

4.2.1.9 Emergency Maximum Regulation Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints apply only in the ***Emergency Mode*** of SCUC and require that a specific resource in a specific hour not be simultaneously selected for regulation and the release of the emergency maximum operating range. These constraints also limit the amount of the emergency maximum operating range to be released to 100%, and require that a resource be committed in a specific hour in order for the resource to be selected for regulation or the release of the emergency maximum operating range during that hour.

RF(r,h)
\+ EmerMaxRelease(r,h)
≤
CF(r,h)

If the regulation flag is 1 for a specific resource and hour, then none of the emergency maximum operating range can be released on that resource during that hour. Likewise, if any of the emergency maximum operating range is released on a specific resource during a specific hour, then the regulation flag must be 0 for that specific resource and hour. If a resource is committed during a specific hour, then the regulation flag for that resource may be set to 1 for that hour or up to 100% of the emergency maximum operating range may be released on that resource during that hour based on economics and other constraints. If a resource is not committed during a specific hour, then the regulation flag cannot be set to 1 on that resource during that hour nor can any of the emergency maximum operating range be released on that resource during that hour.

4.2.1.10 Emergency Minimum Regulation Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints apply only in the ***Emergency Mode*** of SCUC and require that a specific resource in a specific hour not be simultaneously selected for regulation and release of the emergency minimum operating range. These constraints also limit the amount of the emergency minimum operating range to be released to 100% and require that a resource be committed in a specific hour in order for the resource to be selected for regulation or the release of the emergency minimum operating range during that hour.

RF(r,h)
+ EmergMinRelease(r,h)
≤
CF(r,h)

If the regulation flag is 1 for a specific resource and hour, then none of the emergency minimum operating range can be released on that resource during that hour. Likewise, if any of the emergency minimum operating range is released on a specific resource during a specific hour, then the regulation flag must be 0 for that specific resource and hour. If a resource is committed during a specific hour, then the regulation flag for that resource may be set to 1 for that hour or up to 100% of the emergency minimum operating range may be released on that resource during that hour based on economics and other constraints. If a resource is not committed during a specific hour, then the regulation flag cannot be set to 1 on that resource during that hour nor can any of the emergency minimum operating range be released on that resource during that hour.

4.2.1.11 Initial Hour Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to the first hour of the SCUC period only and require the start-up flag for a specific resource to be 1 in the first hour of the SCUC period if that resource is initially off-line and is then committed in the first hour of the SCUC period.

SU(r,1)
≥
CF(r,1)
- InitialOnStatus(r)

If a resource is initially off-line and the commitment flag for that resource is set to 1 in the first hour of the SCUC period, the start-up-flag for that resource must also be set to 1 in the first hour of the SCUC period. Otherwise, economics will force the start-up flag to be set to 0 for that resource in the first hour of the SCUC period to avoid the incurrence of a start-up cost.

4.2.1.12 Hourly Start-Up/Shut-Down Commitment Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to all hours subsequent to the first hour of the SCUC period, and require the value of the Start-Up flag less the value of the Shut-Down flag for a given resource in a given hour to be equal to the Commitment Flag for the resource and hour less the Commitment flag for the resource in the previous hour.

SU(r,h) – SD(r,h)
=
CF(r,h)
- CF(r,h-1)

Together, the Hourly Start-Up/Shut-Down Commitment constraints and the Hourly Start-Up/Shut-Down constraints ensure that any change of commitment flag CF(r,h) between two adjacent hours will set either the SU(r,h) or the SD(r,h) flag to the value 1.

4.2.1.13 Hourly Start-Up/Shut-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to all hours subsequent to the first hour of the SCUC period, and require that the sum of the Start-Up flag and the Shut-Down flag for the resource and hour to be less than or equal to one. A resource can Start-Up or Shut-Down in a given hour, but not both.

$$SU(r,h) + SD(r,h) \leq 1$$

Together, the Hourly Start-Up/Shut-Down Commitment constraints and the Hourly Start-Up/Shut-Down constraints ensure that any change of commitment flag CF(r,h) between two adjacent hours will set either the SU(r,h) or the SD(r,h) flag to the value 1.

4.2.1.14 Initial Hour Shut-Down Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to the first hour of the SCUC period only and requires the shut-down flag for a specific resource to be 1 in the first hour of the SCUC period if that resource is initially on-line and is then decommitted in the first hour of the SCUC period.

$$SD(r,1) \geq InitialOnStatus(r) - CF(r,1)$$

If a resource is initially on-line and the commitment flag for that resource is set to 0 in the first hour of the SCUC period, the shut-down-flag for that resource must be set to 1 in the first hour of the SCUC period. This constraint does not restrict the value of the shut-down flag for other conditions. However, the shut-down flag is only relevant in the formulations (i.e., minimum down-time constraints) when an actual shut-down occurs.

4.2.1.15 Hot Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraint is applied to a resource r in all hours of the SCUC study period.

IF { h > HotToIntTime(r) }

$$SUH(r,h) \le \sum_{h'=h-HotToIntTime(r)}^{h-1} \{ SD(r, h') \}$$

ELSE IF { InitialOnHours (r) > 0 }

SUH(r,h) = SU(r,h)

ELSE IF { InitialOnHours (r) <= 0 }
AND { h – 1 – InitialOnHours(r) < HotToIntTime(r)}

SUH(r,h) = SU(r,h)

ELSE IF { InitialOnHours (r) <= 0 } and { h =1 }
AND { – InitialOnHours(r) >= HotToIntTime(r)}

SUH(r,h) = 0

ELSE IF { InitialOnHours (r) <= 0 } and { h > 1 }
AND { h - 1 – InitialOnHours(r) >= HotToIntTime(r)}

$$SUH(r,h) \le \sum_{h'=1}^{h-1} \{ SD(r, h') \}$$

END IF

This constraint ensures that the Hot Startup flag will be set to 1 if and only if the Hot Startup conditions are met.

4.2.1.16 Intermediate Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraint is applied to a resource r in any hour h of the SCUC study period.

IF { h > HotToColdTime(r) **}**

$$SUI(r,h) \le \sum_{h'=h - HotToColdTime(r)}^{h- HotToIntTime(r) - 1} \{ SD(r, h') \}$$

ELSE IF { InitialOnHours (r) <= 0 **}**
AND { h – 1 – InitialOnHours(r) < HotToColdTime(r)**}**

SUH(r,h) + SUI(r,h) = SU(r,h)

ELSE IF { (InitialOnHours (r) <= 0) AND { h=1 **}**
AND { – InitialOnHours(r) >= HotToColdTime(r)**}**

SUI(r,h) = 0

ELSE IF {(InitialOnHours (r) <= 0) AND { h > 1 **}**
AND { h – 1 – InitialOnHours(r) >= HotToColdTime(r)**}**

$$SUI(r,h) <= \sum_{h'=1}^{h-1} \{ SD(r, h') \}$$

END IF

This constraint ensures that the Intermediate Startup flag will be set to 1 if and only if the Intermediate Startup conditions are met.

4.2.1.17 Must-Run Startup Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

This constraint applies for all hours of the SCUC study period.

IF { PossibleMustRunStartupPeriod(r,h) and h1 > h and h1 < NextMustRunPeriod(r,h)**}**
MRSU(r,h) <= 1 - SD(r, h1)
END IF

This constraint ensures that if a shut down occurred before the next must-run commitment period, then a resource startup cannot qualify as must-run startup.

4.2.1.18 Certain Must Run Startup Constraint

Constraint Classification: Physical

Constraint Type: Hard EQ

This constraint applies for all hours of the SCUC study period.

IF { CertainMustRunStartup(r,h) = 1 **}**
MRSU(r,h) = SU(r,h)
END IF

This constraint requires that if a resource has the preprocessed flag CertainMustRunStartup(r,h) set to 1 in an hour, then whenever there is a startup of the resource in the hour, it is a must-run startup.

4.2.1.19 Possible Must-Run Start-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard EQ

This constraint applies for all hours of the SCUC study period.

IF { NOT PossibleMustRunStartupPeriod(r,h)**}**
MRSU(r,h) = 0
END IF

This constraint requires that if a resource does not have the preprocessed flag PossibleMustRunStartupPeriod(r,h) flag set to 1 in an hour, then a startup of the resource in the hour will not be a Must-Run Startup.

4.2.1.20 Cold Start-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard EQ

This constraint applies to all hours of the SCUC study period. It ensures that a startup is labeled as a cold startup if it does not meet the constraints of hot or intermediate start-up.

SUH(r,h) + SUI(r,h) + SUC(r,h) + MRSU(r,h) = SU(r,h)

The start-up constraints concerning cold startup, intermediate startup, hot startup and must-run startup are formulated based on the assumption that hot start-up cost is not higher than intermediate start-up cost, and intermediate start-up cost is not higher than cold start-up cost. The order of the start-up costs is the driving force to arrive at appropriate start-up status. For example, if hot start-up cost is the lowest start-up cost, a start-up will be solved as hot start-up as long as it satisfies the hot start-up constraints.

If in any hour the must-run startup can be set to 1 (under constraints described in the following sections), the optimization will set it to 1 since this will reduce the objective cost by eliminating the resource's startup cost, and correctly acknowledging that Must-Run commitments do not incur start-up costs to the system. When the must-run startup (MRSU(r,h)) is set to 1, SUH(r,h), SUI(r,h) and SUC(r,h) are set to 0.

4.2.1.21 Initial Minimum Run Time Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints are used to enforce the minimum run time of a resource at the beginning of the SCUC period if the resource is initially on-line.

IF { h + InitialOnHours(r) < MinRunTime(r)**}**
CF(r,h)
≥
InitialOnStatus(r) + CommitAvailability(r,h)-1
END IF

If the resource is initially on-line and the minimum run time has not expired at the beginning of the SCUC period, this constraint ensures that the resource is committed until the minimum run time expires. A commitment availability of 0 for the resource and hour overrides this constraint.

4.2.1.22 Initial Minimum Down Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the minimum down time of a resource at the beginning of the SCUC period if the resource is initially off-line.

IF { h + InitialOffHours(r) < MinDownTime(r)**}**
CF(r,h)
≤
InitialOnStatus(r) + MustRunStatus(r,h)
END IF

If the resource is initially off-line and the minimum down time has not expired at the beginning of the SCUC period, this constraint ensures that the resource is not committed until the minimum down time expires. A must run status of 1 for the resource and hour overrides this constraint.

4.2.1.23 Minimum Run Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the minimum run time of a resource for the start-up of a resource in a specific hour.

$$SU(r,h) \leq \sum_{h'=h}^{h+MinCommitTime(r,h)-1} \{ CF(r,h) \} / MinCommitTime(r,h)$$

This constraint ensures that when a resource is started, it will be subsequently committed for the lesser of the minimum run time or the remainder of the SCUC period.

NOTE: While this is not a penalized constraint, it could oppose certain must run constraints, commitment availability constraints and/or maximum daily energy constraints. If this happens in the initial SCUC iteration, the infeasibility will be detected, the specific minimum run time constraints causing the infeasibility will be disabled to honor the must run constraints, commitment availability constraints and/or maximum daily energy constraints, and SCUC will be re-executed.

4.2.1.24 Minimum Down Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the minimum down time of a resource for the shut-down of a resource in a specific hour.

$$SD(r,h) \leq \sum_{h'=h}^{h+MinDecommitTime(r,h)-1} \{ 1 - CF(r,h) \} / MinDecommitTime(r,h)$$

This constraint ensures that when a resource is shut-down, it will not be subsequently committed for the lesser of the minimum down time or the remainder of the SCUC period.

NOTE: While this is not a penalized constraint, it could oppose the combination of certain must run constraints and commitment availability constraints. If this happens in the initial SCUC iteration, the infeasibility will be detected, the specific minimum down time constraints causing the infeasibility will be disabled to honor the must run and commitment availability constraints, and SCUC will be re-executed.

4.2.1.25 Initial Maximum Run Time Constraint

Constraint Classification: Physical

Constraint Type: Hard Equality
The following constraints apply only in the first hour of the SCUC period and are used to ensure a resource is not committed in the first hour of the SCUC period if the initial on hours associated

with the resource exceed the maximum run time of the resource unless the resource is offered as must run.

IF { InitialOnHours(r) ≥ MaxRunTime(r)}
CF(r,1) = MustRunStatus(r,h)
END IF

4.2.1.26 Maximum Run Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the maximum run time of a resource.

IF { h > MaxRunTime(r)**}**

$$\sum_{h'=h-MaxRunTime(r)}^{h} \{ CF(r,h') \} \leq MaxRunTime(r)$$

ELSE IF { InitialOnStatus(r) = 1 **}**

$$\sum_{h'=1}^{h} \{ CF(r,h') \} + InitialOnHours(r) \leq MaxRunTime(r)$$

END IF

This constraint ensures that a resource will not be committed in a specific hour if commitment in that hour causes the resource to exceed its maximum run time.

NOTE: While this is not a penalized constraint, it could oppose the combination of certain must run constraints. If this happens in the initial SCUC iteration, the infeasibility will be detected, the specific maximum run time constraints causing the infeasibility will be disabled to honor the must run constraints, and SCUC will be re-executed.

4.2.1.27 Off-Line Supplemental Reserve Minimum Down Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to ensure off-line Supplemental Reserve is not dispatched on a resource prior to the expiration of the minimum down time of the resource.

IF { MinDownTime(r) ≥ h - InitialOnHours(r)**}**

OffLineSupResDispatch(r,h)

≤

InitialOnStatus(r) * MaxOffLineResponse(r,h)

ELSE

$$\sum_{h'=h}^{h+MinDownTime(r)-1} OffLineSupResDispatch(r,h') \leq [1-CF(r,h-1)]*\sum_{h'=h}^{h+MinDownTime(r)-1}\{EmergencyMax(r,h')\}$$

END IF

4.2.1.28 Off-Line Short Term Reserve Minimum Down Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to ensure off-line Short Term Reserve is not dispatched on a resource prior to the expiration of the minimum down time of the resource.

IF { MinDownTime(r) ≥ h - InitialOnHours(r)**}**

OffLineSTRResDispatch(r,h)

≤

InitialOnStatus(r) * MaxOffLineSTR (r,h)

ELSE

h+MinDownTime(r)-1

Σ OffLineSTRResDispatch(r,h’)
h’=h
≤
h+MinDownTime(r)-1
[1-CF(r,h-1)]*Σ{ EmergencyMax(r,h’)}
h'=h
END IF

4.2.1.29 First Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints are used to set the first start-up flag for a specific resource in a specific hour where the first start-up flag indicates the first start-up of the SCUC period.

IF { h > 1 **}**
FirstSU(r,h)
≥
SU(r,h)
h-1
- Σ { SU(r,h')}
h'=1
ELSE
FirstSU(r,1)
≥
SU(r,1)
END IF

If the start-up flag for a resource in a specific hour is set to 1 and the start-up flag is not set for the resource in any of the preceding hours of the SCUC period, then the first start-up flag will set to 1 for the resource during that hour as well.

4.2.1.30 Cold Start-Up Notification Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to disallow a cold start-up as the first start-up in a SCUC period in any hour where the cold start-up time plus the cold start-up notification time would not be honored based on the anticipated posting time of the Day-Ahead Energy and Operating Reserve Market results (typically 17:00 the day before the operating day).

IF { SUCTime(r,h) + SUCNotTime(r,h) > h + PostingPeriod – 1 **}**

SUC(r,h)

≤

1

\- FirstSU(r,h)

END IF

If the number of hours from the Day-Ahead Energy and Operating Reserve Market posting time to the beginning of hour h is less than the cold start-up time plus the cold start-up notification time of a specific resource, then a cold start-up cannot be allowed for the resource during this hour, and this constraint will not allow both the cold start-up and first start-up flags to be set to 1.

4.2.1.31 Intermediate Start-Up Notification Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to disallow an intermediate start-up as the first start-up in a SCUC period in any hour where the intermediate start-up time plus the intermediate start-up notification time would not be honored based on the anticipated posting time of the Day-Ahead Energy and Operating Reserve Market results (typically 17:00 the day before the operating day).

IF { SUITime(r,h) + SUINotTime(r,h) > h + PostingTime – 1 **}**

SUI(r,h)

≤

1

\- FirstSU(r,h)

END IF

If the number of hours from the Day-Ahead Energy and Operating Reserve Market posting time to the beginning of hour h is less than the intermediate start-up time plus the intermediate start-up notification time of a specific resource, then an intermediate start-up cannot be allowed for the resource during this hour, and this constraint will not allow both the intermediate start-up and first start-up flags to be set to 1. In this case, an intermediate start-up would also not be allowed.

4.2.1.32 Hot Start-Up Notification Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to disallow a hot start-up as the first start-up in a SCUC period in any hour where the hot start-up time plus the hot start-up notification time would not be honored based on the anticipated posting time of the Day-Ahead Energy and Operating Reserve Market results (typically 17:00 the day before the operating day).

IF { SUHTime(r,h) + SUHNotTime(r,h) > h + PostingPeriod – 1 **}**
SUH(r,h)
≤
1
- FirstSU(r,h)
END IF

If the number of hours form the Day-Ahead Energy and Operating Reserve Market posting time to the beginning of hour h is less than the hot start-up time plus the hot start-up notification time of a specific resource, then a hot start-up cannot be allowed for the resource during this hour, and this constraint will not allow both the hot start-up and first start-up flags to be set to 1. In this case, a cold start-up and intermediate start-up would also not be allowed, thus this resource could not be started in this hour.

4.2.1.33 Maximum Daily Starts Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the maximum number of daily starts allowed for a resource.

$$\sum_{h \in d} SU(r,h) \le MaxDailyStarts(r,d)$$

A resource cannot have more start-up flags set to 1 in a day then the maximum number of daily starts specified in the offer.

4.2.1.34 Energy Step Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific energy offer curve step is less than or equal to the step width or zero if the resource is not committed:

$$EnergyStepDispatch(r,h,st) \le CF(r,h) * EnergyStepWidth(r,h,st)$$

If the commitment flag is set to 0 for a resource during a specific hour, then the energy dispatch for each energy offer curve step associated with the resource must be zero. If the commitment flag is set to 1 for a resource during a specific hour, then the energy dispatch for a specific energy offer curve step must be less than or equal to the energy offer curve step width.

4.2.1.35 Resource Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that the total energy dispatched on a resource is equal to the sum of the energy dispatched on each individual energy offer curve step associated with the resource.

EnergyDispatch(r,h)
=
Σ { EnergyStepDispatch(r,h,st)}
st

4.2.1.36 Maximum Resource Daily Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints limit the maximum amount of energy that can be dispatched on a resource during a specific calendar day to no more than the maximum daily energy limit specified in the offer for that day.

Σ { EnergyDispatch(r,h)}
h∈d
≤
MaxDailyEnergyLimit(r,d)

The sum of the energy dispatched on a specific resource across all twenty-four hours in a specific calendar day must be less than or equal to the maximum daily energy limit specified for that resource and day.

4.2.1.37 Regulating Reserve Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that Regulating Reserve is only dispatched on a resource during an hour where the resource is selected for regulation (i.e., the regulation flag is 1). This constraint also limits the amount of Regulating Reserve that can be dispatched on a resource to fifty percent of the difference between the regulation maximum limit and the regulation minimum limit.

RegResDispatch1(r,h) + RegResDispatch2(r,h)
≤
0.5 * RF(r,h) * [RegMaxLimit(r,h) - RegMinLimit(r,h)]

If the regulation flag is set to 1 for a resource during a specific hour, an amount of regulating reserve may be dispatched on the resource equal to the 50% of the difference between the regulation maximum limit and the regulation minimum limit for the resource during the hour. If the regulation flag is set to 0 for a resource during a specific hour, no Regulating Reserve may be dispatched on the resource during that hour.

Further regulation dispatch constraints ensure that both portions of Regulating Reserve cleared on a resource (the portion cleared considering the regulating reserve total offer cost, and the portion cleared considering the regulation capacity offer cost only), are greater than or equal to zero:

RegResDispatch1(r,h) ≥ 0

and

RegResDispatch2(r,h) ≥ 0

4.2.1.38 Maximum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following maximum limit constraints apply to resources during each hour of a ***Normal Mode*** SCUC execution or during any hour of an ***Emergency Mode*** SCUC execution when there was no shortage detected for that hour during the initial ***Normal Mode*** SCUC iteration.

EnergyDispatch(r,h)
+ RegResDispatch1(r,h) + RegResDispatch2(r,h)
+ ContResDispatch(r,h)
≤
RF(r,h) * RegMaxLimit(r,h)
+ [CF(r,h) – RF(r,h)] * EcoMaxLimit(r,h)
+ MaxLimitViolation(r,h)

If the commitment flag and the regulation flag are set to 1 for the resource during the hour, the sum of the energy, regulating reserve and contingency reserve dispatch must be less than or equal to the regulation maximum limit. If the commitment flag is set to 1 and the regulation flag is set to 0 for the resource during the hour, the sum of the energy, regulating reserve and contingency reserve dispatch must be less than or equal to the economic maximum limit (the regulating reserve dispatch would be 0 in this case). If the commitment flag and regulation flag are both set to 0 for the resource during the hour, then the energy, regulating reserve and contingency reserve dispatch must all sum to zero for the resource during the hour. Since the dispatch variables cannot be negative, they all must be zero. Other constraints prohibit the scenario where the commitment flag is set to 0 and the regulation flag is set to 1.

The following maximum limit constraints apply to resources during any hour of an emergency mode SCUC execution when there was a shortage detected for that hour during the initial normal mode SCUC iteration.

EnergyDispatch(r,h)
+ + RegResDispatch1(r,h) + RegResDispatch2(r,h)
+ ContResDispatch(r,h)
≤
RF(r,h) * RegMaxLimit(r,h)
+ [CF(r,h) – RF(r,h)] * EcoMaxLimit(r,h)
+ EmerMaxRelease(r,h) * [EmerMaxLimit(r,h) - EcoMaxLimit(r,h)]
+ MaxLimitViolation(r,h)

If the commitment flag is set to 1, the regulation flag is set to 0 and 100% of the emergency maximum operating range is released, the sum of the energy, regulating reserve and contingency reserve dispatch must be less than or equal to the emergency maximum limit (of course the regulating reserve dispatch would be 0 in this case).

4.2.1.39 Minimum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following minimum limit constraints apply to resources during each hour of a ***Normal Mode*** SCUC execution or during any hour of an ***Emergency Mode*** SCUC execution when there was no surplus detected for that hour during the initial ***Normal Mode*** SCUC iteration.

EnergyDispatch(r,h)
- RegResDispatch1(r,h)

≥
RF(r,h) * RegMinLimit(r,h)
+ [CF(r,h) – RF(r,h)] * EcoMinLimit(r,h)
- MinLimitViolation(r,h)

If the commitment flag and the regulation flag are set to 1 for the resource during the hour, the energy dispatch less the portion of regulating reserve dispatch based on total offer must be greater than or equal to the regulation minimum limit. If the commitment flag is set to 1 and the regulation flag is set to 0 for the resource during the hour, the energy dispatch less the portion of regulating reserve dispatch based on total offer must be greater than or equal to the economic minimum limit (the regulating reserve dispatch would be 0 in this case). If the commitment flag and regulation flag are both set to 0 for the resource during the hour, then the energy dispatch less the portion of regulating reserve dispatch based on total offer must be equal to zero. Since a different constraint forces the regulating reserve dispatch to zero when the regulation flag is set to zero, this constraint will force the energy dispatch to be zero. Other constraints prohibit the scenario where the commitment flag is set to 0 and the regulation flag is set to 1.

The following minimum limit constraints apply to resources during any hour of an ***Emergency Mode*** SCUC execution when there was a surplus detected for that hour during the initial ***Normal Mode*** SCUC iteration.

EnergyDispatch(r,h)
- RegResDispatch1(r,h)
≥
RF(r,h) * RegMinLimit(r,h)
+ [CF(r,h) – RF(r,h)] * EcoMinLimit(r,h)
- EmerMinRelease(r,h) * [EcoMinLimit(r,h) - EmerMinLimit(r,h)]
- MinLimitViolation(r,h)

If the commitment flag is set to 1, the regulation flag is set to 0 and 100% of the emergency minimum operating range is released, the energy dispatch less the portion of regulating reserve dispatch based on total offer must be greater than or equal to the emergency minimum limit (the regulating reserve dispatch would be 0 in this case).

4.2.1.40 Resource Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to quantify and limit the ramping capability of the Resource in the upward direction.

> RampUpCap(r,h)
> <=
> CF(r,h)*[1-IF(r)]*[InputRampRate(r,h)*RampMinutes/60]

RampMinutes is a configurable parameter that represents the allowed Resource ramping time to meet the total ramp requirement. The Resource Ramp Constraints, along with the Ramp Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramp-up capability and ramp-down capability is cleared to satisfy ramping requirements.

4.2.1.41 Resource Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to quantify and limit the ramping capability of the Resource in the downward direction.

> RampDnCap(r,h)
> <=
> CF(r,h)*[1-IF(r)]*[InputRampRate(r,h)*RampMinutes/60]

RampMinutes is a configurable parameter that represents the allowed Resource ramping time to meet the total ramp requirement. The Resource Ramp Constraints, along with the Ramp Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramp capability is cleared to satisfy ramping requirements.

4.2.1.42 Ramp-Up Capability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following ramp-up capability constraints, used to quantify and limit the ramp-up capability of each Resource, apply to on-line resources during each hour of a ***Normal Mode*** SCUC execution or during any hour of an ***Emergency Mode*** SCUC execution when there was no shortage detected for that hour during the initial ***Normal Mode*** SCUC iteration.

RampUpCap(r,h)
<=
CF(r,h)*EcoMaxLimit(r,h)
+ RF(r,h)*[RegMaxLimit(r,h) – EcoMaxLimit(r,h)]
– EnergyDispatch(r,h)
– RampCapReg*[RegResDispatch1(r,h) + RegResDispatch2(r,h)]
– RampCapContRes*ContResDispatch(r,h)

The following ramp-up capability constraints apply to on-line resources during any hour of an ***Emergency Mode*** SCUC execution when there was a shortage detected for that hour during the initial ***Normal Mode*** SCUC iteration

RampUpCap(r,h)
<=
CF(r,h)*EcoMaxLimit(r,h)
+ RF(r,h)*[RegMaxLimit(r,h) – EcoMaxLimit(r,h)]
+ EmerMaxRelease(r,h) *[EmerMaxLimit(r,h) – EcoMaxLimit(r,h)]
– EnergyDispatch(r,h)
– RampCapReg*[RegResDispatch1(r,h) + RegResDispatch2(r,h)]
– RampCapContRes*ContResDispatch(r,h)

The Ramp Capability Constraints, along with the Resource Ramp Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-

Wide Ramp-Down Requirements are respected; that is, that sufficient ramp capability is cleared to satisfy ramping requirements. RampCapReg and RampCapContRes are configurable Boolean parameters that determine whether cleared Regulating Reserves and/or cleared Contingency Reserves, respectively, are considered in the Ramp-Up Capability and Ramp-Down Capability Constraints.

4.2.1.43 Ramp-Down Capability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following ramp-down capability constraints, used to quantify and limit the ramp-down capability of each Resource, apply to resources during each hour of a ***Normal Mode*** SCUC execution or during any hour of an ***Emergency Mode*** SCUC execution when there was no surplus detected for that hour during the initial ***Normal Mode*** SCUC iteration.

RampDnCap(r,h)
<=
EnergyDispatch(r,h)
– RampCapReg*RegResDispatch1(r,h)
– CF(r,h)*EcoMinLimit(r,h)
– RF(r,h)*[RegMinLimit(r,h) – EcoMinLimit(r,h)]

The following ramp-down capability constraints apply to resources during any hour of an ***Emergency Mode*** SCUC execution when there was a surplus detected for that hour during the initial ***Normal Mode*** SCUC iteration

RampDnCap(r,h)
<=
EnergyDispatch(r,h)
– RampCapReg*RegResDispatch1(r,h)
– CF(r,h)*EcoMinLimit(r,h)
– RF(r,h)*[RegMinLimit(r,h) – EcoMinLimit(r,h)]
+ EmerMinRelease(r,h) * [EcoMinLimit(r,h) – EmerMinLimit(r,h)]

The Ramp-Down Capability Constraints, along with the Resource Ramp Constraints, Ramp-Up Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramping capability is cleared to satisfy ramping requirements. RampCapReg is a configurable Boolean parameter that determines whether cleared Regulating Reserves is considered in the Ramp-Up Capability and Ramp-Down Capability Constraints.

4.2.1.44 Long-Term Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to limit the increase in energy dispatch on a specific resource from one hour to the next based on ramp-up capability.

IF { h > 1 and CF(r,h-1)=1 **}**
EnergyDispatch(r,h)
≤
EnergyDispatch(r,h-1)
+ [1- SU(r,h)] * 60 * LTSCUCRampUpRate(r,h)
+ SU(r,h) * 60 * LTSCUCSURampRate(r,h)
ELSE IF { h > 1 **}**
EnergyDispatch(r,h)
≤
EcoMinLimit(r,h) + 30 * LTSCUCSURampRate(r,h)
ELSE IF { InitialOnStatus(r) = 0 **}**
EnergyDispatch(r,h)
≤
EcoMinLimit(r,h) + 30 * LTSCUCSURampRate(r,h)
END IF

If a resource is started in a specific hour, the long-term SCUC start-up ramp rate must be used to ensure a resource can achieve an output at the appropriate minimum limit at the beginning of the hour. In the first hour of the SCUC period, the long-term SCUC ramp-up constraint only applies to resources that are started during the first hour.

4.2.1.45 Long-Term Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints are used to limit the decrease in energy dispatch on a specific resource from one hour to the next based on ramp-down.

IF { h > 1 **}**
EnergyDispatch(r,h)
≥
EnergyDispatch(r,h-1)
- CF(r,h) * 60 * LTSCUCRampDownRate(r,h)
- [1-CF(r,h)] * 60 * LTSCUCSDRampRate(r,h)
END IF

If a resource is not committed in a specific hour, the long-term SCUC shut-down ramp rate must be used to ensure a resource can achieve a zero output at the beginning of the hour. This constraint does not apply to the first hour of the SCUC period.

4.2.1.46 Contingency Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Contingency Reserve dispatched on a resource during an hour based on ramp capability.

[ContResRampMult / ContResDeployTime]* ContResDispatch(r,h)
≤
InputRampRate(r,h)
+ ContResRampViolation(r,h)

The Contingency Reserve ramp multiplier is a tuning parameter that determines the percentage of cleared Contingency Reserve that should be deployable within the Contingency Reserve Deployment Time.

4.2.1.47 Regulating Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve dispatched on a resource during an hour based on ramp capability.

[RegRampMult/RegResponseTime]*[RegResDispatch1(r,h)+RegResDispatch2(r,h)]
≤
InputRampRate(r,h)
+ RegRampViolation(r,h)

The Regulating Reserve ramp multiplier is a tuning parameter that determines the percentage of cleared Regulating Reserve that should be deployable within the Regulation Response Time.

4.2.1.48 Maximum Resource Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve that can be dispatched on a single resource) in a specific hour to a maximum percentage of the market-wide Regulating Reserve requirement for that hour.

RegResDispatch1(r,h) + RegResDispatch2(r,h)
≤
MaxRegResFactor * MWRegReq(h)
+ MaxResourceRegViolation(r,h)

4.2.1.49 Maximum Resource Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Contingency Reserve that can be dispatched on a single resource in a specific hour to a maximum percentage of the market-wide Contingency Reserve requirement.

ContResDispatch(r,h)
≤
MaxContResFactor * MWContResReq(h)
+ MaxResourceContResViolation(r,h)

4.2.1.50 Maximum Resource Short Term Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Short Term Reserve that can be dispatched on a single resource in a specific hour to a maximum percentage of the market-wide Contingency Reserve requirement.

OnlineSTRResDispatch(r,h) + OfflineSTRResDispatch(r,h)
≤
MaxSTRResFactor * MWSTRReq(h)
+ MaxResourceSTRResViolation(r,h)

4.2.1.51 Self-Scheduled Energy Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the energy dispatched on a resource is greater than or equal to the self-scheduled energy on the resource if the resource is committed and the Energy Dispatch status is set to ***Self Schedule***.

EnergyDispatch(r,h)
≥
CF(r,h) * SSEnergyStatus(r,h) * SSEnergyMW(r,h)
- SSEnergyDeficit(r,h)

Energy self-schedules are enforced only in hours when a resource is committed and the resource Energy Dispatch Status is set to ***Self Schedule***. This constraint does not restrict the dispatch of energy above the self-schedule.

4.2.1.52 Self-Scheduled Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the portion of Regulating Reserve based on total offer dispatched on a resource is greater than or equal to the self-scheduled regulating reserve on the resource if the resource is committed and the Regulating Reserve Dispatch Status is set to ***Self Schedule***.

RegResDispatch1(r,h)
≥
CF(r,h) * SSRegResStatus(r,h) * SSRegResMW(r,h)
- SSRegResDeficit(r,h)

Regulating Reserve self-schedules are enforced only in hours when a resource is committed and the resource Regulating Reserve Dispatch Status is set to ***Self Schedule***. This constraint does not restrict the dispatch of regulating reserve above the self-schedule.

4.2.1.53 Self-Scheduled Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the Contingency Reserve dispatched on a committed resource is greater than or equal to the self-scheduled Contingency Reserve on the resource if the resource is committed and the Spinning Reserve Dispatch Status and/or On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule***.

ContResDispatch(r,h)
≥
CF(r,h) * SSSpinResStatus(r,h) * SSSpinResMW(r,h) * SpinAvailability(r,h)
+ CF(r,h) * SSOnLineSupResStatus(r,h) * SSOnLineSupResMW(r,h)
* [SupAvailability(r,h) - SpinAvailability(r,h)]
- SSContResDeficit(r,h)

Spinning Reserve self-schedules are enforced only in hours when a resource is committed, the resource Spinning Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to supply Spinning Reserve. On-Line Supplemental Reserve self-schedules are enforced only in hours when a resource is committed, when the resource On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule***, the resource is available to supply Supplemental Reserve and the resource is not available to supply Spinning Reserve. This constraint does not restrict the dispatch of Contingency Reserve above the self-schedule.

4.2.1.54 Self Scheduled Off-Line Supplemental Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the off-line supplemental reserve dispatched on an uncommitted resource is greater than or equal to the self-scheduled contingency reserve on the resource if the resource is uncommitted and the Off-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule***.

OffLineSupResDispatch(r,h)
≥
[1 - CF(r,h)] * SSOffLineSupResStatus(r,h) * SSOffLineSupResMW(r,h)
* OffLineSupAvailability(r,h)
- SSOffLineSupResDeficit(r,h)

Off-Line Supplemental Reserve self-schedules are enforced only in hours when a resource is not committed, when the resource Off-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to supply Supplemental Reserve. This constraint does not restrict the dispatch of Off-Line Supplemental Reserve above the self-schedule.

4.2.1.55 Online STR Clearing Prior to Shutdown Constraint

Constraint Classification: Good Utility Practice

Constraint Type: Hard LE

Resources scheduled to come offline within the Short Term Reserve response period are not available to provide response for the required Short Term Reserve response period. Under some conditions, it may be desirable to modify the commitment schedule, such as extending a resource commitment, to ensure there is sufficient capacity to provide the needed reliability over the Short Term Reserve response period.

$$\sum_{h1=h_{1st\ overlap}}^{h-1} \{OnlineSTRResDispatch(r, h1)\}$$

$$\le CF(r,h) * \sum_{h1=h_{1st\ overlap}}^{h-1} \{EcoMaxLimit(r,h1) - EcoMinLimit(r,h1)\}$$

$h_{1st\ overlap}$ indicates the earliest hour which is fully or partially within the STR response period of the beginning of hour h.

4.2.2 Demand Response Resource – Type I Constraints

4.2.2.1 Commitment Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for commitment during a specific hour in order to be committed in that hour.

$$CF(r,h) \le CommitAvailability(r,h)$$

If the commitment availability of a specific resource is 0 during a specific hour, the commitment flag for that resource and hour must also be 0. If the commitment availability for a specific resource is 1 during a specific hour, the commitment flag for that resource and hour may be 0 or 1 based on economics and other constraints.

4.2.2.2 Regulation Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints prevent a Demand Response Resource - Type I from being selected to supply Regulating Reserve during a specific hour.

RF(r,h)

=
0

4.2.2.3 Contingency Reserve Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for Spinning Reserve or Supplemental Reserve in a specific hour in order to be dispatched for Contingency Reserve during that hour.

ContResDispatch(r,h)
≤
TargetDemRedLevel(r,h) * SpinAvailability(r,h)
+ TargetDemRedLevel(r,h) * [SupAvailability(r,h) - SpinAvailability(r,h)]

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during a specific hour, the contingency reserve dispatched on that resource during that hour must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a specific resource is 1during a specific hour, the contingency reserve dispatched on that resource may be as high as the targeted demand reduction level, based on economics and other constraints.

4.2.2.4 Off-Line Supplemental Reserve Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints require a Demand Response Resource - Type I from dispatching off-line Supplemental Reserve during any hour.

OffLineSupResDispatch(r,h)
=
0

4.2.2.5 Off-Line Short Term Reserve Dispatch Constraints

Constraint Classification: Physical

Constraint Type: LE

The following constraints ensure that Short Term Reserve is only dispatched on a resource during an hour where the resource is not committed (i.e., the commitment flag is 0). This constraint also limits the amount of Short Term Reserve that can be dispatched on a resource during an hour to the targeted demand reduction level of the resource during that hour.

> OfflineSTRResDispatch (r,h)
> ≤
>
> [1 - CF(r,h)] * TargetDemRedLevel(r,h) * STROfflineAvailability(r,h)

4.2.2.6 Initial Hour Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to the first hour of the SCUC period only and require the start-up flag for a specific resource to be 1 in the first hour of the SCUC period if that resource is initially off-line and is then committed in the first hour of the SCUC period.

> SU(r,1)
> ≥
> CF(r,1)
> - InitialOnStatus(r)

If a resource is initially off-line and the commitment flag for that resource is set to 1 in the first hour of the SCUC period, the start-up-flag for that resource must also be set to 1 in the first hour of the SCUC period. Otherwise, economics will force the start-up flag to be set to 0 for that resource in the first hour of the SCUC period.

4.2.2.7 Hourly Start-Up/Shut-Down Commitment Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to all hours subsequent to the first hour of the SCUC period, and require the value of the Start-Up flag less the value of the Shut-Down flag for a given resource in a given hour to be equal to the Commitment Flag for the resource and hour less the Commitment flag for the resource in the previous hour.

SU(r,h) – SD(r,h)
=
CF(r,h)
- CF(r,h-1)

Together, the Hourly Start-Up/Shut-Down Commitment constraints and the Hourly Start-Up/Shut-Down constraints ensure that any change of commitment flag CF(r,h) between two adjacent hours will set either the SU(r,h) or the SD(r,h) flag to the value 1.

4.2.2.8 Hourly Start-Up/Shut-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to all hours subsequent to the first hour of the SCUC period, and require that the sum of the Start-Up flag and the Shut-Down flag for the resource and hour to be less than or equal to one. A resource can Start-Up or Shut-Down in a given hour, but not both.

SU(r,h) + SD(r,h) ≤ 1

Together, the Hourly Start-Up/Shut-Down Commitment constraints and the Hourly Start-Up/Shut-Down constraints ensure that any change of commitment flag CF(r,h) between two adjacent hours will set either the SU(r,h) or the SD(r,h) flag to the value 1.

4.2.2.9 Initial Hour Shut-Down Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to the first hour of the SCUC period only and requires the shut-down flag for a specific resource to be 1 in the first hour of the SCUC period if that resource is initially on-line and is then decommitted in the first hour of the SCUC period.

SD(r,1)
≥
InitialOnStatus(r)
- CF(r,1)

If a resource is initially on-line and the commitment flag for that resource is set to 0 in the first hour of the SCUC period, the shut-down-flag for that resource must be set to 1 in the first hour of the SCUC period. This constraint does not restrict the value of the shut-down flag for other conditions. However, the shut-down flag is only relevant in the formulations (i.e., minimum down-time constraints) when an actual shut-down occurs.

4.2.2.10 Initial Minimum Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints are used to enforce the minimum interruption time of a resource at the beginning of the SCUC period if the resource is initially on-line.

IF { h + InitialOnHours(r) < MinIntTime(r)**}**
CF(r,h)
≥
InitialOnStatus(r)
END IF

If the resource is initially on-line and the minimum interruption time has not expired at the beginning of the SCUC period, this constraint ensures that the resource is committed until the minimum interruption time expires.

4.2.2.11 Initial Minimum Non-Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the minimum non-interruption time of a resource at the beginning of the SCUC period if the resource is initially off-line.

IF { h + InitialOffHours(r) < MinNonIntTime(r)**}**
CF(r,h)
≤
InitialOnStatus(r)
END IF

If the resource is initially off-line and the minimum non-interruption time has not expired at the beginning of the SCUC period, this constraint ensures that the resource is not committed until the minimum non-interruption time expires.

4.2.2.12 Minimum Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the minimum interruption time of a resource for the start-up of a resource in a specific hour.

$$SU(r,h) \leq \sum_{h'=h}^{h+MinCommitTime(r,h)-1} \{ CF(r,h) \} / MinCommitTime(r,h)$$

This constraint ensures that when a resource is started, it will be subsequently committed for the lesser of the minimum interruption time or the remainder of the SCUC period.

4.2.2.13 Minimum Non-Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the minimum non-interruption time of a resource for the shut-down of a resource in a specific hour.

$$SD(r,h) \leq \sum_{h'=h}^{h+MinDecommitTime(r,h)-1} \{1 - CF(r,h)\} / MinDecommitTime(r,h)$$

This constraint ensures that when a resource is shut down, it will not be subsequently committed for the lesser of the minimum non-interruption time or the remainder of the SCUC period.

4.2.2.14 Initial Maximum Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints apply only in the first hour of the SCUC period and are used to ensure a resource is not committed in the first hour of the SCUC period if the initial on hours associated with the resource exceed the maximum interruption time of the resource.

IF { InitialOnHours(r) ≥ MaxIntTime(r)**}**

$$CF(r,1) = 0$$

END IF

4.2.2.15 Maximum Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the maximum interruption time of a resource.

IF { h > MaxIntTime(r)**}**

h
Σ { CF(r,h')}
h' = h-MaxIntTime(r)
≤
MaxIntTime(r)

ELSE IF { InitialOnStatus(r) = 1 **}**

h
Σ{ CF(r,h')}
h'=1
+ InitialOnHours(r)
≤
MaxIntTime(r)

END IF

This constraint ensures that a resource will not be committed in a specific hour if commitment in that hour causes the resource to exceed its maximum interruption time.

4.2.2.16 Contingency Reserve Minimum Non-Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following hard constraints are used to ensure contingency reserve is not dispatched on a resource prior to the expiration of the minimum non-interruption time of the resource.

IF { MinNonIntTime(r) ≥ h – InitialOnHours **}**

ContResDispatch(r,h)
≤
InitialOnStatus(r) * TargetDemRedLevel(r,h)

ELSE

h+ MinNonIntTime (r)-1
Σ ContResDispatch(r,h')
h'=h
≤

h+ MinNonIntTime (r)-1
[1-CF(r,h-1)] * Σ { TargetDemRedLevel (r,h')}
h'=h

END IF

4.2.2.17 Short Term Reserve Minimum Non-Interruption Time Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following hard constraints are used to ensure Contingency Reserve is not dispatched on a resource prior to the expiration of the minimum non-interruption time of the resource.

IF { MinNonIntTime(r) ≥ h – InitialOnHours **}**
OffLineSTRResDispatch(r,h)
≤
InitialOnStatus(r) * TargetDemRedLevel(r,h)
ELSE
h+ MinNonIntTime (r)-1
Σ OffLineSTRResDispatch(r,h')
h'=h
≤
h+ MinNonIntTime (r)-1
[1-CF(r,h-1)] * Σ { TargetDemRedLevel (r,h')}
h'=h
END IF

4.2.2.18 First Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints are used to set the first start-up flag for a specific resource in a specific hour where the first start-up flag indicates the first start-up of the SCUC period.

IF { h > 1 **}**

FirstSU(r,h)
≥
SU(r,h)
h-1
- Σ { SU(r,h')}
h'=1
ELSE
FirstSU(r,1)
≥
SU(r,1)
END IF

If the start-up flag for a resource in a specific hour is set to 1 and the start-up flag is not set for the resource in any of the preceding hours of the SCUC period, then the first start-up flag will set to 1 for the resource during that hour as well.

4.2.2.19 Start-Up Notification Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to disallow a start-up in a SCUC period in any hour where the start-up time plus the start-up notification time would not be honored based on the anticipated posting time of the Day-Ahead Energy and Operating Reserve Market results (typically 17:00 the day before the operating day).

IF { SUTime(r,h) + SUNotTime(r,h) > h + PostingPeriod – 1 }
SU(r,h)
≤
1
- FirstSU(r,h)
END IF

If the number of hours from the Day-Ahead Energy and Operating Reserve Market posting time to the beginning of hour h is less than the start-up time plus the start-up notification time of a specific resource, then a start-up cannot be allowed for the resource during this hour, and this constraint will not allow both the start-up and first start-up flags to be set to 1.

4.2.2.20 Maximum Daily Starts Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to enforce the maximum number of daily starts allowed for a resource.

$$\sum_{h \in d} SU(r,h) \leq MaxDailyStarts(r,d)$$

A resource cannot have more start-up flags set to 1 in a day then the maximum number of daily starts specified in the offer.

4.2.2.21 Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that the energy dispatch associated with a specific energy offer curve step is equal to the targeted demand reduction level or zero if the resource is not committed.

$$EnergyDispatch(r,h) = CF(r,h) * TargDemRedLevel(r,h)$$

If the commitment flag is set to 0 for a resource during a specific hour, then the energy dispatch for the resource must be zero. If the commitment flag is set to 1 for a resource during a specific hour, then the energy dispatch for the resource is equal to the targeted demand reduction level.

4.2.2.22 Regulating Reserve Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that no regulating reserve is dispatched on a Demand Response Resource- Type I:

RegResDispatch1(r,h)
=
0
RegResDispatch2(r,h)
=
0

4.2.2.23 Contingency Reserve Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that contingency reserve is only dispatched on a resource during an hour where the resource is not committed (i.e., the commitment flag is 0). This constraint also limits the amount of contingency reserve that can be dispatched on a resource during an hour to the targeted demand reduction level of the resource during that hour.

ContResDispatch(r,h)
≤
[1 - CF(r,h)] * TargetDemRedLevel(r,h)

If the commitment flag is set to 0 for a resource during in a specific hour, an amount of contingency reserve may be dispatched on the resource up to the targeted demand reduction level of the resource during that hour. If the commitment flag is set to 1 for a resource during a specific hour, no contingency reserve may be dispatched on that resource during that hour.

4.2.2.24 Resource Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints are used to quantify and limit the ramping capability of the Resource in the upward direction.

RampUpCap(r,h)
=
0

The Resource Ramp Constraints, along with the Ramp Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramp capability is cleared to satisfy ramping requirements. The ramp-up capability on a DRR-Type I Resource is equal to zero.

4.2.2.25 Resource Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints are used to quantify and limit the ramping capability of the Resource in the downward direction.

RampDnCap(r,h)
=
0

The Resource Ramp Constraints, along with the Ramp Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramp capability is cleared to satisfy ramping requirements. The ramp-up capability on a DRR-Type I Resource is equal to zero.

4.2.2.26 Maximum Resource Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve that can be dispatched on a single resource in a specific hour to a maximum percentage of the market-wide contingency reserve requirement.

> ContResDispatch(r,h)
> ≤
> MaxContResFactor * MWContResReq(h)
> + MaxResourceContResViolation(r,h)

4.2.2.27 Maximum Resource Short Term Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Short Term Reserve that can be dispatched on a single resource in a specific hour to a maximum percentage of the market-wide Short Term Reserve requirement.

> OfflineSTRResDispatch(r,h)
> ≤
> MaxSTRResFactor * MWSTRReq(h)
> + MaxResourceSTRResViolation(r,h)

4.2.2.28 Self-Scheduled Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the contingency reserve dispatched on an uncommitted resource is greater than or equal to the self-scheduled contingency reserve on the resource if the resource is uncommitted and the Spinning Reserve Dispatch Status and/or Supplemental Reserve Dispatch Status is set to ***Self Schedule***.

ContResDispatch(r,h)
≥
[1 - CF(r,h)] * SSSpinResStatus(r,h) * SSSpinResMW(r,h) * SpinAvailability(r,h)
+ [1 - CF(r,h)] * SSSupResStatus(r,h) * SSSupResMW(r,h)
* [SupAvailability(r,h) - SpinAvailability(r,h)]
- SSContResDeficit(r,h)

Spinning Reserve self-schedules are enforced only in hours when a resource is uncommitted, the resource Spinning Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to supply Spinning Reserve. Supplemental Reserve self-schedules are enforced only in hours when a resource is uncommitted, when the resource Supplemental Reserve Dispatch Status is set to ***Self Schedule***, the resource is available to supply Supplemental Reserve and the resource is not available to supply Spinning Reserve. This constraint does not restrict the dispatch of Contingency Reserve above the self-schedule.

4.2.3 External Asynchronous Resource Constraints

4.2.3.1 Commitment Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints require that a resource be available for commitment in a specific hour in order to be committed in that hour.

CF(r,h)
=
CommitAvailability(r,h)

If the commitment availability of a specific resource is 0 during a specific hour, the commitment flag for that resource and hour must also be 0. If the commitment availability for a specific resource is 1 during a specific hour, the commitment flag for that resource and hour may be 0 or 1 based on economics and other constraints.

4.2.3.2 Regulation Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for regulation a specific hour in order to be selected for regulation during that hour.

RF(r,h)
≤
RegAvailability(r,h)

If the regulation availability of a specific resource is 0 during a specific hour, the regulation flag for that resource and hour must also be 0. If the regulation availability for a specific resource is 1 during a specific hour, the regulation flag for that resource and hour may be 0 or 1 based on economics and other constraints.

4.2.3.3 Contingency Reserve Availability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for Spinning Reserve or Supplemental Reserve in a specific hour in order to be dispatched for Contingency Reserve during that hour.

ContResDispatch(r,h)
≤
[EmerMaxLimit(r,h) - EmerMinLimit(r,h)] * [SpinAvailability(r,h)]
+ [EmerMaxLimit(r,h) - EmerMinLimit(r,h)]
* [SupAvailability(r,h) - SpinAvailability(r,h)]

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during a specific hour, the contingency reserve dispatched on that resource during that hour must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a specific resource is 1 during a specific hour, the contingency reserve dispatched on that resource may be as high as the emergency maximum limit less the emergency minimum limit, based on economics and other constraints. It is important to note that the purpose of this constraint is to prevent contingency reserve from being dispatched on a resource during an hour when neither spinning reserve nor supplemental reserve is available from the resource. Other constraints will likely restrict the contingency reserve dispatch to levels well below what is allowed by this constraint during hours when contingency reserve is available from the resource.

4.2.3.4 Off-Line Supplemental Reserve Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints require prevent an External Asynchronous Resource from dispatching off-line Supplemental Reserve during any hour.

OffLineSupResDispatch(r,h)
=
0

4.2.3.5 On-Line Short Term Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for on-line Short Term Reserve during a specific hour in order to be dispatched for on-line Short Term Reserve during that hour.

OnLineSTRDispatch(r,h)
≤
{ - EnergyDispatch(r,h) - RegResDispatch1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]}
* OnLineSTRAvailabity(r,h)

The following maximum limit constraints apply to resources during any hour of an emergency mode SCUC execution when there was a shortage detected for that hour during the initial normal mode SCUC iteration.

OnLineSTRDispatch(r,h)
≤
{ - EnergyDispatch(r,h) - RegResDispatch1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]
+ EmerMaxRelease(r,h) * [EmerMaxLimit(r,h) - EcoMaxLimit(r,h)] }
* OnLineSTRAvailabity(r,h)

4.2.3.6 On-Line Short Term Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Hard LE
The following on-line Short Term Reserve ramp constraints is used to quantify and limit the cleared on-line Short Term Reserve on each Resource based on ramp rate.

[STRRampMult / STRDeployTime] * OnlineSTRResDispatch(r,h)
<= [1 – CF(r,h)] * InputRampRate(r,h)

4.2.3.7 Regulation Commitment Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a specific resource be committed in a specific hour in order to be considered for regulation for that hour.

RF(r,h)
≤
CF(r,h)

If the commitment flag is 0 for a specific resource and hour, the regulation flag for that resource and hour must also be zero. If the commitment flag is 1 for a specific resource and hour, the regulation flag for that resource and hour may 0 or 1 based on economics and other constraints.

4.2.3.8 Emergency Maximum Regulation Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints apply only in the ***Emergency Mode*** of SCUC and require that a specific resource in a specific hour not be simultaneously selected for regulation and the release of the emergency maximum operating range. These constraints also limit the amount of the emergency maximum operating range to be released to 100%, and require that a resource be committed in a specific hour in order for the resource to be selected for regulation or the release of the emergency maximum operating range during that hour.

RF(r,h)
+ EmerMaxRelease(r,h)
≤
CF(r,h)

If the regulation flag is 1 for a specific resource and hour, then none of the emergency maximum operating range can be released on that resource during that hour. Likewise, if any of the emergency maximum operating range is released on a specific resource during a specific hour, then the regulation flag must be 0 for that specific resource and hour. If a resource is committed during a specific hour, then the regulation flag for that resource may be set to 1 for that hour or up to 100% of the emergency maximum operating range may be released on that resource during that hour based on economics and other constraints. If a resource is not committed during a specific hour, then the regulation flag cannot be set to 1 on that resource during that hour nor can any of the emergency maximum operating range be released on that resource during that hour.

4.2.3.9 Energy Step Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific energy offer curve step is less than or equal to the step width or zero if the resource is not committed:

EnergyStepDispatch(r,h,st)
≤
CF(r,h) * EnergyStepWidth(r,h,st)

If the commitment flag is set to 0 for a resource during a specific hour, then the energy dispatch for each energy offer curve step associated with the resource must be zero. If the commitment flag is set to 1 for a resource during a specific hour, then the energy dispatch for a specific energy offer curve step must be less than or equal to the energy offer curve step width.

4.2.3.10 Resource Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that the total energy dispatched on a resource is equal to the sum of the energy dispatched on each individual energy offer curve step associated with the resource.

EnergyDispatch(r,h)
=
Σ { EnergyStepDispatch(r,h,st)}
st

4.2.3.11 Regulating Reserve Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that regulating reserve is only dispatched on a resource during an hour where the resource is selected for regulation (i.e., the regulation flag is 1). This constraint also limits the amount of regulating reserve that can be dispatched on a resource to fifty percent of the difference between the regulation maximum limit and the regulation minimum limit.

RegResDispatch1(r,h)+RegResDispatch2(r,h)
≤
0.5 * RF(r,h) * [RegMaxLimit(r,h) - RegMinLimit(r,h)]

If the regulation flag is set to 1 for a resource during a specific hour, an amount of regulating reserve may be dispatched on the resource equal to the 50% of the difference between the regulation maximum limit and the regulation minimum limit for the resource during the hour. If the regulation flag is set to 0 for a resource during a specific hour, no regulating reserve may be dispatched on the resource during that hour.

Further regulation dispatch constraints ensure that both portions of regulating reserve cleared on a resource (the portion cleared considering the regulating reserve total offer cost, and the portion cleared considering the regulation capacity offer cost only), are greater than or equal to zero:

RegResDispatch1(r,h) ≥ 0
and
RegResDispatch2(r,h) ≥ 0

4.2.3.12 Maximum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following maximum limit constraints apply to resources during each hour of a ***Normal Mode*** SCUC execution or during any hour of an ***Emergency Mode*** SCUC execution when there was no shortage detected for that hour during the initial ***Normal Mode*** SCUC iteration.

EnergyDispatch(r,h)
+ RegResDispatch1(r,h) + RegResDispatch2(r,h)
+ ContResDispatch(r,h)
≤
RF(r,h) * RegMaxLimit(r,h)
+ [CF(r,h) – RF(r,h)] * EcoMaxLimit(r,h)
+ MaxLimitViolation(r,h)

If the commitment flag and the regulation flag are set to 1 for the resource during the hour, the sum of the energy, regulating reserve and contingency reserve dispatch must be less than or equal to the regulation maximum limit. If the commitment flag is set to 1 and the regulation flag is set to 0 for the resource during the hour, the sum of the energy, regulating reserve and contingency reserve dispatch must be less than or equal to the economic maximum limit (of course the regulating reserve dispatch would be 0 in this case). If the commitment flag and regulation flag are both set to 0 for the resource during the hour, then the energy, regulating reserve and contingency reserve dispatch must all sum to zero for the resource during the hour. Since the dispatch variables cannot be negative, they all must be zero. Other constraints prohibit the scenario where the commitment flag is set to 0 and the regulation flag is set to 1.

The following maximum limit constraints apply to resources during any hour of an emergency mode SCUC execution when there was a shortage detected for that hour during the initial normal mode SCUC iteration.

EnergyDispatch(r,h)
+ RegResDispatch1(r,h) + RegResDispatch2(r,h)
+ ContResDispatch(r,h)
≤
RF(r,h) * RegMaxLimit(r,h)
+ [CF(r,h) – RF(r,h)] * EcoMaxLimit(r,h)
+ EmerMaxRelease(r,h) * [EmerMaxLimit(r,h) - EcoMaxLimit(r,h)]
+ MaxLimitViolation(r,h)

If the commitment flag is set to 1, the regulation flag is set to 0 and 100% of the emergency maximum operating range is released, the sum of the energy, regulating reserve and contingency reserve dispatch must be less than or equal to the emergency maximum limit (of course the regulating reserve dispatch would be 0 in this case).

4.2.3.13 Minimum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following minimum limit constraints apply to resources during each hour.

EnergyDispatch(r,h)
- RegResDispatch1(r,h)
≥
RF(r,h) * RegMinLimit(r,h)
- MinLimitViolation(r,h)

If the regulation flag is set to 1 for the resource during the hour, the energy dispatch less the portion of regulating reserve dispatch based on total offer must be greater than or equal to the regulation minimum limit.

4.2.3.14 Resource Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to quantify and limit the ramping capability of the Resource in the upward direction.

RampUpCap(r,h)
<=
CF(r,h)*[InputRampRate(r,h)*RampMinutes/60]

RampMinutes is a configurable parameter that represents the allowed Resource ramping time to meet the total ramp requirement. The Resource Ramp Constraints, along with the Ramp Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramp capability is cleared to satisfy ramping requirements.

4.2.3.15 Resource Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to quantify and limit the ramping capability of the Resource in the downward direction.

RampDnCap(r,h)
<=
CF(r,h)*[InputRampRate(r,h)*RampMinutes/60]

RampMinutes is a configurable parameter that represents the allowed Resource ramping time to meet the total ramp requirement. The Resource Ramp Constraints, along with the Ramp Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramp capability is cleared to satisfy ramping requirements.

4.2.3.16 Ramp-Up Capability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following ramp-up capability constraints, used to quantify and limit the ramp-up capability of each Resource, apply to on-line resources during each hour of a ***Normal Mode*** SCUC execution or during any hour of an ***Emergency Mode*** SCUC execution when there was no shortage detected for that hour during the initial ***Normal Mode*** SCUC iteration.

RampUpCap(r,h)
<=
CF(r,h)*EcoMaxLimit(r,h)
+ RF(r,h)*[RegMaxLimit(r,h) – EcoMaxLimit(r,h)]
– EnergyDispatch(r,h)
– RampCapReg*[RegResDispatch1(r,h) + RegResDispatch2(r,h)]
– RampCapContRes*ContResDispatch(r,h)

The following ramp-up capability constraints apply to resources during any hour of an ***Emergency Mode*** SCUC execution when there was a shortage detected for that hour during the initial ***Normal Mode*** SCUC iteration

RampUpCap(r,h)
<=
CF(r,h)*EcoMaxLimit(r,h)
+ RF(r,h)*[RegMaxLimit(r,h) – EcoMaxLimit(r,h)]

+ EmerMaxRelease(r,h) *[EmerMaxLimit(r,h) – EcoMaxLimit(r,h)]
– EnergyDispatch(r,h)
– RampCapReg*[RegResDispatch1(r,h) + RegResDispatch2(r,h)]
– RampCapContRes*ContResDispatch(r,h)

The Ramp Capability Constraints, along with the Resource Ramp Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramp capability is cleared to satisfy ramping requirements. RampCapReg and RampCapContRes are configurable Boolean parameters that determine whether cleared Regulating Reserves and/or cleared Contingency Reserves, respectively, are considered in the Ramp-Up Capability and Ramp-Down Capability Constraints.

4.2.3.17 Ramp-Down Capability Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following ramp-down capability constraints, used to quantify and limit the floor-room of each Resource, apply to resources during each hour of a SCUC execution.

RampDnCap(r,h)
<=
EnergyDispatch(r,h)
– RampCapReg*RegResDispatch1(r,h)
– RF(r,h)*RegMinLimit(r,h)

The Ramp-Down Capability Constraints, along with the Resource Ramp Constraints, Ramp-Up Capability Constraints, and the Market-Wide Ramp Capacity Constraints are used to ensure that the Market-Wide Ramp-Up and Market-Wide Ramp-Down Requirements are respected; that is, that sufficient ramping capability is cleared to satisfy ramping requirements. RampCapReg is a configurable Boolean parameter that determines whether cleared Regulating Reserves is considered in the Ramp-Up Capability and Ramp-Down Capability Constraints.

4.2.3.18 Long-Term Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints are used to limit the increase in energy dispatch on a specific resource from one hour to the next based on ramp-up capability.

IF { h > 1 **}**
EnergyDispatch(r,h)
≤
EnergyDispatch(r,h-1)
60 * LTSCUCRampUpRate(r,h)
END IF

4.2.3.19 Long-Term Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints are used to limit the decrease in energy dispatch on a specific resource from one hour to the next based on ramp-down capability.

IF { h > 1 **}**
EnergyDispatch(r,h)
≥
EnergyDispatch(r,h-1)
- 60 * LTSCUCRampDownRate(r,h)
END IF

4.2.3.20 Contingency Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve dispatched on a resource during an hour based on ramp capability.

[ContResRampMult / ContResDeployTime]* ContResDispatch(r,h)
≤
InputRampRate(r,h)
+ ContResRampViolation(r,h)

The contingency reserve ramp multiplier is a tuning parameter that determines the percentage of cleared contingency reserve that should be deployable within the Contingency Reserve Deployment Time.

4.2.3.21 Regulating Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve dispatched on a resource during an hour based on ramp capability.

[RegRampMult / RegResponseTime]* [RegResDispatch1(r,h) + RegResDispatch2(r,h)]
≤
InputRampRate(r,h)
+ RegRampViolation(r,h)

The regulating reserve ramp multiplier is a tuning parameter that determines the percentage of cleared regulating reserve that should be deployable within the Regulation Response Time.

4.2.3.22 Maximum Resource Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve that can be dispatched on a single resource in a specific hour to a maximum percentage of the market-wide Regulating Reserve requirement for that hour.

[RegResDispatch1(r,h) + RegResDispatch2(r,h)]
≤
MaxRegResFactor * MWRegReq(h)
+ MaxResourceRegViolation(r,h)

4.2.3.23 Maximum Resource Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve that can be dispatched on a single resource in a specific hour to a maximum percentage of the market-wide contingency reserve requirement.

ContResDispatch(r,h)
≤
MaxContResFactor * MWContResReq(h)
+ MaxResourceContResViolation(r,h)

4.2.3.24 Maximum Resource Short Term Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Short Term Reserve that can be dispatched on a single resource in a specific hour to a maximum percentage of the market-wide Short Term Reserve requirement.

OnlineSTRResDispatch(r,h)
≤
MaxSTRResFactor * MWSTRReq(h)
+ MaxResourceSTRResViolation(r,h)

4.2.3.25 Self-Scheduled Energy Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the energy dispatched on a resource is greater than or equal to the self-scheduled energy on the resource if the resource is committed and the Energy Dispatch status is set to ***Self Schedule***.

EnergyDispatch(r,h)
≥
CF(r,h) * SSEnergyStatus(r,h) * SSEnergyMW(r,h)
- SSEnergyDeficit(r,h)

Energy self-schedules are enforced only in hours when a resource is committed and the resource Energy Dispatch Status is set to ***Self Schedule***. This constraint does not restrict the dispatch of energy above the self-schedule.

4.2.3.26 Self-Scheduled Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the portion of regulating reserve based on total offer dispatched on a resource is greater than or equal to the self-scheduled regulating reserve on the resource if the resource is committed and the Regulating Reserve Dispatch Status is set to ***Self Schedule***.

RegResDispatch1(r,h)
≥
CF(r,h) * SSRegResStatus(r,h) * SSRegResMW(r,h)
- SSRegResDeficit(r,h)

Regulating Reserve self-schedules are enforced only in hours when a resource is committed and the resource Regulating Reserve Dispatch Status is set to ***Self Schedule***. This constraint does not restrict the dispatch of regulating reserve above the self-schedule.

4.2.3.27 Self-Scheduled Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the contingency reserve dispatched on a committed resource is greater than or equal to the self-scheduled contingency reserve on the resource if the resource is committed and the Spinning Reserve Dispatch Status and/or On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule***.

ContResDispatch(r,h)
≥
CF(r,h) * SSSpinResStatus(r,h) * SSSpinResMW(r,h) * SpinAvailability(r,h)
+ CF(r,h) * SSOnLineSupResStatus(r,h) * SSOnLineSupResMW(r,h)
* [SupAvailability(r,h) - SpinAvailability(r,h)]
- SSContResDeficit(r,h)

Spinning Reserve self-schedules are enforced only in hours when a resource is committed, the resource Spinning Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to supply Spinning Reserve. On-Line Supplemental Reserve self-schedules are enforced only in hours when a resource is committed, when the resource On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule***, the resource is available to supply Supplemental Reserve and the resource is not available to supply Spinning Reserve. This constraint does not restrict the dispatch of Contingency Reserve above the self-schedule.

4.2.3.28 Online Short Term Reserve Clearing Prior to Shutdown Constraint

Constraint Classification: Good Utility Practice

Constraint Type: Hard LE

Resources scheduled to come offline within the Short Term Reserve response period are not available to provide response for the required Short Term Reserve response period. Under some conditions, it may be desirable to modify the commitment schedule, such as extending a resource commitment, to ensure there is sufficient capacity to provide the needed reliability over the STR response period.

$$\sum_{h1=h_{1st\ overlap}}^{h-1} \{OnlineSTRResDispatch(r, h1)\}$$

$$<= CF(r,h) * \sum_{h1=h_{1st\ overlap}}^{h-1} \{EcoMaxLimit(r,h1) – EcoMinLimit(r,h1)\}$$

$h_{1st\ overlap}$ indicates the earliest hour which is fully or partially within the Short Term Reserve response period of the beginning of hour h.

4.2.4 Energy Transaction Constraints

4.2.4.1 Price Sensitive Demand Segment Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific price sensitive demand bid segment is less than or equal to segment MW bid.

$DemSegDispatch(tr,h,sg)$

≤
DemSegMW(tr,h,sg)

4.2.4.2 Dispatchable Import Segment Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific dispatchable import segment is less than or equal to the segment MW offer.

ImportSegDispatch(tr,h,sg)
≤
ImportSegMW(tr,h,sg)

4.2.4.3 Dispatchable Export Segment Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific dispatchable export segment is less than or equal to the segment MW bid.

ExportSegDispatch(tr,h,sg)
≤
ExportSegMW(tr,h,sg)

4.2.4.4 Virtual Supply Segment Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific virtual supply offer segment is less than or equal to the segment MW offer.

VirtualSupSegDispatch(tr,h,sg)
≤
VirtualSupSegMW(tr,h,sg)

4.2.4.5 Virtual Demand Segment Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific virtual demand bid segment is less than or equal to the segment MW bid.

VirtualDemSegDispatch(tr,h,sg)
≤
VirtualDemSegMW(tr,h,sg)

4.2.4.6 Up-to-TUC Transaction Segment Energy Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the energy dispatch associated with a specific up-to-TUC wheel through transaction segment is less than or equal to the segment MW bid.

UpToTUCSegDispatch(tr,h,sg)
≤
UpToTUCSegMW(tr,h,sg)

4.2.5 Reliability Constraints

4.2.5.1 Global Power Balance Constraints

Constraint Classification: Reliability

Constraint Type: Penalized Equality

The global power balance constraints ensure that the net Energy injections into the Network Model during a specific hour equal the net Energy out of the Network Model plus projected losses for that hour.

$$
\begin{aligned}
&\sum_{r} \{ \text{EnergyDispatch}(r,h) \} \\
&+ \sum_{tr} \sum_{sg} \{ \text{ImportSegDispatch}(tr,h,sg) \} \\
&+ \sum_{tr} \sum_{sg} \{ \text{VirtualSupSegDispatch}(tr,h,sg) \} \\
&+ \sum_{tr} \{ \text{FixedImportMW}(tr,h) \} \\
&+ \text{GlobalEnergyShortage}(h) \\
&= \\
&\sum_{tr} \{ \text{FixedDemBidMW}(tr,h) \} * [1 + \text{LossRate}] \\
&+ \sum_{tr} \sum_{sg} \{ \text{DemSegDispatch}(tr,h,sg) \} \\
&+ \sum_{tr} \sum_{sg} \{ \text{ExportSegDispatch}(tr,h,sg) \} \\
&+ \sum_{tr} \sum_{sg} \{ \text{VirtualDemSegDispatch}(tr,h,sg) \} \\
&+ \sum_{tr} \{ \text{FixedExportMW}(tr,h) \} \\
&+ \text{GlobalEnergySurplus}(h)
\end{aligned}
$$

On an hourly basis, the global power balance constraint requires all energy supplied to the market by resources, imports and virtual transactions to equal energy demanded from the market by market load, market loses, exports and virtual transactions.

The global power balance constraint does not consider external generation serving external load and external losses (including Up-To-TUC wheel through transactions) since external generation must balance external load and external losses independently of the MISO market. However, external generation serving external load is modeled in the transmission constraints via the loop flow injection/withdrawal model.

4.2.5.2 Market-Wide Operating Reserve Constraint

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The market-wide Operating Reserve constraints require that the total of the minimum zonal Operating Reserve Requirements (Regulating, Spinning, and Supplemental) in an hour be greater than or equal to the market-wide Operating Reserve requirement for that hour.

$$\sum_{z} \{ ZminRegReq(z,h) \} + \sum_{z} \{ ZminSpinReq(z,h) \} + \sum_{z} \{ ZMinSuppReq(z,h) \} \geq MWORReq(h) - MWOpResShortage(h)$$

4.2.5.3 Market-Wide Regulating plus Spinning Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The market-wide Regulating plus Spinning Reserve constraints require that the sum of the zonal minimum regulating reserve requirements and the zonal minimum spinning reserve requirements in an hour be greater than or equal to the market-wide Regulating plus Spinning Reserve requirement for that hour.

$$\sum_{z} \{ ZMinRegReq(z,h) \} + \sum_{z} \{ ZMinSpinReq(z,h) \} \geq MWRegSpinReq(h)$$

- MWRegSpinResShortage(h)

4.2.5.4 Market-Wide Regulating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Penalized GE

The market-wide Regulating Reserve constraints require that the sum of each Reserve Zone's minimum zonal regulating reserve requirement in an hour be greater than or equal to the market-wide Regulating Reserve requirement for that hour.

Σ { ZminRegReq(z,h)}
z
≥
MWRegReq(h)
- MWRegResShortage(h)

4.2.5.5 Market-Wide Short Term Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Penalized GE

The market-wide Short Term Reserve constraints require that the total supply of Short Term Reserve from the sum of each Reserve Zone's minimum zonal Short Term Reserve requirement in an hour be greater than or equal to the market-wide Short Term Reserve requirement for that hour.

Σ { ZminSTRReq(z,h)}
z
≥
MWSTRReq(h) - MWSTRShortage(h)

4.2.5.6 Market-Wide Ramp-Up Capacity Constraints

Constraint Classification: Reliability

Constraint Type: Penalized GE

The market-wide Ramp-Up Capacity constraints require that the total supply of Ramp-Up Capacity from the sum of each Reserve Zone's minimum zonal Ramp-Up Capacity requirement in an hour be greater than or equal to the market-wide Ramp-Up Capacity requirement for that hour.

Σ { ZminRCUpReq(z,h)}
z
≥ MWRampUpReq(h)*MWRampUpReqScaleFactor(h)
- MWHourlyRampUpViolation(h)

4.2.5.7 Market-Wide Ramp-Down Capacity Constraints

Constraint Classification: Reliability

Constraint Type: Penalized GE

The market-wide Ramp-Down Capacity constraints require that the total supply of Ramp-Down Capacity from the sum of each Reserve Zone's minimum zonal Ramp-Down Capacity requirement in an hour be greater than or equal to the market-wide Ramp-Down Capacity requirement for that hour.

Σ { ZminRCDownReq(z,h)}
z
≥ MWRampDnReq(h)*MWRampDnReqScaleFactor(h)
- MWHourlyRampDnViolation(h)

4.2.5.8 Reserve Procurement Minimum Reserve Zone Regulating Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Regulating Reserve constraints require that the total supply of Regulating Reserve within a reserve zone in an hour be greater than or equal to the minimum reserve zone Regulating Reserve requirement for that reserve zone.

Σ { RegResDispatch1r,h)}

r∈z
≥
ZMinRegReq(z,h)

These constraints require that sum of the Regulating Reserve dispatched within a specific reserve zone during the hour is greater than or equal to the minimum zonal regulating reserve requirement for that reserve zone. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

4.2.5.9 Reserve Procurement Minimum Reserve Zone Regulating plus Spinning Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Regulating plus Spinning Reserve constraints require that the total supply of Regulating plus Contingency Reserve within a reserve zone in an hour be greater than or equal to the minimum reserve zone Regulating plus Spinning Reserve requirement for that reserve zone.

Σ { RegResDispatch1(r,h) + RegResDispatch2(r,h)}
r∈z
+
Σ { ContResDispatch(r,h)*CF(r,h)}
r∈z

≥
ZMinRegReq(z,h)
+
ZMinSpinReq(z,h)

These constraints require that sum of the Regulating Reserve and Contingency Reserves dispatched on all resources within a specific reserve zone during the hour is greater than or equal to the minimum zonal regulating plus spinning reserve requirement for that reserve zone. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

4.2.5.10 Reserve Procurement Minimum Reserve Zone Operating Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Operating Reserve constraints require that the total supply of Operating Reserves within a reserve zone in an hour be greater than or equal to the sum of the minimum reserve zone Regulating Reserve requirement and the minimum reserve zone Regulating plus Spinning Reserve requirement for that reserve zone and that hour.

$$\sum_{r \in z} \{ RegResDispatch1(r,h) + RegResDispatch2(r,h) \}$$

$$+$$

$$\sum_{r \in z} \{ ContResDispatch(r,h) \}$$

$$\geq$$

$$ZMinRegReq(z,h)$$

$$+$$

$$ZMinSpinReq(z,h)$$

$$+$$

$$ZMinSuppReq(z,h)$$

These constraints require that sum of the Regulating Reserve and Contingency Reserves dispatched on all resources within a specific reserve zone during the hour is greater than or equal to the sum of the minimum zonal regulating reserve requirement and the minimum zonal regulating plus spinning reserve requirement for that reserve zone. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

4.2.5.11 Reserve Procurement Minimum Reserve Zone Short Term Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Short Term Reserve constraints require that the total supply of Short Term Reserves within a Reserve Zone in an hour be greater than or equal to the sum of the minimum Reserve Zone Short Term Reserve requirement for that Reserve Zone and that hour.

$$\sum_{r \in z} \{ OnlineSTRResDispatch(r,h) + OfflineSTRResDispatch(r,h) \} \geq ZMinSTRReq(z,h)$$

These constraints require that sum of the Short Term Reserve on all resources within a specific Reserve Zone during the hour is greater than or equal to the sum of the minimum zonal Short Term Reserve requirement. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

4.2.5.12 Ramp Procurement Minimum Reserve Zone Up Ramp Capability Requirement

Constraint Classification: Good Utility Practice

Constraint Type: Hard GE

The ramp procurement minimum Reserve Zone Up Ramp Capability constraints require that the total supply of Up Ramp Capability within a Reserve Zone in an hour be greater than or equal to the minimum Reserve Zone Up Ramp Capability requirement for that Reserve Zone.

$$\sum_{r \in z} \{ RampUpCap(r,h) \} \geq ZMinRCUpReq(z,h)$$

These constraints require that sum of Up Ramp Capability dispatched on all resources within a specific Reserve Zone during the Dispatch Interval is greater than or equal to the minimum zonal Up Ramp Capability requirement for that Reserve Zone. The Ramp procurement minimum reserve zone Up Ramp Capability requirements ensure that cleared Up Ramp Capability are deliverable as needed.

4.2.5.13 Ramp Procurement Minimum Reserve Zone Down Ramp Capability Requirement

Constraint Classification: Good Utility Practice

Constraint Type: Hard GE

The ramp procurement minimum Reserve Zone Down Ramp Capability constraints require that the total supply of Down Ramp Capability within a Reserve Zone in an hour be greater than or equal to the minimum Reserve Zone Down Ramp Capability requirement for that Reserve Zone.

$$\sum_{r \in z} \{ RampDnCap(r,h) \} \geq ZMinRCDownReq(z,h)$$

These constraints require that sum of Down Ramp Capability dispatched on all resources within a specific Reserve Zone during the Dispatch Interval is greater than or equal to the minimum zonal Down Ramp Capability requirement for that Reserve Zone. The Ramp procurement minimum Reserve Zone Down Ramp Capability requirements ensure that cleared Down Ramp Capability are deliverable as needed.

4.2.5.14 Generation-Based Operating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The generation-based Operating Reserve constraints are used to comply with reliability standards that limit the amount of Operating Reserve that can be carried on demand response resources.

IF { SERSSRegResMW(h)< MWRegReq(h)**}**

$$\sum_{r \notin DRR1} \{ RegResDispatch1(r,h) + RegResDispatch2(r,h) \} + \sum_{r \notin DRR1} \{ ContResDispatch(r,h) \}$$

+ Σ { OffLineSupResDispatch(r,h)}
r∉DRR1
≥
MWORReq(h) * GenORReqFactor
- GenOpResShortage(h)

ELSE

MWRegResReq(h)
+ Σ { ClearedRegRes(r,h)}

+ Σ { ContResDispatch(r,h)}
r∉DRR1
+ Σ { OffLineSupResDispatch(r,h)}
r∉DRR1
≥
MWORReq(h) * GenORReqFactor
- GenOpResShortage(h)

END IF

These constraints require that the amount of regulating reserve and contingency reserve dispatched on all resources other than Demand Response Resources - Type I must be greater than or equal to the market-wide Operating Reserve requirement multiplied by a generation-based Operating Reserve requirement factor.

4.2.5.15 Generation-Based Regulating plus Spinning Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The generation-based Regulating plus Spinning Reserve constraints are used to limit the amount of Regulating and/or Spinning reserve that can be carried on demand response resources.

IF { SERSSRegResMW(h)< MWRegReq(h)**}**
Σ { RegResDispatch1(r,h) + RegResDispatch2(r,h)}
r∉DRR1
+ Σ { ContResDispatch(r,h) * SpinAvailability(r,h)}

r∉DRR1

≥

MWRegSpinReq(h) * GenRegSpinReqFactor

- GenRegSpinResShortage(h)

ELSE

MWRegResReq(h)

+ Σ { ClearedRegRes(r,h)}

r ≠SER

+ Σ { ContResDispatch(r,h) * SpinAvailability(r,h)}

r∉DRR1

≥

MWRegSpinReq(h) * GenRegSpinReqFactor

- GenRegSpinResShortage(h)

END IF

These constraints require that the amount of regulating reserve and contingency reserve dispatched on all resources that are 1) qualified to provide Regulating Reserve and/or Spinning Reserve and 2) are not Demand Response Resources - Type I, must be greater than or equal to the market-wide Regulating plus Spinning Reserve requirement multiplied by a generation-based Regulating plus Spinning Reserve requirement factor.

The Cleared Regulating Reserve Constraints for Demand Response Resources – Type I (see 4.2.2.2) prevent Demand Response Resources – Type I from clearing Regulating Reserves. Currently, GenRegSpinReqFactor is set such that the Spinning Reserve cleared on qualified Resources other than Demand Response Resources – Type I is greater than or equal to 60%.

4.2.5.16 Generation-Based Regulating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The generation-based Regulating Reserve constraints are used to comply with reliability standards that limit the amount of Regulating Reserve that can be carried on demand response resources.

IF { SERSSRegResMW(h)< MWRegReq(h)**}**

Σ { RegResDispatch1(r,h) + RegResDispatch2(r,h)
r
≥
MWRegReq(h) * GenRegReqFactor
- GenRegResShortage(h)

ELSE

MWRegResReq(h)
+ Σ { RegResDispatch(r,h)}
≥
MWRegReq(h) * GenRegReqFactor
- GenRegResShortage(h)

END IF

These constraints require that the amount of regulating reserve dispatched on all resources that are not Demand Response Resources - Type I to be greater than or equal to the market-wide Regulating Reserve requirement multiplied by a generation-based Regulating Reserve requirement factor.

Since pre-SCUC processing already prohibits Demand Response Resources - Type 1 from supplying Regulating Reserve based on the Tariff rules, **these constraints are unnecessary and have been disabled** in the SCUC algorithm.

As reliability standards continue to be developed and modified, these constraints may need to re-enabled and/or modified accordingly. For example, if a reliability standard were developed restricting the percentage of Regulating Reserve that could be cleared on controllable load to some value less than 100% but greater than 0% of the market-wide Regulating Reserve requirement, this constraint would be re-enabled.

4.2.5.17 Watch List Transmission Flowgate Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Watch list transmission flowgate constraints represent the subset of transmission constraints most likely to bind or violate. These constraints are enforced in the SCUC algorithm to ensure resources are committed as necessary to effectively manage potential congestion on the transmission system. Performance limitations associated with the MIP solver do not allow the full set of SCED transmission constraints to be modeled within SCUC.

$$
\begin{aligned}
&\sum_{r} \{[EnergyDispatch(r,h)][\partial Flow(k,h)/\partial P(r,h)]\} \\
&+ \sum_{tr} \{ ImportSegDispatch(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&+ \sum_{tr} \{ VirtualSupSegDispatch(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&+ \sum_{tr} \{ UpToTucSegDispatch(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&+ \sum_{tr} \{ FixedImportMW(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&+ \sum_{i} \{ LoopFlowInjectionMW(i,h) * \partial Flow(k,h)/\partial P(i,h)\} \\
&- \sum_{tr} \{ DemSegDispatch(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&- \sum_{tr} \{ ExportSegDispatch(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&- \sum_{tr} \{ VirtualDemSegDispatch(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&- \sum_{tr} \{ FixedExportMW(tr,h) * \partial Flow(k,h)/\partial P(tr,h)\} \\
&- \sum_{i} \{ LoopFlowWithdrawalMW(i,h) * \partial Flow(k,h)/\partial P(i,h)\} \\
&\leq \\
&FGLimit(k,h) \\
&+ \sum_{st} TransLimitStepViolation(st,k,h)
\end{aligned}
$$

Together, the left hand side of this constraint is defined as “Flow_SystemEnergySCUC(k,h)”, a useful expression which is used again in the constraints that follow.

4.2.5.18 Sub-Regional Power Balance Constraint

Constraint Classification: Reliability

Constraint Type: Penalized LE

The Sub-Regional Power Balance Constraint represents a net energy injection and withdrawal constraint established to manage intra-regional flows in accordance with applicable seams agreements, coordination agreements, transmission service agreements or operating procedures. This constraint is enforced in the SCUC algorithm to ensure resources are committed as necessary to effectively manage its binding limit.

$$
\begin{aligned}
&\sum_{r} \{[EnergyDispatch(r,h)][InyC(k,r,h)]\} \\
&+ \sum_{tr} \{ ImportSegDispatch(tr,h) * InyC(k, tr, h)\} \\
&+ \sum_{tr} \{ VirtualSupSegDispatch(tr,h) * InyC(k, tr, h)\} \\
&+ \sum_{tr} \{ UpToTucSegDispatch(tr,h) * InyC(k, tr, h)\} \\
&+ \sum_{tr} \{ FixedImportMW(tr,h) * InyC(k, tr, h)\} \\
&- \sum_{tr} \{ DemSegDispatch(tr,h) * InyC(k, tr, h)\} \\
&- \sum_{tr} \{ ExportSegDispatch(tr,h) * InyC(k, tr, h)\} \\
&- \sum_{tr} \{ VirtualDemSegDispatch(tr,h) * InyC(k, tr, h)\} \\
&- \sum_{tr} \{ FixedExportMW(tr,h) * InyC(k, tr, h)\} \\
&\le \\
&FGLimit(k,h) \\
&+ \sum_{st} SubRegLimitStepViolation(st,k,h)
\end{aligned}
$$

4.2.5.19 Reserve Procurement Regulation-Up Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Reserve Procurement Regulation-Up constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Regulating Reserves are deployed in the upward direction.

Flow_SystemEnergySCUC(k,h)
+ Σ ZMinRegReq(z,h) * ZonalRegDepSens(k,z,h)
z
≤
FGLimit(k,h)
+ TransLimitViolationRegUp(k,h)

One Reserve Procurement Regulation-Up constraint exists for each transmission constraint that is selected to be a reserve procurement regulation constraint prior to the market processes. The constraint ensures that the total flow on the flowgate as a result of the system cleared energy, as defined in Section4.2.5.17, plus the sum of the minimum zonal regulating reserve requirements multiplied by the zonal regulation deployment sensitivities, is less than or equal to the flowgate limit. The zonal regulation deployment sensitivity is a ramp-rate weighted average of the sensitivities of the regulation-qualified resources in the zone.

4.2.5.20 Reserve Procurement Regulation-Down Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Reserve Procurement Regulation-Down constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Regulating Reserves are deployed in the downward direction.

Flow_SystemEnergySCUC(k,h)
- Σ ZMinRegReq(z,h) * ZonalRegDepSens(k,z,h)
z
≤
FGLimit(k,h)

+ TransLimitViolationRegDown(k,h)

One Reserve Procurement Regulation-Down constraint exists for each transmission constraint that is selected to be a reserve procurement regulation constraint prior to the market processes. The constraint ensures that the total flow on the flowgate as a result of the system cleared energy, as defined in Section4.2.5.17, minus the sum of the minimum zonal regulating reserve requirements multiplied by the zonal regulation deployment sensitivities, is less than or equal to the flowgate limit. The zonal regulation deployment sensitivity is a ramp-rate weighted average of the sensitivities of the regulation-qualified resources in the zone.

4.2.5.21 Reserve Procurement Contingency Reserve Event Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based Penalized LE

Reserve Procurement Contingency Reserve Event constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when a contingency reserve event takes place for the loss of the largest resource in the zone.

IF { PMaxEvent(z,h) ≥ PmaxThreshold}
IF {(1/SpinImpact) * PMaxEvent(z,h) ≤MWRegSpinReq(h)-MWRegReq(h)**}**
Flow_SystemEnergySCUC(k,h)
-
PMaxEvent(z,h) * ZonalTripSens(k,z,h)
+
RegImpact * { Σ ZMinRegReq(z1,h) * ZonalRegDepSens(k,z1,h)
z1
+
{(1/SpinImpact) * PMaxEvent(z,h)} ÷ [MWRegSpinReq(h)-MWRegReq(h)]}
* { Σ ZMinSpinReq(z1,h) * ZonalSpinDepSens(k,z1,h)}* SpinImpact
z1
≤
FGLimit_CREvent(k,h)
+ TransLimitViolationCREvent(k,h)
ELSE
Flow_SystemEnergySCUC(k,h)
-
PMaxEvent(z,h)* ZonalTripSens(k,z,h)
+
RegImpact * { Σ ZMinRegReq(z1,h) * ZonalRegDepSens(k,z1,h)
z1
+
SpinImpact * { Σ ZMinSpinReq(z1,h) * ZonalSpinDepSens(k,z1,h)
z1
+
{ PMaxEvent(z,h) - SpinImpact * [MWRegSpinReq(h)-MWRegReq(h)]
÷ {[MWOpResReq(h)-MWRegSpinReq(h)]
* { SuppImpact * Σ ZminSuppReq(z1,h) * ZonalSuppDepSens(k,z1,h)}
z1
≤
FGLimit_CREvent(k,h)
+ TransLimitViolationCREvent(k,h)
END IF
ELSE

No constraint is modeled for that transmission constraint and that zone.

END IF

WHERE

PMaxEvent(z,h) is the size of the largest resource in zone z during hour h;

PmaxThreshold is a tuning parameter, a threshold on the size of the largest resource in a zone that triggers the modeling of a Reserve Procurement Contingency Reserve constraint for transmission constraints in the zone;

ZonalTripSens(k,z,h), or the zonal trip sensitivity, is a capacity-weighted average of the sensitivities of the resources available for commitment in the zone during hour h;

ZonalSpinDepSens(k,z,h), or the zonal spin deployment sensitivity, is a ramp-rate weighted average of the sensitivities of the regulation or spin qualified resources in the zone during hour h;

ZonalSuppDepSens(k,z,h), or the zonal supplemental deployment sensitivity, is a weighted average of the sensitivities of resources in the zone that are qualified to provied off-line supplemental reserves, weighted by the ramp rate and the offline response capabilities of each resource during hour h;

RegImpact is a tuning parameter that adjusts the impact on the constraint from regulating reserves;

SpinImpact is a tuning parameter that adjusts the impact on the constraint from spinning reserves;

SuppImpact is a tuning parameter that adjusts the impact on the constraint from supplemental reserves;

FGLimit_CREvent(k,h) is the flow limit on the transmission constraint given the post-contingency system topology.

One Reserve Procurement Contingency Reserve Event constraint exists for each transmission constraint and each reserve zone, provided that the size of the largest contingent event in the zone is greater than a threshold, and only for transmission constraints that have been selected to be reserve procurement contingency constraints prior to the market processes (this statement is represented by the outer “IF” statement in the logic above). The constraints ensure that reserves are deliverable during a contingency reserve event by enforcing that the pre-contingency system flow on the constraint, modified by several terms representing the impacts of regulating reserves, spinning reserves, and supplemental reserves, is less than the limit of the transmission constraint. The modifying terms are slightly different, depending on whether the size of the largest contingent event in the zone is greater than the amount of spinning reserves required for the zone (this statement is represented by the inner "IF" statement in the logic above.

4.2.5.22 Reserve Procurement Short Term Reserve Event Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based Penalized LE

Reserve Procurement Short Term Reserve Event constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when a Short Term Reserve event takes place for the loss of the largest resource in the zone.

Flow_SystenEnergy(k,e,t)
=
Flow_SystemEnergySCUC(k,h)
-
ZonalSTRNeed (e,h)* ZonalTripSens(k,e,h)
+
$\sum_{z}$ STRResponse(z,e,h) * ZonalSTRDepSens(k,z,h)
≤
STRTransLimit (k,h)
+ TransLimitViolationSTREvent(k,e,h)

WHERE

ZonalSTRNeed (e,h), the possible deployment MW for STR if event e happens at hour h. Event e is defined as the largest generation contingency MW for a Reserve Zone. e is the collection for max events for each zone.

ZonalTripSens(k,e,h), zonal STR trip sensitivity, the sensitivity of the largest generation which is tripped in event e for transmission constraint k in hour h.

STRResponse(z,e,h), STR response provided by resources for constraint *k* in zone *z* at hour h. STR Response is less than the sum of all cleared STR in zone z excluding cleared STR on the event contingency generation.

ZonalSTRDepSens(k,z,h), Zonal STR response sensitivity from zone z to constraint k at hour h, calculated as a weighted average of the constraint flow sensitivities of resources in the zone that are qualified to provide STR, weighted by the up ramp rate of online resources and maximum offline STR response of offline resources.

STRTransLimit (k,h), STR transmission constraint maximum flow allowed after STR response for constraint k at hour h .

One Reserve Procurement Short Term Reserve Event constraint exists for each transmission constraint and each Reserve Zone, provided that the size of the largest Short Term Reserve event in the zone is greater than a threshold, and only for transmission constraints that have been selected to be reserve procurement Short Term Reserve constraints prior to the market processes. The constraints ensure that reserves are deliverable during a Short Term Reserve event by enforcing that the pre-contingency system flow on the constraint, modified by several terms representing the impacts of Short Term Reserves, is less than the limit of the transmission constraint.

4.2.5.23 Ramp Procurement Up Ramp Capability Post Deployment Transmission Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Ramp Procurement Up Ramp Capability constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Up Ramp Capability are deployed in the upward direction.

$$FG\_SystemEnergySCED(k,h)$$

$$+ \sum_{z} ZMinRCUpReq(z,h) * ZonalRCUpDepSens(k,z,h)$$

$\leq$

FGLimit(k,h)

+ TransLimitViolationRCUp(k,h)

One Ramp Procurement Up Ramp Capability post deployment transmission constraint exists for each transmission constraint that is selected to be a ramp procurement ramp capability constraint prior to the market processes. The constraint ensures that the total flow on the flowgate because of the system cleared energy, as defined in Section **Error! Reference source not found.**, plus the sum of the minimum zonal up ramp capability requirements multiplied by the zonal up ramp capability deployment sensitivities, is less than or equal to the flowgate limit. The zonal up ramp capability deployment sensitivity is a ramp-rate weighted average of the sensitivities of the ramp capability qualified resources in the zone.

4.2.5.24 Ramp Procurement Down Ramp Capability Post deployment transmission Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Ramp Procurement Down Ramp Capability post deployment transmission constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Ramp Capability are deployed in the downward direction.

FG_SystemEnergySCED(k,h)

$- \sum_{z}$ ZMinRCDownReq(z,h) * ZonalRCDownDepSens(k,z,h)

$\leq$

FGLimit(k,h)

+ TransLimitViolationRCDown(k,h)

One Ramp Procurement Down Ramp Capability constraint exists for each transmission constraint that is selected to be a ramp procurement ramp capability constraint prior to the market processes. The constraint ensures that the total flow on the flowgate as a result of the system cleared energy, as defined in Section **Error! Reference source not found.**, plus the sum of the minimum zonal down ramp capability requirements multiplied by the zonal down ramp capability deployment sensitivities, is less than or equal to the flowgate limit. The zonal down ramp capability deployment sensitivity is a ramp-rate weighted average of the sensitivities of the Ramp Capability qualified resources in the zone.

4.2.5.25 Short Term Reserve Post-Deployment Power Balance Constraint

Constraint Classification: Reliability

Constraint Type: Penalized LE

Post-event power balance constraints maintain power balance with the consideration of Short Term Reservedeployment and zonal events. The post-event power balance will be enforced for each Short Term Reserveevent.

$$\sum_{z} \mathrm{STRResponse}(\mathrm{z},\mathrm{e},\mathrm{h}) + \mathrm{ZNeedViolSTRPos}(\mathrm{e},\mathrm{h}) - \mathrm{ZNeedViolSTRNeg}(\mathrm{e},\mathrm{h}) = \mathrm{ZonalSTRNeed}\ (\mathrm{e},\mathrm{h})\ \forall e$$

$$\mathrm{ZNeedViolSTRPos}(\mathrm{e},\mathrm{h}), \mathrm{ZNeedViolSTRNeg}(\mathrm{e},\mathrm{h}) \geq 0$$

4.2.5.26 Maximum Zonal Short Term Reserve deployment constraint

Constraint Classification: Reliability

Constraint Type: Hard

Short Term Reserveresponse provided by resources in zone *z* for contingency event at time h has to be less than the dynamically calculated zonal requirement.

STRResponse(z,e,h)
<=
ZminSTR(z,h)

4.3 SCUC Emergency Logic

During the ***Normal Mode*** execution of SCUC, an hourly shortage flag, designated as **ShortFlag(h)**, will be set to 1 in any hour where any of the following occurs:

- Global energy shortage or GlobalEnergyShortage(h) > 0
- Market-Wide Operating Reserve Shortage or MWOpResShortage(h) > 0
- Market-Wide Regulating plus Spinning Reserve Shortage or MWRegSpinResShortage(h) > 0
- Market-Wide Regulating Reserve Shortage or MWRegResShortage(h) > 0

During the ***Normal Mode*** execution of SCUC, an hourly surplus flag, designated as **SurplusFlag(h)**, will be set to 1 in any hour where any of the following occur:

- Global energy surplus or GlobalEnergySurplus(h) > 0

When the ***Normal Mode*** execution of SCUC completes, if a shortage or surplus is detected for any hour, that is, if the shortage flag or surplus flag is set to 1 in any hour, then re-execution of SCUC in ***Emergency Mode*** is triggered.

The following logic is used by SCUC when executing in ***Emergency Mode.***

A resource with a Commitment Status of ***Emergency*** in a specific hour may be considered for commitment in that hour if a shortage was detected in at least one hour of the commitment period.

- Off-Line Supplemental Reserve may be dispatched on an uncommitted resource in an hour where the Off-Line Supplemental Reserve Dispatch Status of that resource is set to ***Emergency*** if a shortage was detected in at least one hour of the commitment period.
- The emergency maximum operating range may be released on any resource in any hour where a shortage was detected.
- The emergency minimum operating range may be released on any resource in any hour where a surplus was detected.
- An Electric Storage Resource with a Commitment Status of EmergencyDischarge status in a specific hour will be commited in that hour if a shortage was detected
- An Electric Storage Resource with a Commitment Status of EmergencyCharge status in a specific hour will be commited in that hour if a surplus was detected

The following flags are established by SCUC after a solution is obtained when executing in ***Emergency Mode.***

4.3.1 Emergency Maximum Flag

If EmerMaxRelease(r,h) > 0 for a specific resource in a specific hour indicating that the emergency maximum operating range was utilized by SCUC for that resource and hour, then the emergency maximum flag, designated as **EmerMaxFlag(r,h)**, is set to 1 for that resource and hour.

4.3.2 Emergency Minimum Flag

If EmerMinRelease(r,h) > 0 for a specific resource in a specific hour indicating that the emergency minimum operating range was utilized by SCUC for that resource and hour, then the emergency minimum flag, designated as **EmerMinFlag(r,h)**, is set to 1 for that resource and hour.

4.3.3 Emergency Condition Flag

An hourly emergency condition flag, designated as **EmerCond(h)**, is established by SCUC for each hour and is set as follows:

- If no shortage or surplus conditions exist for the hour, the emergency condition flag is set to 0 for the hour.
- If an energy shortage is detected for the hour, the emergency condition flag is set to 3 for the hour.
- If an operating reserve shortage is detected for the hour, but an energy shortage is not detected for the hour, the emergency condition flag is set to 2 for the hour.
- If no energy or operating shortage is detected for the hour, but emergency capacity is utilized during the hour, the emergency condition flag is set to 1 for the hour.
- If the emergency minimum operating range is released on one or more resources during the hour, the emergency condition flag is set to -1 for the hour.
- If there is an energy surplus during the hour, the emergency condition flag is set to -2 for the hour.

4.4 SCUC Output

The following output is generated by the SCUC algorithm and used as input to the hourly SCED executions in the Day-Ahead Energy and Operating Reserve Market:

- Hourly commitment flags for each resources or **CF(r,h)**
- Hourly regulation flags for each resource or **RF(r,h)**
- Hourly emergency maximum flags for each resource or **EmerMaxFlag(r,h)**
- Hourly emergency minimum flags for each resource or **EmerMinFlag(r,h)**

- Hourly emergency condition flag for each hour or **EmerCond(h)**

5. Pre-SCED Processing

Pre-SCED processing includes calculations performed just prior to each hourly execution of SCED in the Day-Ahead Energy and Operating Reserve Market. Pre-SCED processing establishes the following:

5.1 SCED Day-Ahead Limit Processing

5.1.1 Maximum Limit Calculation

A single maximum limit, designated in the formulations as **MaxLimit(r,h)**, is calculated for each Generation Resource, Demand Response Resource - Type II, Electric Storage Resource and External Asynchronous Resource for a specific hourly SCED execution as follows.

- If a resource was selected for regulation for the hour (i.e., RF(r,h) = 1 from SCUC), the maximum limit for the resource during that hour is set equal to the Regulation Maximum Limit included in the Day-Ahead Limit Set determined for the resource and hour during pre-SCUC processing.
- If a resource was not selected for regulation for the hour (i.e., RF(r,h) = 0 from SCUC), a shortage condition was logged for the hour (i.e., EmerCond(h) > 0 from SCUC) and the emergency maximum range was released on the resource for the hour (i.e., EmerMaxFlag(r,h) = 1 from SCUC), then the maximum limit for the resource during that hour is set equal to the Emergency Maximum Limit included in the Day-Ahead Limit Set determined for the resource and hour during pre-SCUC processing.
- If a resource was not selected for regulation for the hour (i.e., RF(r,h) = 0 from SCUC) and either a shortage condition was not logged for the hour (i.e., EmerCond(h) < 0 from SCUC) and/or the emergency maximum range was not released on the resources for that hour (i.e., EmerMaxFlag(r,h) = 0 from SCUC), then the maximum limit for the resource during that hour is set equal to the Economic Maximum Limit included in the Day-Ahead Limit Set determined for the resource and hour during pre-SCUC processing.

5.1.2 Minimum Limit Calculations

A single minimum limit, designated in the formulations as **MinLimit(r,h)**, is calculated for each Generation Resource, Demand Response Resource - Type II, Electric Storage Resources and External Asynchronous Resource for a specific hourly SCED execution as follows.

- If a resourcewas selected for regulation for the hour (i.e., RF(r,h) = 1 from SCUC), the minimum limit for the resource during that hour is set equal to the Regulation Minimum

Limit included in the Day-Ahead Limit Set determined for the resource and hour during pre-SCUC processing.

- If a resource was not selected for regulation for the hour (i.e., RF(r,h) = 0 from SCUC), a surplus condition was logged for the hour (i.e., EmerCond(h) < 0 from SCUC) and the emergency minimum range was released on the resource for the hour (i.e., EmerMinFlag(r,h) = 1 from SCUC), then the minimum limit for the resource during that hour is set equal to the Emergency Minimum Limit included in the Day-Ahead Limit Set determined for the resource and hour during pre-SCUC processing.
- If a resource was not selected for regulation for the hour (i.e., RF(r,h) = 0 from SCUC) and either a surplus condition was not logged for the hour (i.e., EmerCond(h) > -1 from SCUC) and/or the emergency minimum range was not released on the resource for that hour (i.e., EmerMinFlag(r,h) = 0 from SCUC), then the minimum limit for the resource during that hour is set equal to the Economic Minimum Limit included in the Day-Ahead Limit Set determined for the resource and hour during pre-SCUC processing.

5.1.3 Maximum Energy Limit Calculations

The maximum energy limits, which are designated in the formulations as **MaxEnergyLimit(r,h)** are used in the maximum daily energy constraints in the SCED algorithm. Maximum energy limits are calculated for each resource for each hourly SCED execution.

$$
\begin{aligned}
&\text{MaxEnergyLimit}(r,h)\\
&= \textbf{MAX}\ \textbf{\{}\ \text{MinLimit}(r,h),\\
&\qquad \text{MaxDailyEnergyLimit}(r,d) -\\
&\qquad \left[\sum_{h'=1}^{h-1} \text{ClearedEnergy}(r,h') + \sum_{h'=h+1}^{24} \text{EnergyDispatch}(r,h')\right]
\end{aligned}
$$

5.2 SCED Day-Ahead Ramp Rate Set

The following ramp rates are determined for each Generation Resource, Demand Response Resource - Type II, Electric Storage Resource and External Asynchronous Resource for use in the SCED algorithm:

5.2.1 Long-Term SCED Ramp-Up Rates

Long-term SCED ramp-up rates, which are designated in the formulations as **LTSCEDRampUpRate(r,h)**, are used in the long-term ramp-up constraints in the SCED algorithm. Long-term SCED ramp-up rates are calculated for each resource for each hourly SCED execution (except for the first hourly SCED execution).

5.2.1.1 Scenario 1

For resources committed in the current hour (i.e., CF(r,h) = 1 from SCUC) and committed in the previous hour (i.e., CF(r,h-1) = 1 from SCUC), the long-term SCED ramp-up rate for the resource and hour is set equal to the greater of the following:

- The input ramp rate for the hour
- The minimum limit in the current hour less the energy cleared in the previous hour divided by 60.

5.2.1.2 Scenario 2

For resources committed in the current hour (i.e., CF(r,h) = 1 from SCUC) and not committed in the previous hour (i.e., CF(r,h-1) = 0 from SCUC), the long-term SCED ramp-up rate for the resource and hour is set equal to the greater of the following:

- The input ramp rate for the hour
- The minimum limit in the current hour divided by 60 plus the input ramp rate for the hour.

5.2.1.3 Scenario 3

For resources not committed in the current hour (i.e., CF(r,h) = 0 from SCUC), the long-term SCED ramp-up rate for the resource and hour is set equal to the input ramp rate for the hour.

5.2.2 Long-Term SCED Ramp-Down Rates

Long-term SCED ramp-down rates, which are designated in the formulations as **LTSCEDRampDownRate(r,h)**, are used in the long-term ramp-down constraints in the SCED algorithm. Long-term SCED ramp-down rates are calculated for each resource for each hourly SCED execution (except for the first hourly SCED execution).

5.2.2.1 Scenario 1

For resources committed in the current hour (i.e., CF(r,h) = 1 from SCUC) and committed in the previous hour (i.e., CF(r,h-1) = 1 from SCUC), the long-term SCED ramp-down rate for the resource and hour is set equal to the greater of the following:

- The input ramp rate for the hour
- The energy cleared in the previous hour less the maximum limit in the current hour divided by 60.

5.2.2.2 Scenario 2

For resources not committed in the current hour (i.e., CF(r,h) = 0 from SCUC) but committed in the previous hour (i.e., CF(r,h-1) = 1 from SCUC), the long-term SCED ramp-down rate for the resource and hour is set equal to the greater of the following: The input ramp rate for the hour

- The energy cleared in the previous hour divided by 60.

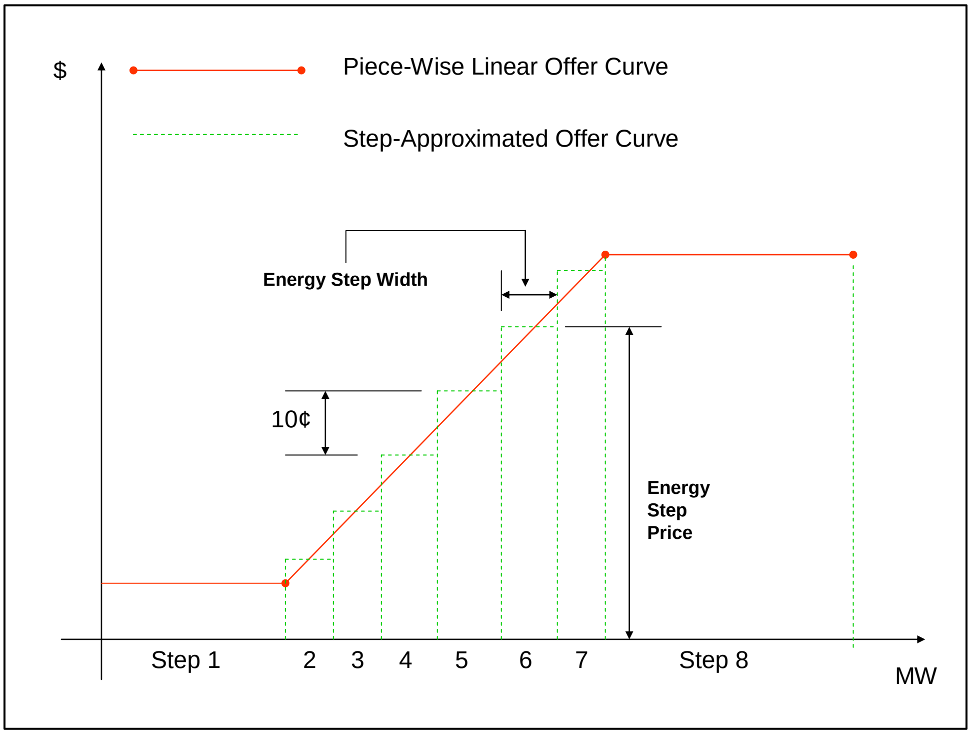
5.2.2.3 Scenario 3

For resources not committed in the previous hour (i.e., CF(r,h-1) = 0 from SCUC), the long-term SCED ramp-down rate for the resource and hour is set equal to the input ramp rate for the hour.

5.3 SCED Energy Offer Curve Linearization

For each resource, if the energy offer curve for the hour is modeled as a piece-wise linear curve, it is converted to an approximated step offer curve for use in the SCED algorithm. The SCED energy offer curve linearization is much more granular than the SCUC offer curve linearization. The SCED energy offer curve linearization creates a new offer curve step for each ten cent ($0.10) increase in the offer curve price, up to a maximum of 100 offer curve steps. Exhibit 5-1 below provides a graphical illustration of the SCED offer curve linearization:

Exhibit 5-1: SCED Energy Offer Curve Linearization Illustration



The energy step width and energy step price of each approximated energy offer curve step are designated in the formulations as **EnergyStepWidth(r,h,st)** and **EnergyStepPrice(r,h,st)** respectively.

5.4 Market-Wide Operating Reserve Demand Curve Construction

Prior to each hourly SCED execution, the following demand curves are constructed. The Market-Wide Operating Reserve Demand Curve is constructed for the hour based on the specification in the Tariff and the Market-Wide Operating Reserve Requirement calculated for the hour during Pre-SCUC processing. The Market-Wide Operating Reserve Demand Curve includes a primal dispatch variable for each demand curve step, designated in the formulations as **MWOpResStepClearing(st,h)**, a MW step width for each demand curve step, designated in the formulations as **MWOpResStepWidth(st,h)** and a price for each demand curve step, designated in the formulations as **MWOpResStepPrice(st,h)**.

All other demand curves are either single step curves (Market-Wide Regulating Reserve Demand Curve and Reserve Zone Regulating Reserve Demand Curves), two step curves (Reserve Zone Operating Reserve Demand Curves), or three-step curves (Market-Wide Regulating and Spinning

Reserve Demand Curve, Reserve Zone Regulating and Spinning Reserve Demand Curves), that can be modeled directly in the SCED formulations.

5.5 SCED Resource Regulating Reserve Total Offer Price

The Regulating Reserve total offer price, designated in the formulations as **RegResOfferPrice(r,h)** is determined for each resource prior to executing the SCED algorithm. The Regulating Reserve total offer price is equal to the sum of the resource's Regulation Capacity offer (in $/MWh), and the Resource's Regulation Mileage Offer (in $/MW) multiplied by the Regulation Deployment Factor (in units of deployments/hour). The Regulation Deployment Factor is needed to convert the mileage offer per MW of movement into an hourly offer. The Regulation Deployment Factor is updated for each calendar Operating Month, based on analysis performed for a one month period ending on the fifteenth of the month prior to the Operating Month. The factor is determined by first calculating the average ratio of deployed Regulating Mileage to cleared Regulating Capacity, averaged across all Resources providing Regulation, and across all Dispatch Intervals. This average is then multiplied by 12 to convert from average deployments per interval to average deployments per hour.

5.6 SCED Contingency Reserve Offer Price

The Contingency Reserve offer price is determined for each resource prior to executing the hourly SCED algorithm. The Contingency Reserve Offer Price is designated in the formulations as **ContResOfferPrice(r,h)**.

5.6.1 Contingency Reserve Offer Price – Generation Resources and Demand Response Resources – Type II

The following logic is used to set the contingency reserve offer price for Generation Resources and Demand Response Resources - Type II for use in the SCED algorithm.

- If a Generation Resources or Demand Response Resources - Type II is available to provide Spinning Reserve per Section 3.4.1 and has been committed for the hour by SCUC, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price.
- If a Generation Resource or Demand Response Resource - Type II is available to provide Supplemental Reserve per Section 3.5.1 but is not available to provide Spinning Reserve per Section 3.4.1, and has been committed for the hour by SCUC, then the Contingency Reserve offer price is set equal to the On-Line Supplemental Reserve offer price.

- If a Generation Resource or Demand Response Resource - Type II is available to provide Off-Line Supplemental Reserve per Section 3.2 and has not been committed for the hour by SCUC, then the Contingency Reserve offer price is set equal to the Off-Line Supplemental Reserve offer price.

5.6.2 Contingency Reserve Offer Price – External Asynchronous Resources

The following logic is used to set the contingency reserve offer price for External Asynchronous Resources for use in the SCED algorithm.

- If an External Asynchronous Resource is available to provide Spinning Reserve per Section 3.4.2, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price.
- If an External Asynchronous Resource is available to provide Supplemental Reserve per Section 3.5.2 but is not available to provide Spinning Reserve per Section 3.4.2, then the Contingency Reserve offer price is set equal to the Supplemental Reserve offer price.

5.6.3 Contingency Reserve Offer Price – Demand Response Resources – Type I

The following logic is used to set the contingency reserve offer price for Demand Response Resources - Type I for use in the SCED algorithm.

- If a Demand Response Resource - Type I is available to provide Spinning Reserve per Section 3.4.3, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price for the hour.
- If a Demand Response Resource - Type I is available to provide Supplemental Reserve per Section 3.5.3 but is not available to provide Spinning Reserve per Section 3.4.3, then the Contingency Reserve offer price is set equal to the Supplemental Reserve offer price for the hour.

5.6.4 Contingency Reserve Offer Price – Electric Storage Resource

The following logic is used to set the Contingency Reserve offer price for Electric Storage Resource for use in the SCED algorithm.

- If an Electric Storage Resource is available to provide Spinning Reserve per Section 3.4.1 and has been committed for the hour, then the Contingency Reserve offer price is set equal to the Spinning Reserve offer price.
- If an Electric Storage Resource is available to provide Supplemental Reserve per Section 3.5.1 but is not available to provide Spinning Reserve per Section 3.4.1, and

has been committed for the hour, then the Contingency Reserve offer price is set equal to the On-Line Supplemental Reserve offer price.

- If an Electric Storage Resource is available to provide Off-Line Supplemental Reserve per Section 3.2 and Commitment Status is AVAILABL for the hour, then the Contingency Reserve offer price is set equal to the Off-Line Supplemental Reserve offer price.

5.7 SCED Offline Short Term Reserve Offer Price

The Offline Short Term Reserve offer price is determined for each resource prior to executing the hourly SCED algorithm. The Off-line Short Term Reserve Offer Price is designated in the formulations as **offlineSTRResOfferPrice(r,h)**.

5.7.1 Offline Short Term Reserve Offer Price – Generation Resources

The following logic is used to set the Off-line Short Term Reserve offer price for Generation Resources for use in the SCED algorithm.

- If a Generation Resources is available to provide offline Short Term Reserve per Section 3.4.1 and has not been committed for the hour by SCUC, then the offline Short Term Reserve offer price is set equal to the Offline Short Term Reserve offer price.

5.7.2 Offline Short Term Reserve Offer Curve – Demand Response Resources – Type I and Type II

The following logic is used to set the Off-line Short Term Reserve offer price curve for Demand Response Resources - Type I and II for use in the SCED algorithm.

If a Demand Response Resource - Type I and II is available to provide offline Short Term Reserve per Section 3.4.3 or Section 3.7.2, then the offline Short Term Reserve offer curve is set based upon participant-submitted values, up to a three segment offer curve and usebidslope flag specified for the hour.

5.8 Bus Admittance Matrix Inversion

The bus admittance matrix for the hour must be inverted prior to executing the SCED algorithm to allow for the formulation of the optimal power flow (OPF) constraints within SCED. The inverted bus admittance matrix elements are designated in the formulations as **InvB(i,j,h)**.

6. SCED Formulations

The Day-Ahead SCED algorithm is executed for each hour of the operating day to:

- Clear Energy, Regulating Reserve, Spinning Reserve and Supplemental Reserve, Up Ramp, Down Ramp Capability and Short Term Reserve on resources
- Clear energy on virtual transactions, dispatchable interchange schedules and price sensitive demands
- Calculate Ex Ante Locational Marginal Prices (LMPs) for Energy
- Calculate Ex Post Market Clearing Prices (MCPs) for Regulating Reserve, Spinning Reserve and Supplemental Reserve, Up Ramp and Down Ramp Capability and Short Term Reserve

The Day-Ahead SCED algorithm uses a Linear Programming (LP) solver. In the formulations that follow, continuous primal variables are shown in a red font and constraint violation variables are shown in a blue font. See Attachment A on Market Optimization Techniques for background information on LP SCED formulations.

6.1 SCED Objective Function

The overall objective function of the SCED algorithm is to minimize the following cost function over a single hour in the operating day:

MINIMIZE { Resource Energy Costs
- Price Sensitive Demand Value
+ Dispatchable Import Costs
- Dispatchable Export Value
+ Virtual Supply Costs
- Virtual Demand Value
- Up-to-TUC Transaction Costs
+ Regulating Reserve Costs
+ Contingency Reserve Costs
+ Off-Line Short Term Reserve Costs
- Market-Wide Operating Reserve Value
- Market-Wide Regulating Reserve Value
- Market-Wide Regulating plus Spinning Reserve Value
- Market-Wide Up Ramp Capability Value
- Market-Wide Down Ramp Capability Value
- Market-Wide Short Term Reserve Value
+ Constraint Violation Penalty Costs**

+ Energy Balance Scaling Penalty Costs***
+ Tie-Breaking Penalty Costs
}

**Note: Applies only when there are opposing constraints
***Note: Applies only under an energy surplus or energy deficit

The cost terms in the objective function above are described as follows.

6.1.1 Resource Energy Costs

Resource energy costs apply only to Generation Resources, Demand Response Resources - Type I and II, Electric Storage Resource and External Asynchronous Resources. Energy costs are expressed mathematically in the SCED objective function as follows:

Resource Energy Costs

$$= \sum_{r} \left\{ \int_{0}^{ClearedEnergy(r,h)} EnergyOfferCurve(r,h,MW)dMW \right\}$$

NOTE: The energy offer curve must be converted to an approximated stepped curve in order to linearize the SCED optimization problem. Each step of the approximated offer curve is then treated as a separate offer and the amount of dispatch within each step is treated as a separate continuous primal variable in the SCED optimization problem. Therefore, the following mathematical expression for Energy Costs is incorporated into the actual SCED objective function:

Energy Costs

$$= \sum_{r} \sum_{st} \{ EnergyStepPrice(r,h,st) * EnergyStepClearing(r,h,st) \}$$

where

ClearedEnergy(r,h)

$$= \sum_{st} \{ EnergyStepClearing(r,h,st) \}$$

6.1.2 Price Sensitive Demand Value

Price sensitive demand value is expressed mathematically in the SCED objective function as follows:

Price Sensitive Demand Value

$$= \sum_{tr} \sum_{sg} \{ DemSegPrice(tr,h,sg) * ClearedDemSeg(tr,h,sg) \}$$

6.1.3 Dispatchable Import Costs

Dispatchable import cost is expressed mathematically in the SCED objective function as follows:

Dispatchable Import Cost

$$= \sum_{tr} \sum_{sg} \{ ImportSegPrice(tr,h,sg) * ClearedImportSeg(tr,h,sg) \}$$

6.1.4 Dispatchable Export Value

Dispatchable export value is expressed mathematically in the SCED objective function as follows:

Dispatchable Export Value

$$= \sum_{tr} \sum_{sg} \{ ExportSegPrice(tr,h,sg) * ClearedExportSeg(tr,h,sg) \}$$

6.1.5 Virtual Supply Cost

Virtual supply cost is expressed mathematically in the SCED objective function as follows:

Virtual Supply Cost

$$= \sum_{tr} \sum_{sg} \{ VirtualSupSegPrice(tr,h,sg) * ClearedVirtualSupSeg(tr,h,sg) \}$$

6.1.6 Virtual Demand Value

Virtual demand value is expressed mathematically in the SCED objective function as follows:

Virtual Demand Value

$$= \Sigma\, \Sigma \{ VirtualDemSegPrice(tr,h,sg) * ClearedVirtualDemSeg(tr,h,sg) \}$$

tr sg

6.1.7 Up-to-TUC Transaction Value

Up-to-TUC transaction value is expressed mathematically in the SCED objective function as follows:

Up to TUC Transaction Value

$$= \sum_{tr} \sum_{sg} \{ UpToTUCSegPrice(tr,h,sg) * ClearedUpToTUCSeg(r,h,sg) \}$$

6.1.8 Regulating Reserve Costs

Regulating Reserve costs apply only to Generation Resources, Demand Response Resources - Type II, Electric Storage Resources and External Asynchronous Resources. Regulating Reserve costs are expressed mathematically in the SCED objective function as follows:

Regulating Reserve Costs

$$= \sum_{r} \{ RegResOfferPrice(r,h) * ClearedRegRes1(r,h) + RegCapOfferPrice(r,h) * ClearedRegRes2(r,h) \}$$

6.1.9 Contingency Reserve Costs

Contingency Reserve costs apply to all resources. Contingency Reserve costs are expressed mathematically in the SCED objective function as follows:

Contingency Reserve Costs

$$= \sum_{r} \{ ContResOfferPrice(r,h) * ClearedContRes(r,h) \}$$

6.1.10 Off-Line Short Term Reserve Costs

Off-Line Short Term Reserve costs apply to uncommitted Generation Resources and Demand Response Resources - Type I and II. Off-Line Short Term Reserve costs are expressed mathematically in the SCED objective function as follows:

Off-Line Short Term Reserve Costs

$$= \sum \sum \{ OffLineSTROfferPrice(r,h) * ClearedOffLineSTR(r,h) \}$$

r h

6.1.11 Market-Wide Operating Reserve Value

Market-Wide Operating Reserve Value is expressed mathematically in the SCED objective function as follows:Market Wide Operating Reserve Value

$$= \int_{0}^{ClearedMWOpRes(h)} MWOpResDemandCurve(h,MW)dMW$$

NOTE: The market-wide operating reserve demand curve is a stepped curve. Therefore, the following mathematical expression for market-wide operating reserve value is incorporated into the actual SCED objective function:

Market Wide Operating Reserve Value

$$= \sum_{st} \{ MWOpResStepPrice(st,h) * MWOpResStepClearing(st,h)\}$$

6.1.12 Market-Wide Regulating Reserve Value

Market-Wide Regulating Reserve Value is expressed mathematically in the SCED objective function as follows:

Market Wide Regulating Reserve Value

$$= \int_{0}^{ClearedMWRegRes(h)} MWRegResDemandCurve(h,MW)dMW$$

NOTE: The market-wide regulating reserve demand curve is a two-step curve (**RegResDemandPrice** per MWhr and $0 per MWhr). Therefore, the following mathematical expression for market-wide regulating reserve value is incorporated into the actual SCED objective function:

Market-Wide Regulating Reserve Value
= RegResDemandPrice * MWRegResStep1Clearing(h)

6.1.13 Market-Wide Regulating plus Spinning Reserve Value

Market-Wide Regulating plus Spinning Reserve Value is expressed mathematically in the SCED objective function as follows:

Market Wide Regulating plus Spinning Reserve Value

$$= \int_{0}^{ClearedMWRegRes(h)+ClearedMWSpinRes(h)} MWRegSpinResDemandCurve(h,MW)dMW$$

NOTE: The market-wide regulating plus spinning reserve demand curve is a three-step curve ($98 per MWhr, $65 per MWhr and $0 per MWhr). Therefore, the following mathematical expression for market-wide regulating plus spinning reserve value is incorporated into the actual SCED objective function:

Market-Wide Regulating plus Spinning Reserve Value

$$= \{(98) * MWRegSpinResStep1Clearing(h) + 65 * MWRegSpinResStep2Clearing(h) + 0 * MWRegSpinResStep3Clearing(h)\}$$

6.1.14 Market Wide Up Ramp Capability value

The Market Wide Up Ramp Capability Value

$$= \int_{0}^{ClearedMWRCUp(di)} MWRCUpDemandCurve(h,MW)dMW$$

NOTE: The market-wide up ramp capability demand curve is a stepped curve. Therefore, the following mathematical expression for market-wide ramp up capability value is incorporated into the actual SCED objective function:

Market-Wide Up Ramp Capability Value

$$= \sum_{st} \{ MWRCUpResStepPrice(st,h) * MWRCUpResStepClearing(st,h)\}$$

6.1.15 Market Wide Down Ramp Capability value

The Market Wide Down Ramp Capability Value

ClearedMWRCDown(di)

$$= \int_{0} MWRCDownDemandCurve(h,MW)dMW$$

NOTE: The market-wide down ramp capability demand curve is $0 penalty one-step curve (down ramp capability demand is not required). Therefore, the following mathematical expression for Down Market-Wide Ramp Capability Value is incorporated into the actual SCED objective function:

Market-Wide Down Ramp Capability Value

$$= 0 * MWRCDownStepClearing(h)$$

6.1.16 Market-Wide Short Term Reserve Value

Market-Wide Short Term Reserve Value is expressed mathematically in the SCED objective function as follows:

Market Wide Short Term Reserve Value

$$= \int_{0}^{ClearedMWSTRRes(h)} MWSTRResDemandCurve(h,MW)dMW$$

NOTE: The market-wide Short Term Reserve demand curve is a stepped curve. Therefore, the following mathematical expression for market-wide Short-Term Reserve value is incorporated into the actual SCED objective function:

Market-Wide Short Term Reserve Value

$$= \sum_{st} \{ MWSTRResStepPrice(st,h) * MWSTRResStepClearing(st,h) \}$$

6.1.17 Opposing Constraint Violation Penalty Costs

Opposing constraint violation penalty costs are included in the SCED objective function to avoid an infeasible solution when opposing constraints exists (see Attachment A on Market Optimization Techniques for more information on addressing infeasible solutions). Constraint violation variables are introduced into the cost minimization objective function with penalty price coefficients. The opposing constraint violation penalty terms are used to ensure the solution satisfies all constraints if possible and/or to prioritize the constraints to determine which constraints are violated under an opposing constraint scenario. The following opposing constraint violation penalty terms are included in the cost minimization objective function of the SCED algorithm:

6.1.17.1 Resource Maximum Limit Violation Cost:

Applies to Generation Resources, Demand Response Resources - Type II, Electric Storage Resources and External Asynchronous Resources:

Resource Maximum Limit Violation Cost

$$= \sum_{r} \{ \text{LimitPenPrice} * \text{MaxLimitViolation}(r,h) \}$$

6.1.17.2 Resource Maximum Energy Limit Violation Cost:

Applies to Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources:

Resource Maximum Energy Limit Violation Cost

$$= \Sigma \{ \text{LimitPenPrice} * \text{MaxEnergyLimitViolation}(r,h) \}$$

6.1.17.3 Resource Maximum Energy Storage Limit Violation Cost:

Applies to Electric Storage Resource:

Resource Maximum Energy Storage Limit Violation Cost

$$=\Sigma\{\text{ESRMaxEnergyStorageViolationPenaltyPrice}*\text{MaxEnergyStorageLimitViolation}(r,h)\}$$

6.1.17.4 Resource Minimum Energy Storage Limit Violation Cost:

Applies to Electric Storage Resource:

Resource Minimum Energy Storage Limit Violation Cost

$$=\Sigma\{\text{ESRMaxEnergyStorageViolationPenaltyPrice}*\text{MinEnergyStorageLimitViolation}(r,h)\}$$

6.1.17.5 Resource Minimum Limit Violation Cost:

Applies to Generation Resources, Demand Response Resources - Type II, Electric Storage Resources and External Asynchronous Resources:

Resource Minimum Limit Violation Cost

$$= \sum_{r} \{ \text{LimitPenPrice} * \text{MinLimitViolation}(r,h) \}$$

6.1.17.6 Resource Ramp Rate Violation Cost:

Applies to Generation Resources, Demand Response Resources - Type II, Electric Storage Resources and External Asynchronous Resources:

Resource Ramp Rate Violation Cost

$$= \sum_{r} \{ \text{RampPenPrice} * \text{LTRampUpViolation}(r,h) \}$$
$$+ \sum_{r} \{ \text{RampPenPrice} * \text{LTRampDownViolation}(r,h) \}$$
$$+ \sum_{r} \{ \text{RampPenPrice} * \text{ContResRampViolation}(r,h) \}$$
$$+ \sum_{r} \{ \text{RampPenPrice} * \text{RegRampViolation}(r,h) \}$$
$$+ \sum_{r} \{ \text{RampPenPrice} * \text{STRRampViolation}(r,h) \}$$
$$+ \sum_{r} \{ \text{RampPenPrice} * \text{RCUpRampViolation}(r,h) \} / 12$$
$$+ \sum_{r} \{ \text{RampPenPrice} * \text{RCDownRampViolation}(r,h) \} / 12$$

6.1.17.7 Generation-Based Regulating Reserve Violation Cost:

Applies to the entire market

Generation Based Regulating Reserve Violation Cost

$$= \text{GenRegShortagePenPrice} * \text{GenRegShortage}(h)$$

6.1.17.8 Generation-Based Regulating plus Spinning Reserve Violation Cost:

Applies to the entire market

Generation Based Regulating plus Spinning Reserve Violation Cost
= GenRegSpinShortagePenPrice * GenRegSpinShortage(h)

6.1.17.9 Generation-Based Operating Reserve Violation Cost:

Applies to the entire market

Generation Based Operating Reserve Violation Cost
= GenOpResShortagePenPrice * GenOpResShortage(h)

6.1.17.10 Transmission Demand Curve Violation Cost:

Applies to each transmission constraint. Each Transmission Constraint consists of a step curve with one or more steps.

Transmission Constraint Demand Curve Violation Cost

$$= \sum_{st} \sum_{k} \{ \text{TransLimitPenPrice}(st,k,h) * \text{TransLimitStepViolation}(st,k,h) \}$$

6.1.17.11 Sub-Regional Demand Curve Violation Cost:

Applies to the Sub-Regional Demand Constraint. The Sub-Regional Demand Constraint consists of a step curve.

Sub-Regional Demand Curve Violation Cost

$$= \sum_{st} \sum_{k} \{ \text{SubRegLimitPenPrice}(st,k,h) * \text{SubRegLimitStepViolation}(st,k,h) \}$$

6.1.17.12 Reserve Procurement Transmission Limit Regulation Up Violation Cost:

Applies to each transmission constraint selected as a reserve procurement constraint.

Reserve Procurement Transmission Limit Regulation Up Violation Cost

$$= \sum_{k} \{[\text{TransLimitRegUpPenPrice} * \text{TransLimitViolationRegUp}(k)]$$

6.1.17.13 Reserve Procurement Transmission Limit Regulation Down Violation Cost:

Applies to each transmission constraint selected as a reserve procurement constraint.

Reserve Procurement Transmission Limit Regulation Down Violation Cost

$$= \sum_{k} \{[\text{TransLimitRegDownPenPrice} * \text{TransLimitViolationRegDown}(k)]\}$$

6.1.17.14 Reserve Procurement Transmission Limit Contingency Reserve Event Violation Cost:

Applies to each transmission constraint selected as a reserve procurement constraint.

Reserve Procurement Transmission Limit Contingency Reserve Event Violation Cost

$$= \sum_{k} \{[\text{TransLimitCREventPenPrice} * \text{TransLimitViolationCREvent}(k)]\}$$

6.1.17.15 Short Term Reserve Post-Deployment Power Balance Constraint Violation Cost:

Applies to each Reserve Zone.

Short Term Reserve Post-Deployment Power Balance Constraint Violation Cost

$$= \sum_{z} \sum_{h} \{[\text{ZneedSTRPenPrice} * (\text{ZNeedViolSTRPos}(z,h) + \text{ZNeedViolSTRNeg}(z,h))]\}$$

6.1.17.16 Reserve Procurement Transmission Limit Short Term Reserve Event Violation Cost:

Applies to each transmission constraint selected as a Short Term Reserve procurement constraint.

Short Term Reserve Procurement Transmission Limit Short Term Reserve Event Violation Cost

$$= \sum_{k} \sum_{h} \text{TotalSTRPenaltyCost}(k,h)$$

,where

TotalSTRPenaltyCost(k,h)
>=
TransLimitSTRPenPrice(k,h)*[TransLimitViolSTR(k,e,h)
+ TransLimitSurplusSTR(k,e,h)]

6.1.17.17 Ramp Procurement Transmission Limit Up Ramp Capability Violation Cost:

Applies to each transmission constraint selected as a ramp procurement constraint.

Ramp Procurement Up Ramp Capability post deployment transmission limit Violation Cost

$$= \Sigma \{[\text{TransLimitRCUpPenPrice} * \text{TransLimitViolationRCUp}(k)]\}$$

6.1.17.18 Ramp Procurement Transmission Limit Down Ramp Capability Violation Cost:

Applies to each transmission constraint selected as a ramp procurement constraint.

Ramp Procurement Down Ramp Capability post deployment transmission limit Violation Cost

$$= \Sigma \{[\text{TransLimitRCDownPenPrice} * \text{TransLimitViolationRCDown}(k)]\}$$

6.1.17.19 Maximum Resource Regulating Reserve Violation Cost:

Applies to each resource

Maximum Resource Regulating Reserve Violation Cost

$$= \sum_{r} \{ \text{MaxResourceRegPenPrice} * \text{MaxResourceRegViolation}(r,h)\}$$

6.1.17.20 Maximum Resource Contingency Reserve Violation Cost:

Applies to each resource

Maximum Resource Contingency Reserve Violation Cost

$$= \sum_{r} \{ \text{MaxResourceContResPenPrice} * \text{MaxResourceContResViolation}(r,h)\}$$

6.1.17.21 Maximum Resource Short Term Reserve Violation Cost:

Applies to each resource

Maximum Resource Short Term Reserve Violation Cost

$$= \sum_{r} \{ MaxResourceSTRResPenPrice * MaxResourceSTRResViolation(r,h) \}$$

6.1.17.22 Maximum Resource Up Ramp Capability Violation Cost:

Applies to each resource.

Maximum Resource Down Ramp Capability Violation Cost

$$= \sum_{r} \{ MaxResourceRCUpPenPrice * MaxResourceRCUPViolation(r,h) \}$$

6.1.17.23 Maximum Resource Down Ramp Capability Violation Cost:

Applies to each resource.

Maximum Resource Down Ramp Capability Violation Cost

$$= \sum_{r} \{ MaxResourceRCDownPenPrice * MaxResourceRCDownViolation(r,h) \}$$

6.1.17.24 Resource Self-Scheduled Energy Violation Cost:

Applies to each resource

Resource Self-Scheduled Energy Violation Cost

$$= \sum_{r} \{ SSEnergyPenPrice * SSEnergyDeficit(r,h) \}$$

6.1.17.25 Resource Self-Scheduled Regulating Reserve Violation Cost:

Applies to each resource

Resource Self-Scheduled Regulating Reserve Violation Cost

$$= \sum_{r} \{ SSRegPenPrice * SSRegDeficit(r,h) \}$$

6.1.17.26 Resource Self-Scheduled Contingency Reserve Violation Cost:

Applies to each resource

Resource Self-Scheduled Contingency Reserve Violation Cost

$$= \sum_{r} \{ SSContResPenPrice * SSContResDeficit(r,h) \}$$

6.1.18 Energy Balance Scaling Penalty Costs

Energy balance scaling penalty costs are used to proportionally scale down the fixed demand bid and fixed exports at every load node when there is an energy supply deficit or proportionally scale down the fixed imports and the minimum limits for all resources when there is an energy supply surplus. That is, the penalties avoid minimum limit constraint violations and instead spread the violations proportionally to all load nodes under an energy supply deficit or to all non-regulating reserves under an energy supply surplus. These penalty costs are used only under extreme and rare conditions.

6.1.18.1 Fixed Demand Bid Scale-Down Penalty Cost:

Fixed Demand Bid Scale Down Penalty Cost

$$= FixDemScalePenPrice * [1 - FixDemScaleFactor(h)]$$

6.1.18.2 Minimum Limit Scale-Down Penalty Cost:

Minimum Limit Scale-Down Penalty Cost

$$= MinLimitScalePenPrice * [1 - MinLimitScaleFactor(h)]$$

6.1.19 Tie-Breaking Penalty Costs

Tie-breaking penalty costs are included in the objective function to ensure fair and equitable clearing of energy and operating reserve when there is more than one optimum solution (See Attachment A on Market Optimization Techniques for a discussion of tie-breaking constraints). The tie-breaking penalty prices are hard coded at $0.000001 to prevent any measurable impact on prices.

6.1.19.1 Energy Tie-Breaking Penalty Costs:

Energy Tie Breaking Penalty Costs

$$= \sum_{e1} \sum_{e2} \{ 0.000001 * EnergyTieBreak1(e1,e2) \}$$

$$+ \sum \sum \{ 0.000001 * EnergyTieBreak2(e1,e2) \}$$

e1 e2

6.1.19.2 Regulating Reserve Tie-Breaking Penalty Costs:

Regulating Reserve Tie Breaking Penalty Costs

$$= \sum_{r1} \sum_{r2} \{ 0.000001 * RegResTieBreak1(r1,r2) \} + \sum_{r1} \sum_{r2} \{ 0.000001 * RegResTieBreak2(r1,r2) \}$$

6.1.19.3 Contingency Reserve Tie-Breaking Penalty Costs:

Contingency Reserve Tie Breaking Penalty Costs

$$= \sum_{r1} \sum_{r2} \{ 0.000001 * ContResTieBreak1(r1,r2) \} + \sum_{r1} \sum_{r2} \{ 0.000001 * ContResTieBreak2(r1,r2) \}$$

6.1.19.4 Short Term Reserve Tie-Breaking Penalty Costs:

Short Term Reserve Tie Breaking Penalty Costs

$$= \sum_{r1} \sum_{r2} \{ 0.000001 * STRResTieBreak1(r1,r2) \} + \sum_{r1} \sum_{r2} \{ 0.000001 * STRResTieBreak2(r1,r2) \}$$

6.2 SCED Constraints

The overall objective function of the SCED algorithm is minimized subject to the following constraints:

> **NOTE:** While the formal constraint representation includes all variables on the LHS and a single constant on the RHS, the SCED constraints below have been arranged in a format that provides the most clarity as to the purpose and function of the constraint.

6.2.1 Generation Resource and Demand Response Resource - Type II Constraints

6.2.1.1 Energy Step Clearing Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific energy offer curve step during a specific hour is less than or equal to the energy step width of the energy offer curve step for the hour or zero if the resource was not committed by SCUC:

EnergyStepClearing(r,h,st)
≤
CF(r,h) * EnergyStepWidth(r,h,st)

If the resource commitment flag for the hour is set to 0 by SCUC, then the cleared energy for each energy offer curve step associated with the resource must be zero. If the resource commitment flag for the hour is set to 1 by SCUC, then the cleared energy for a specific energy offer curve step must be less than or equal to the energy step width of that energy offer curve step.

6.2.1.2 Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that the total energy cleared on a resource during the hour is equal to the sum of the energy cleared on each individual energy offer curve step associated with the resource for the hour.

ClearedEnergy(r,h)
=
$\sum_{st}$ { EnergyStepClearing(r,h,st)}

6.2.1.3 Cleared Regulating Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that regulating reserve is only cleared on a resource during the hour if the resource was selected by SCUC to provide regulating reserve for the hour. This constraint also limits the amount of regulating reserve that can be cleared on a resource during the hour to fifty percent of the difference between the maximum limit and the minimum limit of the resource for the hour.

> ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
> ≤
> 0.5 * RF(r,h) * [MaxLimit(r,h) - MinLimit(r,h)]

If the resource regulation flag is set to 1 for the hour by SCUC, an amount of regulating reserve may be cleared on the resource equal to the 50% of the difference between the maximum limit and the minimum limit for the resource that the hour. If the resource regulation flag is set to 0 for the hour by SCUC, no regulating reserve may be cleared on the resource for the hour.

Further regulation clearing constraints ensure that both portions of regulating reserve cleared on a resource (the portion cleared considering the regulating reserve total offer cost, and the portion cleared considering the regulation capacity offer cost only), are greater than or equal to zero:

> ClearedRegRes1(r,h) ≥ 0
> and
> ClearedRegRes2(r,h) ≥ 0

6.2.1.4 Cleared Contingency Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource either 1) be committed by SCUC and be available for Spinning Reserve or Supplemental Reserve for the hour or 2) not be committed by SCUC and be available for off-line Supplemental Reserve for the hour in order for Contingency Reserve to be cleared on that resource during the hour. In addition, these constraints limit the amount of contingency reserve that can be cleared on a committed resource to a value not more than the difference between the maximum limit of the resource for the hour and the minimum limit of the resource for the hour, or on an uncommitted resource to a value not more than the maximum off-line response limit of the resource for the hour.

> ClearedContRes(r,h)
> ≤
> [CF(r,h)] * [MaxLimit(r,h) - MinLimit(r,h)] * SpinAvailability(r,h)

+ [CF(r,h)] * [MaxLimit(r,h) - MinLimit(r,h)]
    * [SupAvailability(r,h) - SpinAvailability(r,h)]
+ [1-CF(r,h)] * [MaxOffLineResponse(r,h)]
    * [OffLineSupAvailability(r,h)]

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during the hour and the resource has been committed by SCUC, the contingency reserve cleared on that resource for that hour must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a specific resource are 1 during a specific hour and the resource is committed by SCUC for that hour, contingency reserve may be cleared on that resource during the hour, based on economics and other constraints, up to the difference between the maximum limit and minimum limit of the resource for the hour. If the off-line supplemental reserve availability of a specific resource is 0 during the hour and the resource has not been committed by SCUC, the contingency reserve cleared on that resource for that hour must also be 0. If the off-line supplemental reserve availability of a specific resource is 1 during the hour and the resource has not been committed by SCUC, contingency reserve may be cleared on that resource during the hour, based on economic and other constraints, up to the maximum off-line response limit of the resource for the hour.

6.2.1.5 On-Line Short Term Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for on-line Short Term Reserve during a specific hour in order to be dispatched for on-line Short Term Reserve during that hour.

ClearedOnLineSTR (r,h)
≤
{ - ClearedEnergy (r,h) - ClearedRegRes1(r,h)
  + CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]}
  * OnLineSTRAvailabity(r,h)

The following maximum limit constraints apply to resources during any hour of an emergency mode SCED execution when there was a shortage detected for that hour during the initial normal mode SCED iteration.

ClearedOnLineSTR (r,h)
≤
{ - ClearedEnergy (r,h) - ClearedRegRes1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]
+ EmerMaxRelease(r,h) * [EmerMaxLimit(r,h) - EcoMaxLimit(r,h)] }
* OnLineSTRAvailabity(r,h)

6.2.1.6 Off-Line Short Term Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for off-line Short Term Reserve during a specific hour in order to be dispatched for off-line Short Term Reserve during that hour.

ClearedOffLineSTR (r,h)
≤
{[1 – CF(r,h)] * min[MaxOffLineSTR(r,h) , EcoMaxLimit (r,h)]}
* OffLineSTRAvailabity(r,h)

6.2.1.7 Maximum Limit Constraints

Constraint Classification: Physical
Constraint Type: Penalized LE
The following maximum limit constraints apply to resources during the hour.

ClearedEnergy(r,h)
+ ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
+ ClearedContRes(r,h)
≤
CF(r,h) * MaxLimit(r,h)
+ [1 - CF(r,h)] * MaxOffLineResponse(r,h)
+ MaxLimitViolation(r,h)

If the resource commitment flag is set to 1 for the hour by SCUC, the sum of the energy, regulating reserve and contingency reserve cleared on the resource during the hour cannot exceed the maximum limit of the resource for the hour. If the resource commitment flag is set to 0 for the hour by SCUC, the sum of the energy, regulating reserve and contingency reserve cleared on the resource during the hour cannot exceed the maximum off-line response of the resource for the hour (in this scenario the cleared energy and regulating reserve would be zero, and the cleared contingency reserve could only be non-zero if the resource is available for off-line supplemental reserve).

6.2.1.8 Maximum Energy Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following maximum energy limit constraints apply to resources during the hour.

ClearedEnergy(r,h)
≤
MaxEnergyLimit(r,h)
+ MaxEnergyLimitViolation(r,h)

The cleared energy on resource r during hour h must not exceed the maximum available energy for the hour based on the maximum daily energy limit of the resource, cleared energy by SCED during previous hours of the operating day and dispatched energy by SCUC during upcoming hours of the operating day.

6.2.1.9 Minimum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following minimum limit constraints apply to resources during the hour.

ClearedEnergy(r,h) -ClearedRegRes1(r,h)
≥
CF(r,h) * MinLimit(r,h) * MinLimitScaleFactor(h)
- MinLimitViolation(r,h)

If the resource commitment flag is set to 1 for the hour by SCUC, the energy cleared on the resource during the hour less portion of the regulating reserve cleared based on total offer on the resource during the hour must be greater than or equal to the minimum limit of the resource for the hour. If the resource commitment flag is set to 0 for the hour by SCUC, the energy cleared on the resource during the hour less the regulating reserve cleared on the resource during the hour are not restricted by the minimum limit of the resource for the hour.

6.2.1.10 Long-Term Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the increase in cleared energy on a specific resource from the previous hour to the current hour based on ramp-up. SU(r,h) represents the Start-Up flag as provided by the SCUC engine. Though a primal variable during the SCUC execution, it is used only as an input parameter in SCED.

IF { h > 1 **} AND {** EmerCond(h)<3 **} AND {** SU(r,h)**}**
ClearedEnergy(r,h)
≤
ClearedEnergy(r,h-1)
+ 60 * LTSCEDRampUpRate(r,h)
+ LTRampUpViolation(r,h)
ELSE IF { h > 1 **} AND {** EmerCond(h)<3 **}**
ClearedEnergy(r,h)
≤
EcoMinLimit(r,h)
+ 30 * LTSCEDRampUpRate(r,h)
LTRampUpViolation(r,h)
END IF

This constraint does not apply during the first hour of the operating day. During the first hour of a commitment, the Long-Term Ramp-Up Constraints restrict the ramp capability of a resource to one-half its usual hourly capability, to allow the integrated value of the Resource’s output to properly reflect its ramping capability during the first hour of commitment.

6.2.1.11 Long-Term Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following constraints are used to limit the decrease in cleared energy on a specific resource from the previous hour to the current based on ramp-down capability.

IF { h > 1 **} AND {** EmerCond(h)>-2 **}**
  ClearedEnergy(r,h)
  ≥
  ClearedEnergy(r,h-1)
  - CF(r,h) * 60 * LTSCEDRampDownRate(r,h)
  - [1- CF(r,h)] * ClearedEnergy(r,h-1)
  - LTRampDownViolation(r,h)
END IF

If a resource was not committed by SCUC during the hour, the long-term SCED ramp-down constraint will allow the cleared energy on the resource to be 0 for the hour. This constraint does not apply to the first hour of the operating day.

6.2.1.12 Contingency Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve cleared on a resource during the hour based on ramp capability.

[ContResRampMult / ContResDeployTime] * ClearedContRes(r,h)
≤
InputRampRate(r,h)
+ ContResRampViolation(r,h)

The contingency reserve ramp multiplier is a tuning parameter that determines the percentage of cleared contingency reserve that should be deployable within the Contingency Reserve Deployment Time.

6.2.1.13 Regulating Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve cleared on a resource during the hour based on ramp capability.

> [RegRampMult / RegResponseTime]* {ClearedRegRes1(r,h) + ClearedRegRes2(r,h)}
> ≤
> InputRampRate(r,h)
> + RegRampViolation(r,h)

The regulating reserve ramp multiplier is a tuning parameter that determines the percentage of cleared regulating reserve that should be deployable within the Regulation Response Time.

6.2.1.14 Up Ramp Capability Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Up Ramp Capability cleared on a resource during the Dispatch Interval based on ramp capability.

> [RCupRampMult/RCUpResponseTime]*[ClearedRCUp(r,h)]
>
> ≤
>
> InputRampRate(r,h)
> + RCUpRampViolation(r,h)

The Up Ramp Capability ramp multiplier is a tuning parameter that determines the percentage of cleared Up Ramp Capability that should be deployable within the Ramp Up Response Time.

6.2.1.15 Down Ramp Capability Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Down Ramp Capability cleared on a Resource during the Dispatch Interval based on ramp capability.

[RCDownRampMult/RCDownResponseTime]*[ClearedRCDown(r,h)]

≤

InputRampRate(r,h)

+ RCDownRampViolation(r,h)

The Down Ramp Capability Ramp Multiplier is a tuning parameter that determines the percentage of cleared Down Ramp Capability that should be deployable within the Ramp Down Response Time.

6.2.1.16 Short Term Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Down Ramp Capability cleared on a Resource during the Dispatch Interval based on ramp capability.

[STRRampMulti/STRResponseTime]*[ClearedOnlineSTR (r,h)]

≤

InputRampRate(r,h)

+ STRRampViolation(r,h)

The Short Term Reserve Ramp Multiplier is a tuning parameter that determines the percentage of cleared Short Term Reserve that should be deployable within the Short Term Reserve Response Time.

6.2.1.17 Maximum Resource Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Regulating Reserve requirement for the hour.

ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
≤
MaxRegResFactor * MWRegReq(h)
+ MaxResourceRegViolation(r,h)

6.2.1.18 Maximum Resource Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Contingency Reserve requirement.

ClearedContRes(r,h)
≤
MaxContResFactor * MWContResReq(h)
+ MaxResourceContResViolation(r,h)

6.2.1.19 Maximum Resource Short Term Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Short Term Reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Short Term Reserve requirement.

ClearedOnlineSTR (r,h) + ClearedOfflineSTR (r,h)

≤

MaxSTRFactor * MWSTRReq(h)

+ MaxResourceSTRResViolation(r,h)

6.2.1.20 Self-Scheduled Energy Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure that the energy cleared on a resource is greater than or equal to the self-scheduled energy on the resource during the hour if the resource has been committed by SCUC and the Energy Dispatch Status is set to ***Self Schedule***.

ClearedEnergy(r,h)

≥

CF(r,h) * SSEnergyStatus(r,h) * SSEnergyMW(r,h)

- SSEnergyDeficit(r,h)

This constraint does not restrict the clearing of energy above the self-scheduled amount.

6.2.1.21 Self-Scheduled Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the portion of regulating reserve based on total offer cleared on a resource is greater than or equal to the self-scheduled regulating reserve on the resource during the hour if the resource has been committed by SCUC, the resource has been selected for regulation by SCUC and the Regulating Reserve Dispatch Status is set to ***Self Schedule***.

> ClearedRegRes1(r,h)
> ≥
> CF(r,h) * RF(r,h) * SSRegResStatus(r,h) * SSRegResMW(r,h)
> - SSRegResDeficit(r,h)

This constraint does not restrict the clearing of regulating reserve above the self-scheduled amount.

6.2.1.22 Self-Scheduled Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the contingency reserve cleared on a resource that has been committed for the hour by SCUC is greater than or equal to the self-scheduled contingency reserve on the resource if 1) the Spinning Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to provide Spinning Reserve or 2) the On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule***, the resource is available to provide Supplemental Reserve but is not available to provide Spinning Reserve. In addition, the following constraints are used to ensure the contingency reserve cleared on a resource that has not been committed for the hour by SCUC is greater than or equal to the self-scheduled contingency reserve on the resource if 1) the Off-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to provide Off-Line Supplemental Reserve.

> ClearedContRes(r,h)
> ≥
> CF(r,h) * SSSpinResStatus(r,h) * SSSpinResMW(r,h) * SpinAvailability(r,h)
> + CF(r,h) * SSOnLineSupResStatus(r,h) * SSOnLineSupResMW(r,h)
> * [SupAvailability(r,h) - SpinAvailability(r,h)]
> + [1 - CF(r,h)] * SSOffLineSupResStatus(r,h) * SSOffLineSupResMW(r,h)
> * OffLineSupAvailability(r,h)

- SSContResDeficit(r,h)

Spinning Reserve self-schedules are enforced during the hour if the resource has been committed by SCUC for the hour, the resource Spinning Reserve Dispatch Status is set to ***Self Schedule*** for the hour and the resource is available to supply Spinning Reserve during the hour. On-Line Supplemental Reserve self-schedules are enforced during the hour if the resource has been committed by SCUC for the hour, the resource On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule*** for the hour, the resource is available to supply Supplemental Reserve during the hour and the resource is not available to supply Spinning Reserve during the hour. Off-Line Supplemental Reserve self-schedules are enforced during the hour if the resource has not been committed by SCUC for the hour, the resource Off-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule*** for the hour and the resource is available to supply off-line Supplemental Reserve during the hour. This constraint does not restrict the clearing of Contingency Reserve above the self-schedule.

6.2.2 Demand Response Resource - Type I Constraints

6.2.2.1 Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that the cleared energy associated with a resource during the hour is equal to the targeted demand reduction level if the resource is committed during the hour or zero if the resource is not committed during the hour.

ClearedEnergy(r,h)
=
CF(r,h) * TargetDemRedLevel(r,h)

If the commitment flag is set to 0 for a resource for the hour by SCUC, then the cleared energy for the resource must be zero for the hour. If the commitment flag is set to 1 for a resource for the hour by SCUC, then the cleared energy for the resource is set equal to the targeted demand reduction level.

6.2.2.2 Cleared Regulating Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints prevent a Demand Response Resource - Type I from clearing any Regulating Reserve during the hour.

$$
\begin{aligned}
&\text{ClearedRegRes}(r,h)\\
&=\\
&0
\end{aligned}
$$

6.2.2.3 Cleared Contingency Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that contingency reserve is only cleared on a resource during the hour when the resource is not committed by SCUC and is available to supply Spinning Reserve and/or Supplemental Reserve. This constraint also limits the amount of contingency reserve that can be cleared on a resource during the hour to the targeted demand reduction level of the resource for the hour.

$$
\begin{aligned}
&\text{ClearedContRes}(r,h)\\
&\leq\\
&[1 - \text{CF}(r,h)] * \text{TargetDemRedLevel}(r,h) * \text{SpinAvailability}(r,h)\\
&+ [1 - \text{CF}(r,h)] * \text{TargetDemRedLevel}(r,h)\\
&\qquad\qquad * [\text{SupAvailability}(r,h) - \text{SpinAvailability}(r,h)]
\end{aligned}
$$

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during the hour or the resource commitment flag has been set to 1 for the hour by SCUC, the contingency reserve cleared on that resource for the hour must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a resource is 1 for the hour and the resource commitment flag has been set to 0 for the hour by SCUC, contingency reserve may be cleared on that resource during the hour, based on economic and other constraints, up to the targeted demand reduction level of the resource for the hour.

6.2.2.4 Cleared Offline Short Term Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that Short Term Reserve is only dispatched on a resource during an hour where the resource is not committed (i.e., the commitment flag is 0). This constraint also limits the amount of Short Term Reserve that can be dispatched on a resource during an hour to the targeted demand reduction level of the resource during that hour.

ClearedOfflineSTR (r,h)
≤
[1 - CF(r,h)] * TargetDemRedLevel(r,h) * STROfflineAvailability(r,h)

If the commitment flag is set to 0 for a resource during a specific hour, an amount of Short Term Reserve may be dispatched on the resource up to the targeted demand reduction level of the resource during that hour. If the commitment flag is set to 1 for a resource during a specific hour, no Contingency Reserve may be dispatched on that resource during that hour.

6.2.2.5 Maximum Resource Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve that can be cleared on a single resource in a specific hour to a maximum percentage of the market-wide contingency reserve requirement.

ClearedContRes(r,h)
≤
MaxContResFactor * MWContResReq(h)
+ MaxResourceContResViolation(r,h)

6.2.2.6 Maximum Resource Short Term Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Short Term Reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Short Term Reserve requirement.

> ClearedOffSTR (r,h)
> ≤
> MaxSTRFactor * MWSTRReq(h)
> + MaxResourceSTRResViolation(r,h)

6.2.2.7 Self-Scheduled Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the contingency reserve cleared on a resource is greater than or equal to the self-scheduled contingency reserve on the resource if the resource has not been committed by SCUC for the hour and 1) the Spinning Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to provide Spinning Reserve or 2) the Supplemental Reserve Dispatch Status is set to ***Self Schedule***, the resource is available to provide Supplemental Reserve but is not available to provide Spinning Reserve.

> ClearedContRes(r,h)
> ≥
> [1 - CF(r,h)] * SSSpinResStatus(r,h) * SSSpinResMW(r,h)
>   * SpinAvailability(r,h)
> + [1 - CF(r,h)] * SSSupResStatus(r,h) * SSSupResMW(r,h)
>   * [SupAvailability(r,h) - SpinAvailability(r,h)]
> - SSContResDeficit(r,h)

6.2.3 External Asynchronous Resource Constraints

6.2.3.1 Energy Step Clearing Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific energy offer curve step during a specific hour is less than or equal to the energy step width of the energy offer curve step for the hour or zero if the resource is not available:

EnergyStepClearing(r,h,st)
≤
CommitAvailability(r,h) * EnergyStepWidth(r,h,st)

If the resource commitment availability flag for the hour is set to 0, then the cleared energy for each energy offer curve step associated with the resource must be zero. If the resource commitment availability flag for the hour is set to 1, then the cleared energy for a specific energy offer curve step must be less than or equal to the energy step width of that energy offer curve step.

6.2.3.2 Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that the total energy cleared on a resource during the hour is equal to the sum of the energy cleared on each individual energy offer curve step associated with the resource for the hour.

ClearedEnergy(r,h)
=
$\sum_{st}$ { EnergyStepClearing(r,h,st)}

6.2.3.3 Cleared Regulating Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that regulating reserve is only cleared on a resource during the hour if the resource was selected by SCUC to provide regulating reserve for the hour. This constraint also limits the amount of regulating reserve that can be cleared on a resource during the hour to fifty percent of the difference between the maximum limit and the minimum limit of the resource for the hour.

ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
≤
0.5 * RF(r,h) * [MaxLimit(r,h) - MinLimit(r,h)]

If the resource regulation flag is set to 1 for the hour by SCUC, an amount of regulating reserve may be cleared on the resource equal to the 50% of the difference between the maximum limit and the minimum limit for the resource that the hour. If the resource regulation flag is set to 0 for the hour by SCUC, no regulating reserve may be cleared on the resource for the hour.

Further regulation clearing constraints ensure that both portions of regulating reserve cleared on a resource (the portion cleared considering the regulating reserve total offer cost, and the portion cleared considering the regulation capacity offer cost only), are greater than or equal to zero:

ClearedRegRes1(r,h) ≥ 0
and
ClearedRegRes2(r,h) ≥ 0

6.2.3.4 Cleared Contingency Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for Spinning Reserve or Supplemental Reserve for the hour in order for Contingency Reserve to be cleared on that resource during the hour. In addition, these constraints limit the amount of contingency reserve that can be cleared to a value not more than the difference between the maximum limit of the resource for the hour and the minimum limit of the resource for the hour.

ClearedContRes(r,h)
≤
[CommitAvailability(r,h)] * [MaxLimit(r,h) - MinLimit(r,h)]
* SpinAvailability(r,h)
+ [CommitAvailability(r,h)] * [MaxLimit(r,h) - MinLimit(r,h)]
* [SupAvailability(r,h) - SpinAvailability(r,h)]

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during the hour or the resource commitment availability flag is set to 0, the contingency reserve cleared on that resource for that hour must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a specific resource are 1 during a specific hour and the resource commitment availability flag is set to 1 for that hour, contingency reserve may be cleared on that resource during the hour, based on economics and other constraints, up to the difference between the maximum limit and minimum limit of the resource for the hour.

6.2.3.5 On-Line Short Term Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for on-line Short Term Reserve during a specific hour in order to be dispatched for on-line Short Term Reserve during that hour.

ClearedOnLineSTR (r,h)
≤
{ - ClearedEnergy (r,h) - ClearedRegRes1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]}
* OnLineSTRAvailability(r,h)

The following maximum limit constraints apply to resources during any hour of an emergency mode SCED execution when there was a shortage detected for that hour during the initial normal mode SCED iteration.

ClearedOnlineSTR (r,h)
≤
{ - ClearedEnergy (r,h) - ClearedRegRes1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]
+ EmerMaxRelease(r,h) * [EmerMaxLimit(r,h) - EcoMaxLimit(r,h)] }
* OnLineSTRAvailability(r,h)

6.2.3.6 Maximum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following maximum limit constraints apply to resources during the hour.

ClearedEnergy(r,h)
+ ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
+ ClearedContRes(r,h)
≤
CommitAvailability(r,h) * MaxLimit(r,h)
+ MaxLimitViolation(r,h)

If the resource commitment availability flag is set to 1 for the hour, the sum of the energy, regulating reserve and contingency reserve cleared on the resource during the hour cannot exceed the maximum limit of the resource for the hour. If the resource commitment availability flag is set to 0 for the hour, the sum of the energy, regulating reserve and contingency reserve cleared on the resource during the hour must be zero.

6.2.3.7 Maximum Energy Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following maximum energy limit constraints apply to resources during the hour.

ClearedEnergy(r,h)
≤
MaxEnergyLimit(r,h)
+ MaxEnergyLimitViolation(r,h)

The cleared energy on resource r during hour h must not exceed the maximum available energy for the hour based on the maximum daily energy limit of the resource, cleared energy by SCED during previous hours of the operating day and dispatched energy by SCUC during upcoming hours of the operating day.

6.2.3.8 Minimum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following minimum limit constraints apply to resources during the hour.

ClearedEnergyDispatch(r,h)
- ClearedRegRes1(r,h)
≥
CommitAvailability(r,h) * MinLimit(r,h)* MinLimitScaleFactor(h)
- MinLimitViolation(r,h)

If the resource commitment availability flag is set to 1 for the hour, the energy cleared on the resource during the hour less the portion of regulating reserve cleared on the resource considering total offer cost during the hour must be greater than or equal to the minimum limit of the resource for the hour. If the resource commitment availability flag is set to 0 for the hour, the energy cleared on the resource during the hour less the regulating reserve cleared on the resource during the hour are not restricted by the minimum limit of the resource for the hour.

6.2.3.9 Long-Term Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the increase in cleared energy on a specific resource from the previous hour to the current hour based on ramp-up capability.

IF { h > 1 **} AND {** EmerCond(h)<3 **}**
ClearedEnergy(r,h)
≤
ClearedEnergy(r,h-1)
+ 60 * LTSCEDRampUpRate(r,h)
+ LTRampUpViolation(r,h)
END IF

This constraint does not apply to the first hour of the operating day.

6.2.3.10 Long-Term Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following constraints are used to limit the decrease in cleared energy on a specific resource from the previous hour to the current based on ramp-down capability.

IF { h > 1 **} AND {** EmerCond(h)>-2 **}**
ClearedEnergy(r,h)
≥
ClearedEnergy(r,h-1)
- CommitAvailability(r,h) * 60 * LTSCEDRampDownRate(r,h)
- [1- CommitAvailability(r,h)] * ClearedEnergy(r,h-1)
- LTRampDownViolation(r,h)
END IF

If the resource commitment availability flag is set to 0 during the hour, the long-term SCED ramp-down constraint will allow the cleared energy on the resource to be 0 for the hour. This constraint does not apply to the first hour of the operating day.

6.2.3.11 Contingency Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve cleared on a resource during the hour based on ramp capability.

> [ContResRampMult / ContResDeployTime] * ClearedContRes(r,h)
> ≤
> InputRampRate(r,h)
> + ContResRampViolation(r,h)

The contingency reserve ramp multiplier is a tuning parameter that determines the percentage of cleared contingency reserve that should be deployable within the Contingency Reserve Deployment Time.

6.2.3.12 Regulating Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve cleared on a resource during the hour based on ramp capability.

> [RegRampMult / RegResponseTime]* * {ClearedRegRes1(r,h) + ClearedRegRes2(r,h)}
> ≤
> InputRampRate(r,h)
> + RegRampViolation(r,h)

The regulating reserve ramp multiplier is a tuning parameter that determines the percentage of cleared regulating reserve that should be deployable within the Regulation Response Time.

6.2.3.13 Up Ramp Capability Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Up Ramp Capability cleared on a resource during the Dispatch Interval based on ramp capability.

[RCupRampMult/RCUpResponseTime]*[ClearedRCUp(r,h)]

≤

InputRampRate(r,h)
+ RCUpRampViolation(r,h)

The Up Ramp Capability ramp multiplier is a tuning parameter that determines the percentage of cleared Up Ramp Capability that should be deployable within the Ramp Up Response Time.

6.2.3.14 Down Ramp Capability Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Down Ramp Capability cleared on a resource during the Dispatch Interval based on ramp capability.

[RCDownRampMult/RCDownResponseTime]*[ClearedRCDown(r,h)]

≤

InputRampRate(r,h)

+ RCDownRampViolation(r,h)

The Down Ramp Capability Ramp Multiplier is a tuning parameter that determines the percentage of cleared Down Ramp Capability that should be deployable within the Ramp Down Response Time.

6.2.3.15 Short Term Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Down Ramp Capability cleared on a resource during the Dispatch Interval based on ramp capability.

> [STRRampMulti/STRResponseTime]*[ClearedOnlineSTR (r,h)]
> ≤
> InputRampRate(r,h)
> + STRRampViolation(r,h)

The Short Term Reserve Ramp Multiplier is a tuning parameter that determines the percentage of cleared Short Term Reserve that should be deployable within the Short Term Reserve Response Time.

6.2.3.16 Maximum Resource Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Regulating Reserve requirement for the hour.

> ClearedRegRes1(r,h) + Cleared RegRes2(r,h)
> ≤
> MaxRegResFactor * MWRegReq(h)
> + MaxResourceRegViolation(r,h)

6.2.3.17 Maximum Resource Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Contingency Reserve requirement.

ClearedContRes(r,h)
≤
MaxContResFactor * MWContResReq(h)
+ MaxResourceContResViolation(r,h)

6.2.3.18 Maximum Resource Up Ramp Capability Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Up Ramp Capability that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Ramp Up Capability requirement.

ClearedRCUp(r,h)

≤

MaxRCUpFactor * MWRCUpReq(h)

+ MaxResourceRCUpViolation(r,h)

6.2.3.19 Maximum Resource Down Ramp Capability Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Down Ramp Capability that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Ramp Down Capability requirement.

ClearedRCDown(r,h)

≤

MaxRCDownFactor * MWRCDownReq(h)

+ MaxResourceRCDownViolation(r,h)

6.2.3.20 Maximum Resource Short Term Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Short Term Reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Short Term Reserve requirement.

OnlineSTRResDispatch (r,h)
≤
MaxSTRFactor * MWSTRReq(h)
+ MaxResourceSTRResViolation(r,h)

6.2.3.21 Self-Scheduled Energy Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure that the energy cleared on a resource is greater than or equal to the self-scheduled energy on the resource during the hour if the resource is available and the Energy Dispatch Status is set to ***Self Schedule***.

ClearedEnergy(r,h)
≥
CommitAvailability(r,h) * SSEnergyStatus(r,h) * SSEnergyMW(r,h)

- SSEnergyDeficit(r,h)

This constraint does not restrict the clearing of energy above the self-scheduled amount.

6.2.3.22 Self-Scheduled Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the regulating reserve cleared on a resource considering the resource's total offer cost is greater than or equal to the self-scheduled regulating reserve on the resource during the hour if the resource is available, has been selected for regulation by SCUC and the Regulating Reserve Dispatch Status is set to ***Self Schedule***.

ClearedRegRes(r,h)
≥
CommitAvailability(r,h) * RF(r,h) * SSRegResStatus(r,h) * SSRegResMW(r,h)
- SSRegResDeficit(r,h)

This constraint does not restrict the clearing of regulating reserve above the self-scheduled amount.

6.2.3.23 Self-Scheduled Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the contingency reserve cleared on a resource is greater than or equal to the self-scheduled contingency reserve on the resource if the resource is available and if 1) the Spinning Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to provide Spinning Reserve or 2) the Supplemental Reserve Dispatch Status is set to ***Self Schedule***, the resource is available to provide Supplemental Reserve but is not available to provide Spinning Reserve.

ClearedContRes(r,h)
≥

CommitAvailability(r,h) * SSSpinResStatus(r,h) * SSSpinResMW(r,h)
* SpinAvailability(r,h)
+ CommitAvailability(r,h) * SSOnLineSupResStatus(r,h)
* SSOnLineSupResMW(r,h)
* [SupAvailability(r,h) - SpinAvailability(r,h)]
- SSContResDeficit(r,h)

Spinning Reserve self-schedules are enforced during the hour if the resource commitment availability flag has been set to 1 for the hour, the resource Spinning Reserve Dispatch Status is set to ***Self Schedule*** for the hour and the resource is available to supply Spinning Reserve during the hour. Supplemental Reserve self-schedules are enforced during the hour if the resource commitment availability flag hast been set to 1 for the hour, the resource Supplemental Reserve Dispatch Status is set to ***Self Schedule*** for the hour, the resource is available to supply Supplemental Reserve during the hour and the resource is not available to supply Spinning Reserve during the hour. This constraint does not restrict the clearing of Contingency Reserve above the self-schedule.

6.2.4 Electric Storage Resource Constraints

6.2.4.1 Energy Step Clearing Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared positive energy associated with a specific energy positive offer curve step during a specific hour is less than or equal to the energy positive step width of the energy offer curve step for the hour or zero if the resource was not committed by SCUC:

EnergyStepPositiveClearing(r,h,st)
≤
CF(r,h) * EnergyStepPositiveWidth(r,h,st)

The following constraints ensure that the negtavie energy associated with a specific enery negative offer curve step during a specific hour is less than or equal to the negative energy step width of the energy offer curve step for the hour or zero if the resource was not committed by SCUC:

> EnergyStepNegativeClearing(r,h,st)
> ≤
> CF(r,h) * EnergyStepNegativeWidth(r,h,st)

If the resource commitment flag for the hour is set to 0 by SCUC, then the cleared energy for each energy offer curve step associated with the resource must be zero. If the resource commitment flag for the hour is set to 1 by SCUC, then the cleared energy (positive/negative) for a specific energy offer curve step must be less than or equal to the (positive/negative) energy step width of that energy offer curve step.

6.2.4.2 Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints ensure that the total energy cleared on a resource during the hour is equal to the sum of the energy cleared on each individual energy offer curve step (positive or negative) associated with the resource for the hour.

> ClearedEnergy(r,h)
> =

$$\sum_{st}\{ EnergyStepPositiveClearing(r,h,st)\} + \sum_{st}\{ EnergyStepNegativeClearing(r,h,st)\}$$

6.2.4.3 Cleared Regulating Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that Regulating Reserve is only cleared on a resource during the hour if the resource was selected by SCUC to provide Regulating Reserve for the hour. This constraint also limits the amount of Regulating Reserve that can be cleared on a resource during the hour to fifty percent of the difference between the maximum limit and the minimum limit of the resource for the hour.

ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
≤
0.5 * RF(r,h) * [MaxLimit(r,h) - MinLimit(r,h)]

If therResource regulation flag is set to 1 for the hour by SCUC, an amount of Regulating Reserve may be cleared on the resource equal to the 50% of the difference between the maximum limit and the minimum limit for the Resource that the hour. If the resource regulation flag is set to 0 for the hour by SCUC, no Regulating Reserve may be cleared on the resource for the hour.

Further regulation clearing constraints ensure that both portions of Regulating Reserve cleared on a resource (the portion cleared considering the Regulating Reserve total offer cost, and the portion cleared considering the regulation capacity offer cost only), are greater than or equal to zero:

ClearedRegRes1(r,h) ≥ 0
and
ClearedRegRes2(r,h) ≥ 0

6.2.4.4 Cleared Contingency Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource either 1) be committed by SCUC and be available for Spinning Reserve or Supplemental Reserve for the hour or 2) not be committed by SCUC and be available for off-line Supplemental Reserve for the hour in order for Contingency Reserve to be cleared on that resource during the hour. In addition, these constraints limit the amount of Contingency Reserve that can be cleared on a committed resource to a value not more than the difference between the maximum limit of the resource for the hour and the minimum limit of the resource for the hour, or on an uncommitted resource to a value not more than the maximum off-line response limit of the resource for the hour.

ClearedContRes(r,h)
≤
[CF(r,h)] * [MaxLimit(r,h) - MinLimit(r,h)] * SpinAvailability(r,h)
+ [CF(r,h)] * [MaxLimit(r,h) - MinLimit(r,h)]
* [SupAvailability(r,h) - SpinAvailability(r,h)]
+ [1-CF(r,h)] * [MaxOffLineResponse(r,h)]
* [OffLineSupAvailability(r,h)]

If the Spinning Reserve availability and the Supplemental Reserve availability of a specific resource are both 0 during the hour and the Resource has been committed by SCUC, the Contingency Reserve cleared on that resource for that hour must also be 0. If either the Spinning Reserve availability or the Supplemental Reserve availability of a specific resource are 1 during a specific hour and the resource is committed by SCUC for that hour, Contingency Reserve may be cleared on that resource during the hour, based on economics and other constraints, up to the difference between the maximum limit and minimum limit of the Resource for the hour. If the off-line Supplemental Reserve availability of a specific resource is 0 during the hour and the resource has not been committed by SCUC, the Contingency Reserve cleared on that Resource for that hour must also be 0. If the off-line Supplemental Reserve availability of a specific resource is 1 during the hour and the resource has not been committed by SCUC, Contingency Reserve may be cleared on that resource during the hour, based on economic and other constraints, up to the maximum off-line response limit of the resource for the hour.

6.2.4.5 On-Line Short Term Reserve Availability and Dispatch Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints require that a resource be available for on-line Short Term Reserve during a specific hour in order to be dispatched for on-line Short Term Reserve during that hour.

ClearedOnLineSTR (r,h)
≤
{ - ClearedEnergy (r,h) - ClearedRegRes1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]}

* OnLineSTRAvailabity(r,h)

The following maximum limit constraints apply to resources during any hour of an emergency mode SCED execution when there was a shortage detected for that hour during the initial normal mode SCED iteration.

ClearedOnLineSTR (r,h)
≤
{ - ClearedEnergy (r,h) - ClearedRegRes1(r,h)
+ CF(r,h)* EcoMaxLimit (r,h) - RF(r,h)*[EcoMaxLimit(r,h) – RegMaxLimit(r,h)]
+ EmerMaxRelease(r,h) * [EmerMaxLimit(r,h) - EcoMaxLimit(r,h)] }
* OnLineSTRAvailabity(r,h)

6.2.4.6 Maximum Limit Constraints

Constraint Classification: Physical
Constraint Type: Penalized LE
The following maximum limit constraints apply to resources during the hour.

ClearedEnergy(r,h)
+ ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
+ ClearedContRes(r,h)
≤
CF(r,h) * MaxLimit(r,h)
+ [1 - CF(r,h)] * MaxOffLineResponse(r,h)
+ MaxLimitViolation(r,h)

If the resource commitment flag is set to 1 for the hour by SCUC, the sum of the energy, Regulating Reserve and Contingency Reserve cleared on the resource during the hour cannot exceed the maximum limit of the resource for the hour. If the resource commitment flag is set to 0 for the hour by SCUC, the sum of the energy, Regulating Reserve and Contingency Reserve cleared on the resource during the hour cannot exceed the maximum off-line response of the resource for the hour (in this scenario the cleared energy and Regulating Reserve would be zero, and the cleared Contingency Reserve could only be non-zero if the resource is available for off-line Supplemental Reserve).

6.2.4.7 Maximum Energy Storage Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following Maximum Energy Storage limit constraints apply to resources during the hour.

Interval-to-Interval SOC

SOC(r,h)

≤

SOCMax(r,h) + MaxEnergyStorageLimitViolation (r,h)

Where:

SOC(r,h) = SOC(r,h-1)_ -

*[*ClearedEnergy(r,h) ** {if* ClearedEnergy(r,h) *>= 0 then 1 else ESR Efficiency Factor}*

+ ClearedRegRes1(r,h) ** RegStorageUseFactor]*

+ ClearedContRes(r,h)**(SpinStorageUseFactor / SuppStorageUseFactor)*

*+Max(0,*ClearedOnlineSTR(r,h) - ClearedContRes(r,h)) ** STRStorageUseFactor]*

AND = SOC(r,1) = $SOC_{initial}$

Intra-Interval SOC

SOC(r,h)

≤

SOCMAX(r,h) + MaxEnergyStorageLimitViolation (r,h)

Where:

SOC(r,h) = SOC(r,h-1)_ -

*[*ClearedEnergy(r,h) ** {if* ClearedEnergy(r,h) *>= 0 then 1 else ESR Efficiency Factor}*

- ClearedRegRes1(r,h) ** RegStorageReliabilityFactor*

The cleared energy storage on resource r during hour h must not exceed the maximum energy storage level limit for the hour of the resource.

6.2.4.8 Minimum Energy Storage Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following Minimum Energy Storage limit constraints apply to resources during the hour.

Interval-to-Interval SOC

SOC(r,h)

≥

SOCMin(r,h) + MinEnergyStorageLimitViolation (r,h)

Where:

Where:

SOC(r,h) = SOC(r,h-1)_ -

*[CleardEnergy(r,h) * {if ClearedEnergy(r,h) >= 0 then 1 else ESR Efficiency Factor}*

*+ ClearedRegRes1(r,h) * RegStorageUseFactor*

+ ClearedContRes(r,h)(SpinStorageUseFactor / SuppStorageUseFactor)*

*+Max(0,ClearedOnlineSTR(r,h) - ClearedContRes(r,h)) * STRStorageUseFactor]*

AND

SOC(r,1) = $SOC_{initial}$

Intra-Interval SOC

SOC(r,h)

≥

SOCMin(r,h) + MinEnergyStorageLimitViolation (r,h)

Where:

SOC(r,h) = SOC(r,h-1)_ -

*[ClearedEnergy(r,h) * {if ClearedEnergy(r,h) >= 0 then 1 else ESR Efficiency Factor}*

*+ ClearedRegRes1(r,h) * RegStorageReliabilityFactor*

+ ClearedContRes(r,h)(SpinStorageReliabilityFactor / SuppStorageReliabilityFactor)*

*+Max(0,ClearedOnlineSTR(r,h) - ClearedContRes(r,h)) * STRStorageReliabilityFactor]*

The cleared energy storage on resource r during hour h must exceed the minimum energy storage level limit for the hour of the resource.

6.2.4.9 Minimum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following minimum limit constraints apply to Resources during the hour.

ClearedEnergy(r,h)
ClearedRegRes1(r,h)
≥
CF(r,h) * MinLimit(r,h) * MinLimitScaleFactor(h)
- MinLimitViolation(r,h)

If the resource commitment flag is set to 1 for the hour by SCUC, the energy cleared on the resource during the hour less portion of the Regulating Reserve cleared based on total offer on the resource during the hour must be greater than or equal to the minimum limit of the resource for the hour. If the resource commitment flag is set to 0 for the hour by SCUC, the energy cleared on the resource during the hour less the Regulating Reserve cleared on the resource during the hour are not restricted by the minimum limit of the resource for the hour.

6.2.4.10 Long-Term Ramp-Up Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the increase in cleared energy on a specific resource from the previous hour to the current hour based on ramp-up. SU(r,h) represents the Start-Up flag as provided by the SCUC engine. Though a primal variable during the SCUC execution, it is used only as an input parameter in SCED.

IF { h > 1 **}**
ClearedEnergy(r,h)

≤

ClearedEnergy(r,h-1)
+ 60 * LTSCEDRampUpRate(r,h)
+ LTRampUpViolation(r,h)

END IF

This constraint does not apply during the first hour of the Operating Day. During the first hour of a commitment, the Long-Term Ramp-Up Constraints restrict the ramp capability of a resource to one-half its usual hourly capability, to allow the integrated value of the resource's output to properly reflect its ramping capability during the first hour of commitment.

6.2.4.11 Long-Term Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following constraints are used to limit the decrease in cleared energy on a specific resource from the previous hour to the current based on ramp-down capability.

IF { h > 1 **} AND {** EmerCond(h)>-2 **}**
ClearedEnergy(r,h)
≥
ClearedEnergy(r,h-1)
- CF(r,h) * 60 * LTSCEDRampDownRate(r,h)
- [1- CF(r,h)] * ClearedEnergy(r,h-1)
- LTRampDownViolation(r,h)
END IF

If a resource was not committed by SCUC during the hour, the long-term SCED ramp-down constraint will allow the cleared energy on the resource to be 0 for the hour. This constraint does not apply to the first hour of the Operating Day.

6.2.4.12 Contingency Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Contingency Reserve cleared on a resource during the hour based on ramp capability.

[ContResRampMult / ContResDeployTime] * ClearedContRes(r,h)
≤
InputRampRate(r,h)
+ ContResRampViolation(r,h)

The Contingency Reserve ramp multiplier is a tuning parameter that determines the percentage of cleared Contingency Reserve that should be deployable within the Contingency Reserve Deployment Time.

6.2.4.13 Regulating Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve cleared on a resource during the hour based on ramp capability.

[RegRampMult / RegResponseTime]* {ClearedRegRes1(r,h) + ClearedRegRes2(r,h)}
≤
InputRampRate(r,h)
+ RegRampViolation(r,h)

The Regulating Reserve ramp multiplier is a tuning parameter that determines the percentage of cleared Regulating Reserve that should be deployable within the Regulation Response Time.

6.2.4.14 Up Ramp Capability Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Up Ramp Capability cleared on a resource during the Dispatch Interval based on ramp capability.

[RCupRampMult/RCUpResponseTime]*[ClearedRCUp(r,h)]

≤

InputRampRate(r,h)
+ RCUpRampViolation(r,h)

The Up Ramp Capability ramp multiplier is a tuning parameter that determines the percentage of cleared Up Ramp Capability that should be deployable within the Ramp Up Response Time.

6.2.4.15 Down Ramp Capability Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Down Ramp Capability cleared on a resource during the Dispatch Interval based on ramp capability.

[RCDownRampMult/RCDownResponseTime]*[ClearedRCDown(r,h)]

≤

InputRampRate(r,h)

+ RCDownRampViolation(r,h)

The Down Ramp Capability Ramp Multiplier is a tuning parameter that determines the percentage of cleared Down Ramp Capability that should be deployable within the Ramp Down Response Time.

6.2.4.16 Short Term Reserve Ramp Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

The following constraints are used to limit the Down Ramp Capability cleared on a resource during the Dispatch Interval based on ramp capability.

[STRRampMulti/STRResponseTime]*[ClearedOnlineSTR (r,h)]

≤

InputRampRate(r,h)

+ STRRampViolation(r,h)

The Short Term Reserve Ramp Multiplier is a tuning parameter that determines the percentage of cleared Short Term Reserve that should be deployable within the Short Term Reserve Response Time.

6.2.4.17 Maximum Resource Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Regulating Reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Regulating Reserve requirement for the hour.

ClearedRegRes1(r,h) + ClearedRegRes2(r,h)
≤
MaxRegResFactor * MWRegReq(h)
+ MaxResourceRegViolation(r,h)

6.2.4.18 Maximum Resource Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the contingency reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Contingency Reserve requirement.

ClearedContRes(r,h)
≤
MaxContResFactor * MWContResReq(h)
+ MaxResourceContResViolation(r,h)

6.2.4.19 Maximum Resource Short Term Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized LE

The following constraints are used to limit the Short Term Reserve that can be cleared on a single resource during the hour to a maximum percentage of the market-wide Short Term Reserve requirement.

ClearedOnlineSTR (r,h)
≤
MaxSTRFactor * MWSTRReq(h)
+ MaxResourceSTRResViolation(r,h)

6.2.4.20 Self-Scheduled Energy Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure that the energy cleared on a resource is greater than or equal to the self-scheduled energy (or less than or equal to the self-scheduled energy if self-scheduled energy is less than 0) on the resource during the hour if the resource has been committed by SCUC and the Energy Dispatch Status is set to ***Self Schedule***.

IF { SSEnergyMW(r,h) > 0 MW }
ClearedEnergy(r,h)
≥
CF(r,h) * SSEnergyStatus(r,h) * SSEnergyMW(r,h)
- SSEnergyDeficit(r,h)

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ClearedEnergy(r,h)

≤

CF(r,h) * SSEnergyStatus(r,h) * SSEnergyMW(r,h)

+ SSEnergySuplus(r,h)

This constraint does not restrict the clearing of energy above the positive self-scheduled amount or the clearning of energy below the negative self-scheduled amount.

6.2.4.21 Self-Scheduled Regulating Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the portion of Regulating Reserve based on total offer cleared on a resource is greater than or equal to the self-scheduled Regulating Reserve on the resource during the hour if the resource has been committed by SCUC, the resource has been selected for regulation by SCUC and the Regulating Reserve Dispatch Status is set to ***Self Schedule***.

ClearedRegRes1(r,h)

≥

CF(r,h) * RF(r,h) * SSRegResStatus(r,h) * SSRegResMW(r,h)

- SSRegResDeficit(r,h)

This constraint does not restrict the clearing of Regulating Reserve above the self-scheduled amount.

6.2.4.22 Self-Scheduled Contingency Reserve Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Penalized GE

The following constraints are used to ensure the Contingency Reserve cleared on a resource that has been committed for the hour by SCUC is greater than or equal to the self-scheduled Contingency Reserve on the resource if 1) the Spinning Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to provide Spinning Reserve or 2) the On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule***, the resource is available to provide Supplemental Reserve but is not available to provide Spinning Reserve. In addition, the following constraints are used to ensure the Contingency Reserve cleared on a resource that has not been committed for the hour by SCUC is greater than or equal to the self-scheduled Contingency Reserve on the resource if 1) the Off-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule*** and the resource is available to provide Off-Line Supplemental Reserve.

ClearedContRes(r,h)
≥
CF(r,h) * SSSpinResStatus(r,h) * SSSpinResMW(r,h) * SpinAvailability(r,h)
+ CF(r,h) * SSOnLineSupResStatus(r,h) * SSOnLineSupResMW(r,h)
* [SupAvailability(r,h) - SpinAvailability(r,h)]
+ [1 - CF(r,h)] * SSOffLineSupResStatus(r,h) * SSOffLineSupResMW(r,h)
* OffLineSupAvailability(r,h)
- SSContResDeficit(r,h)

Spinning Reserve self-schedules are enforced during the hour if the resource has been committed by SCUC for the hour, the resource Spinning Reserve Dispatch Status is set to ***Self Schedule*** for the hour and the resource is available to supply Spinning Reserve during the hour. On-Line Supplemental Reserve self-schedules are enforced during the hour if the resource has been committed by SCUC for the hour, the resource On-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule*** for the hour, the resource is available to supply Supplemental Reserve during the hour and the resource is not available to supply Spinning Reserve during the hour. Off-Line Supplemental Reserve self-schedules are enforced during the hour if the resource has not been committed by SCUC for the hour, the resource Off-Line Supplemental Reserve Dispatch Status is set to ***Self Schedule*** for the hour and the resource is available to supply off-line Supplemental Reserve during the hour. This constraint does not restrict the clearing of Contingency Reserve above the self-schedule.

6.2.5 Energy Transaction Constraints

6.2.5.1 Price Sensitive Demand Segment Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific price sensitive demand bid segment is less than or equal to the segment MW bid.

ClearedDemSeg(tr,h,sg)
≤
DemSegMW(tr,h,sg)

6.2.5.2 Dispatchable Import Segment Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific dispatchable import segment is less than or equal to the segment MW offer.

ClearedImportSeg(tr,h,sg)
≤
ImportSegMW(tr,h,sg)

6.2.5.3 Dispatchable Export Segment Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific dispatchable export segment is less than or equal to the segment MW bid.

ClearedExportSeg(tr,h,sg)
≤
ExportSegMW(tr,h,sg)

6.2.5.4 Virtual Supply Segment Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific virtual supply offer segment is less than or equal to the segment MW offer.

$$ClearedVirtualSupSeg(tr,h,sg) \leq VirtualSupSegMW(tr,h,sg)$$

6.2.5.5 Virtual Demand Segment Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific virtual demand bid segment is less than or equal to the segment MW bid.

$$ClearedVirtualDemSeg(tr,h,sg) \leq VirtualDemSegMW(tr,h,sg)$$

6.2.5.6 Up-to-TUC Transaction Segment Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard LE

The following constraints ensure that the cleared energy associated with a specific up-to-TUC wheel-through transaction segment is less than or equal to the segment MW bid.

$$ClearedUpToTUCSeg(tr,h,sg) \leq UpToTUCSegMW(tr,h,sg)$$

6.2.6 Power Flow Constraints

The power flow (PF) constraints define the DC PF functionality that is embedded in the Day-Ahead Energy and Operating Reserve Market SCED algorithm. These constraints are presented in a manner to maximize understanding and clarity of the DC PF function within the SCED algorithm. The actual constraints within the SCED algorithm represent an equivalent but simplified formulation (i.e., many of the primal variables are eliminated by combining and simplifying the constraints presented in this document into a reduced equivalent constraint set).

6.2.6.1 Bus Energy Injection Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints establish the total energy injected at each bus for the hour:

PI(i,h)
=
Σ { DF(i,r) * ClearedEnergy(r,h)}
r
+ Σ Σ { DF (i,tr) * ClearedImportSeg(tr,h,sg)}
tr sg
+ Σ Σ { DF(i,tr) * ClearedVirtualSupSeg(tr,h,sg)}
tr sg
+ Σ Σ { SourceDF(i,tr) * ClearedUpToTUCSeg(tr,h,sg)}
tr sg
+ Σ { DF(i,tr) * FixedImportMW(tr,h) * MinLimitScaleFactor(h)}
tr
+ Σ { LoopFlowInjectionMW(i,h)}
i

The net energy injected at a bus is equal to the sum of:

- All resource energy injected into the bus
- All fixed and dispatchable import energy injected into the bus
- All virtual supply energy injected into the bus
- All wheel-through energy injected into the bus
- All loop flow energy injected into the bus

6.2.6.2 Bus Energy Withdrawal Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints establish the energy withdrawn at each bus for the hour where net energy withdrawals include all fixed demand bids and modeled losses:

$$
\begin{aligned}
&PW(i,h) \\
&= \\
&\sum_{tr}\sum_{sg} \{ DF(i,tr) * ClearedDemSeg(tr,h,sg) \} \\
&+ \sum_{tr}\sum_{sg} \{ DF(i,tr) * ClearedExportSeg(tr,h,sg) \} \\
&+ \sum_{tr}\sum_{sg} \{ DF(i,tr) * ClearedVirtualDemSeg(tr,h,sg) \} \\
&+ \sum_{tr}\sum_{sg} \{ SinkDF(i,tr) * ClearedUpToTUCSeg(tr,h,sg) \} \\
&+ \sum_{tr} \{ DF(i,tr) * FixedExportMW(tr,h) * FixDemScaleFactor(h) \} \\
&+ \sum_{i} \{ LoopFlowWithdrawalMW(i,h) \} \\
&+ \sum_{tr} \{ RefBusDF(i) * FixedDemBidMW(tr, h) * FixDemScaleFactor(h) \}
\end{aligned}
$$

The energy withdrawn at a bus is equal to the sum of:

- All price sensitive demand energy withdrawn from the bus
- All fixed and dispatchable export energy withdrawn from the bus
- All virtual demand energy withdrawn from the bus
- All wheel-through energy withdrawn from the bus
- All loop flow energy withdrawn from the bus
- Fixed Demand Bid energy withdrawn from the bus
- Modeled loss energy withdrawn from the bus

6.2.6.3 Modeled Losses Constraint

Since the linearized DC OPF does not model branch resistances, the modeled losses constraint must be used to approximate series transmission losses in terms of net injections at all buses using linearized marginal loss sensitivity factors as follows.

$$ModeledLosses(h) = \sum_{i} \{ \partial Loss(i,h)/\partial P(i,h) * [PI(i,h) - PW(i,h)]\} + LossOffsetFactor * LossDemandFactor * MTLF(h)$$

Linearized marginal loss sensitivity factors are used to calculate marginal losses in terms of net injections at each bus. However, marginal losses are greater than actual losses since losses are non-linear (i.e., Branch Losses = 3 * I^2R). The loss offset term in this constraint corrects for the difference between marginal losses and actual losses, and is estimated based on the fixed demand bids and a pre-determined loss offset factor. Modeled losses are actually modeled at the load distributed reference bus in order to distribute losses through the system. Because losses are modeled at the load distributed reference bus, all injections and withdrawals at the load distributed reference bus (which include both fixed demand bids and actual losses) have no net impact on modeled losses in the OPF model.

6.2.6.4 Bus Voltage Angle Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints establish the bus voltage angles at each bus in terms of net energy injections and energy withdrawals at all buses:

$$\theta(i,h) = \sum_{j} \{ InvB(i, j,h) * [PI(j,h) - PW(j,h) - RefBusDF(j) * ModeledLosses(h)]\}$$

The bus voltage angles are expressed in terms of the total net energy injected and withdrawn at each bus and the inverted bus admittance matrix elements. That is, the DC OPF utilizes a linearized flow representation where flows from one bus to the other are assumed equal to the product of the mutual admittance between the buses and the difference between the bus voltage angles at the two buses. This is often referred to as the B-Theta approximation, and assumes bus voltage magnitudes are at 1.0 per unit and the difference in voltage angles between two buses connected by one or more branches is small (i.e., $\sin\theta \approx \theta$). This linearized approximation is required by the LP solver. However, other transmission constraints, including watch list transmission constraints and constraints activated by transmission contingency analysis are also utilized in the SCED algorithm, and are covered under Section 6.2.6).

6.2.6.5 Global Power Balance Constraint

Constraint Classification: Reliability

Constraint Type: Penalized Equality

The global power balance constraints ensure that all Energy injected into the Eastern Interconnection during the hour balances with all Energy withdrawn from the Eastern Interconnection during the Dispatch Interval.

The global power balance constraint is expressed as follows:

Σ { PI(i,h)}
- NSI(h)
+ GlobalEnergyShortage(i,h)
=
Σ { PW(i,h)}
i
+ ModeledLosses(h)
+ GlobalEnergySurplus(i,h)

6.2.6.6 Fixed Demand Scale Factor Constraint

The fixed demand scale factor constraint prevents the fixed demand scale factor from exceeding 1.0.

FixedDemScaleFactor(h)
≤
1.0

The purpose of the fixed demand scale factor is to equally distribute an energy deficit to all fixed demand and fixed export schedules. In the unlikely event of an energy deficit, the result would be VOLL pricing throughout the market.

6.2.6.7 Minimum Limit Scale Factor Constraint

The minimum limit scale factor constraint prevents the minimum limit scale factor from exceeding 1.0.

MinLimitScaleFactor(h)
≤
1.0

The purpose of the minimum limit scale factor is to equally distribute an energy surplus to all fixed demand and fixed export schedules. In the unlikely event of an energy surplus the result would be negative energy scarcity pricing throughout the market.

6.2.7 Reliability Constraints

6.2.7.1 Market-Wide Operating Reserve Constraint

Constraint Classification: Reliability

Constraint Type: Logic-Based, Hard GE

The market-wide Operating Reserve constraints require that the total of the minimum zonal Operating Reserve Requirements (Regulating, Spinning, and Supplemental) in an hour be greater than or equal to the market-wide Operating Reserve requirement for that hour.

MWRegReq(h)

+ Σ { ZminSpinReq(z,h)}
z
+ Σ { ZMinSuppReq(z,h)}
z
≥
Σ { MWOpResStepClearing(st,h)}
st
- MWOpResShortage(h)

6.2.7.2 Market-Wide Regulating plus Spinning Reserve Constraint

Constraint Classification: Reliability

Constraint Type: Logic Based, Hard GE

The market-wide Regulating plus Spinning Reserve constraint requires that the total supply of Regulating Reserve and Spinning Reserve during the hour be greater than or equal to the market-wide Regulating plus Spinning Reserve requirement for the hour.

IF { SERSSRegResMW(h)< MWRegReq(h)**}**
Σ { ZMinRegReq(z,h)}
z
+ Σ { ZMinSpinReq(z,h)}
z
+ Σ { ClearedRegRes1(r,h)}
r=SER
≥
MWRegSpinResStep1Clearing(h)
+
MWRegSpinResStep2Clearing(h)
+
MWRegSpinResStep3Clearing(h)
- MWRegSpinResShortage(h)
ELSE
MWRegReq(h)
+ Σ { ZMinSpinReq(z,h)}

z
≥
MWRegSpinResStep1Clearing(h)
+
MWRegSpinResStep2Clearing(h)
+
MWRegSpinResStep3Clearing(h)
- MWRegSpinResShortage(h)

END IF

6.2.7.3 Market-Wide Regulating Reserve Constraint

Constraint Classification: Reliability

Constraint Type: Hard GE

The market-wide Regulating Reserve constraints require that the sum of each Reserve Zone's minimum zonal regulating reserve requirement in an hour be greater than or equal to the market-wide Regulating Reserve requirement for that hour.

Σ { ZminRegReq(z,h)}
z
≥
MWRegResStep1Clearing(h)
+
MWRegResStep2Clearing(h)
-
MWRegResShortage(h)

6.2.7.4 Market-Wide Short Term Reserve Constraint

Constraint Classification: Reliability

Constraint Type: Hard GE

The market-wide Short Term Reserve constraints require that the total supply of Short Term Reserve from the sum of each Reserve Zone's minimum zonal Short Term Reserve requirement in an hour be greater than or equal to the market-wide Short Term Reserve requirement for that hour.

$$\sum_{z} \{ ZminSTRReq(z,h) \} \geq MWSTRResClearing(h)$$

6.2.7.5 Market-Wide Up Ramp Capability Constraint

Constraint Classification: Good Utility Practice

Constraint Type: Hard GE

The market-wide Up Ramp Capability constraints require that the sum of Up Ramp Capability from each Reserve Zone's minimum zonal Up Ramp Capability requirement in the hour be greater than or equal to the market-wide Up Ramp Capability requirement for the hour

$$\sum_{z} \{ ZminRCUpReq(z,h) \} \geq MWRCUpStep1Clearing(h) + MWRCUpStep2Clearing(h)$$

6.2.7.6 Market-Wide Down Ramp Capability Constraint

Constraint Classification: Good Utility Practice

Constraint Type: Hard GE

The market-wide Down Ramp Capability constraints require that the sum of Down Ramp Capability from each Reserve Zone's minimum zonal Down Ramp Capability requirement in the hour be greater than or equal to the market-wide Down Ramp Capability requirement for that hour.

$$\sum_{z} \{ ZminRCDownReq(z,h) \}$$

$$\geq$$

$$MWRCDownStep1Clearing(h)$$

$$+$$

$$MWRCDownStep2Clearing(h)$$

6.2.7.7 Reserve Procurement Minimum Reserve Zone Regulating Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Regulating Reserve constraints require that the total supply of Regulating Reserve within a reserve zone in an hour be greater than or equal to the minimum reserve zone Regulating Reserve requirement for that reserve zone.

$$\sum_{r \in z} \{ RegResDispatch1(r,h) \}$$

$$\geq$$

$$ZMinRegReq(z,h)$$

These constraints require that sum of the Regulating Reserve dispatched on all resources within a specific reserve zone during the hour is greater than or equal to the minimum zonal regulating reserve requirement for that reserve zone. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

6.2.7.8 Reserve Procurement Minimum Reserve Zone Regulating plus Spinning Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Regulating plus Spinning Reserve constraints require that the total supply of Regulating plus Contingency Reserve within a reserve zone in an hour be greater than or equal to the minimum reserve zone Regulating plus Spinning Reserve requirement for that reserve zone.

$$\sum_{r \in z} \{ ClearedRegRes1(r,h) + ClearedRegRes2(r,h) \} + \sum_{r \in z} \{ ClearedContRes(r,h) \} \geq ZMinRegReq(z,h) + ZMinSpinReq(z,h)$$

These constraints require that sum of the Regulating Reserve and Contingency Reserves dispatched on all resources within a specific reserve zone during the hour is greater than or equal to the minimum zonal regulating plus spinning reserve requirement for that reserve zone. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

6.2.7.9 Reserve Procurement Minimum Reserve Zone Operating Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Operating Reserve constraints require that the total supply of Operating Reserves within a reserve zone in an hour be greater than or equal to the sum of the minimum reserve zone Regulating Reserve requirement and the minimum reserve zone Regulating plus Spinning Reserve requirement for that reserve zone and that hour.

$$\sum_{r \in z} \{ ClearedRegRes1(r,h) + ClearedRegRes2(r,h) \} + \sum_{r \in z} \{ ClearedContRes(r,h) \} \geq ZMinRegReq(z,h) + ZMinSpinReq(z,h) + ZMinSuppReq(z,h)$$

These constraints require that sum of the Regulating Reserve and Contingency Reserves dispatched on all resources within a specific reserve zone during the hour is greater than or equal to the sum of the minimum zonal regulating reserve requirement and the minimum zonal regulating plus spinning reserve requirement for that reserve zone. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

6.2.7.10 Reserve Procurement Minimum Reserve Zone Short Term Reserve Requirement

Constraint Classification: Reliability

Constraint Type: Hard GE

The Reserve Procurement Short Term Reserve Reserve constraints require that the total supply of Short Term Reserves within a Reserve Zone in an hour be greater than or equal to the sum of the minimum Reserve Zone Short Term Reserve requirement for that Reserve Zone and that hour.

$$\sum_{r \in z} \{ ClearedOnlineSTR(r,h) + ClearedOfflineSTR(r,h) \} \geq$$

ZMinSTRReq(z,h)

These constraints require that sum of the Short Term Reserve on all resources within a specific Reserve Zone during the hour is greater than or equal to the sum of the minimum zonal Short Term Reserve requirement. The reserve procurement minimum reserve requirements ensure that cleared reserves are deliverable as needed.

6.2.7.11 Ramp Procurement Minimum Reserve Zone Up Ramp Capability Requirement

Constraint Classification: Good Utility Practice

Constraint Type: Hard GE

The ramp procurement minimum Reserve Zone Up Ramp Capability constraints require that the total supply of Up Ramp Capability within a Reserve Zone in an hour be greater than or equal to the minimum Reserve Zone Up Ramp Capability requirement for that Reserve Zone.

$$\sum_{r \in z} \{ ClearedRCUp(r,h) \}$$

$$\geq$$

$$ZMinRCUpReq(z,h)$$

These constraints require that sum of Up Ramp Capability dispatched on all resources within a specific Reserve Zone during the Dispatch Interval is greater than or equal to the minimum zonal Up Ramp Capability requirement for that Reserve Zone. The Ramp procurement minimum Reserve Zone Up Ramp Capability requirements ensure that cleared Up Ramp Capability are deliverable as needed.

6.2.7.12 Ramp Procurement Minimum Reserve Zone Down Ramp Capability Requirement

Constraint Classification: Good Utility Practice

Constraint Type: Hard GE

The ramp procurement minimum Reserve Zone Down Ramp Capability constraints require that the total supply of Down Ramp Capability within a Reserve Zone in an hour be greater than or equal to the minimum Reserve Zone Down Ramp Capability requirement for that Reserve Zone.

$$\sum_{r \in z} \{ \text{ClearedRCDown}(r,h) \} \geq \text{ZMinRCDownReq}(z,h)$$

These constraints require that sum of Down Ramp Capability dispatched on all resources within a specific Reserve Zone during the Dispatch Interval is greater than or equal to the minimum zonal Down Ramp Capability requirement for that Reserve Zone. The Ramp procurement minimum Reserve Zone Down Ramp Capability requirements ensure that cleared Down Ramp Capability are deliverable as needed.

6.2.7.13 Generation-Based Operating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The generation-based Operating Reserve constraints are used to comply with reliability standards that limit the amount of Operating Reserve that can be carried on demand response resources.

IF { SERSSRegResMW(h)< MWRegReq(h)**}**

$$\sum_{r \notin DRR1} \{ \text{ClearedRegRes1}(r,h) + \text{ClearedRegRes2}(r,h) \} + \sum_{r \notin DRR1} \{ \text{ClearedContRes}(r,h) \} \geq \text{MWORReq}(h) * \text{GenORReqFactor} - \text{GenOpResShortage}(h)$$

ELSE

$$\text{MWRegResReq}(h) + \sum_{r \neq SER} \{ \text{ClearedRegRes1}(r,h) + \text{ClearedRegRes2}(r,h) \} + \sum_{r \notin DRR1} \{ \text{ClearedContRes}(r,h) \} \geq$$

MWORReq(h) * GenORReqFactor
- GenOpResShortage(h)
END IF

These constraints require that the amount of regulating reserve and contingency reserve cleared on all resources other than Demand Response Resources - Type I must be greater than or equal to the market-wide Operating Reserve requirement multiplied by a generation-based Operating Reserve requirement factor.

6.2.7.14 Generation-Based Regulating plus Spinning Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The generation-based Regulating plus Spinning Reserve constraints are used to limit the amount of Regulating and/or Spinning reserve that can be carried on demand response resources.

IF { SERSSRegResMW(h)< MWRegReq(h)**}**
Σ { ClearedRegRes1(r,h) + ClearedRegRes2(r,h)}
r∉DRR1
+ Σ { ClearedContRes(r,h) * SpinAvailability(r,h)}
r∉DRR1
≥
MWRegSpinReq(h) * GenRegSpinReqFactor
- GenRegSpinResShortage(h)
ELSE
MWRegResReq(h)
+ Σ { ClearedRegRes1(r,h) + ClearedRegRes2(r,h)}
r ≠SER
+ Σ { ClearedContRes(r,h) * SpinAvailability(r,h)}
r∉DRR1
≥
MWRegSpinReq(h) * GenRegSpinReqFactor
- GenRegSpinResShortage(h)
END IF

These constraints require that the amount of regulating reserve and contingency reserve cleared on all resources that are 1) qualified to provide Regulating Reserve and/or Spinning Reserve and 2) are not Demand Response Resources - Type I, must be greater than or equal to the market-wide Regulating plus Spinning Reserve requirement multiplied by a generation-based Regulating plus Spinning Reserve requirement factor.

The Cleared Regulating Reserve Constraints for Demand Response Resources - Type I (see 4.2.2.2 prevent Demand Response Resources - Type I from clearing Regulating Reserves. Currently, GenRegSpinReqFactor is set such that the Spinning Reserve cleared on qualified resources other than Demand Response Resources - Type I is greater than or equal to 60%.

6.2.7.15 Generation-Based Regulating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based, Penalized GE

The generation-based Regulating Reserve constraints are used to comply with reliability standards that limit the amount of Regulating Reserve that can be carried on demand response resources.

IF { SERSSRegResMW(h)< MWRegReq(h)**}**

$$\sum_{r} \{ \text{ClearedRegRes1}(r,h) \} \geq \text{MWRegReq}(h) * \text{GenRegReqFactor} - \text{GenRegResShortage}(h)$$

ELSE

$$\text{MWRegResReq}(h) + \sum_{r \neq SER} \{ \text{ClearedRegRes1}(r,h) \} \geq \text{MWRegReq}(h) * \text{GenRegReqFactor} - \text{GenRegResShortage}(h)$$

END IF

These constraints require that the amount of regulating reserve cleared on all resources that are not Demand Response Resources - Type I to be greater than or equal to the market-wide Regulating Reserve requirement multiplied by a generation-based Regulating Reserve requirement factor.

Since pre-SCUC processing already prohibits Demand Response Resources - Type 1 from supplying Regulating Reserve based on the Tariff rules, **these constraints are unnecessary and have been disabled** in the SCED algorithm.

As reliability standards continue to be developed and modified, these constraints may need to re-enabled and/or modified accordingly. For example, if a reliability standard were developed restricting the percentage of Regulating Reserve that could be cleared on controllable load to some value less than 100% but greater than 0% of the market-wide Regulating Reserve requirement, this constraint would be re-enabled.

6.2.7.16 Basecase Transmission Constraints

Basecase transmission constraints ensure the basecase transmission flows determined by the OPF functionality of the SCED algorithm comply with the transmission branch limits.

These constraints are expressed mathematically as follows in the SCED algorithm:

BranchB(k,h) * [θ(j,h) - θ(i,h)]
≤
BranchLimit(k,h)
+ Σ TransLimitStepViolation(st,k,h)
st
AND
-BranchB(k,h) * [θ(j,h) - θ(i,h)]
≤
BranchLimit(k,h)
+ Σ TransLimitStepViolation(st,k,h)
st

6.2.7.17 Watch List Transmission Flowgate Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Watch list transmission flowgate constraints represent the subset of transmission constraints most likely to bind or violate. These constraints are enforced to ensure resources are cleared as necessary to effectively manage potential congestion on the transmission system

$$
\begin{aligned}
&\sum_{r} \{[\text{ClearedEnergy}(r,h)][\partial \text{Flow}(k,h)/\partial P(r,h)]\} \\
&+ \sum_{tr} \{ \text{ClearedImportSeg}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&+ \sum_{tr} \{ \text{ClearedVirtualSupSeg}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&+ \sum_{tr} \{ \text{ClearedUpToTucSeg}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&+ \sum_{tr} \{ \text{FixedImportMW}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&+ \sum_{i} \{ \text{LoopFlowInjectionMW}(i,h) * \partial \text{Flow}(k,h)/\partial P(i,h)\} \\
&- \sum_{tr} \{ \text{ClearedDemSeg}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&- \sum_{tr} \{ \text{ClearedExportSeg}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&- \sum_{tr} \{ \text{ClearedVirtualDemSeg}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&- \sum_{tr} \{ \text{FixedExportMW}(tr,h) * \partial \text{Flow}(k,h)/\partial P(tr,h)\} \\
&- \sum_{i} \{ \text{LoopFlowWithdrawalMW}(i,h) * \partial \text{Flow}(k,h)/\partial P(i,h)\} \\
&\le \\
&\text{FGLimit}(k,h) \\
&+ \sum_{st} \text{TransLimitStepViolation}(st,k,h)
\end{aligned}
$$

Together, the left hand side of this constraint is defined as "Flow_SystemEnergySCED(k,h)", a useful expression which is used again in the constraints that follow.

6.2.7.18 Sub-Regional Power Balance Constraint

Constraint Classification: Reliability

Constraint Type: Penalized LE

The Sub-Regional Power Balance Constraint represents a net energy injection and withdrawal constraint established to manage intra-regional flows in accordance with applicable seams agreements, coordination agreements, transmission service agreements or operating procedures. This constraint is enforced in the SCUC algorithm to ensure resources are committed as necessary to effectively manage its binding limit.

$$
\begin{aligned}
&\sum_{r} \{[ClearedEnergy(r,h)][InyC(k,r,h)]\} \\
&+ \sum_{tr} \{ ClearedImportSeg(tr,h) * InyC(k,tr,h)\} \\
&+ \sum_{tr} \{ ClearedVirtualSupSeg(tr,h) * InyC(k,tr,h)\} \\
&+ \sum_{tr} \{ ClearedUpToTucSeg(tr,h) * InyC(k,tr,h)\} \\
&+ \sum_{tr} \{ FixedImportMW(tr,h) * InyC(k,tr,h)\} \\
&- \sum_{tr} \{ ClearedDemSeg(tr,h) * InyC(k,tr,h)\} \\
&- \sum_{tr} \{ ClearedExportSeg(tr,h) * InyC(k,tr,h)\} \\
&- \sum_{tr} \{ ClearedVirtualDemSeg(tr,h) * InyC(k,tr,h)\} \\
&- \sum_{tr} \{ FixedExportMW(tr,h) * InyC(k,tr,h)\} \\
&\leq \\
&FGLimit(k,h) \\
&+ \sum_{st} SubRegLimitStepViolation(st,k,h)
\end{aligned}
$$

6.2.7.19 Reserve Procurement Regulation-Up Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Reserve Procurement Regulation-Up constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Regulating Reserves are deployed in the upward direction.

$$\text{Flow\_SystemEnergySCED}(k,h) + \sum_{z} \text{ZMinRegReq}(z,h) * \text{ZonalRegDepSens}(k,z,h) \le \text{FGLimit}(k,h) + \text{TransLimitViolationRegUp}(k,h)$$

One Reserve Procurement Regulation-Up constraint exists for each transmission constraint that is selected to be a reserve procurement regulation constraint prior to the market processes. The constraint ensures that the total flow on the flowgate as a result of the system cleared energy, as defined in Section 4.2.5.17, plus the sum of the minimum zonal regulating reserve requirements multiplied by the zonal regulation deployment sensitivities, is less than or equal to the flowgate limit. The zonal regulation deployment sensitivity is a ramp-rate weighted average of the sensitivities of either 1) the regulation-qualified resources in the zone, or 2) the resources scheduled to potentially provide regulating reserves in the zone.

6.2.7.20 Reserve Procurement Regulation-Down Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Reserve Procurement Regulation-Down constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Regulating Reserves are deployed in the downward direction.

$$\text{Flow\_SystemEnergySCED}(k,h)$$

- Σ ZMinRegReq(z,h) * ZonalRegDepSens(k,z,h)
  z
≤
FGLimit(k,h)
+ TransLimitViolationRegDown(k,h)

One Reserve Procurement Regulation-Down constraint exists for each transmission constraint that is selected to be a reserve procurement regulation constraint prior to the market processes. The constraint ensures that the total flow on the flowgate as a result of the system cleared energy, as defined in Section 4.2.5.17, minus the sum of the minimum zonal regulating reserve requirements multiplied by the zonal regulation deployment sensitivities, is less than or equal to the flowgate limit. The zonal regulation deployment sensitivity is a ramp-rate weighted average of the sensitivities of either 1) the regulation-qualified resources in the zone, or 2) the resources scheduled to potentially provide regulating reserves in the zone.

6.2.7.21 Reserve Procurement Contingency Reserve Event Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based Penalized LE

Reserve Procurement Contingency Reserve Event constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when a contingency reserve event takes place for the loss of the largest resource in the zone.

IF { PMaxEvent(z,h) ≥PmaxThreshold }
    IF {(1/SpinImpact) * PMaxEvent(z,h) ≤ MWRegSpinReq(h)-MWRegReq(h)**}**
        Flow_SystemEnergySCED(k,h)
        -
        PMaxEvent(z,h)* ZonalTripSens(k,z,h)
        +
        RegImpact * { Σ ZMinRegReq(z1,h) * ZonalRegDepSens(k,z1,h)
            z1
        +
        {(1/SpinImpact) * PMaxEvent(z,h)} ÷ [MWRegSpinReq(h)-MWRegReq(h)]}
            * { Σ ZMinSpinReq(z1,h) * ZonalSpinDepSens(k,z1,h)}*SpinImpact

z1
≤
FGLimit_CREvent(k,h)
+ TransLimitViolationCREvent(k,h)

ELSE

Flow_SystemEnergySCED(k,h)
-
PMaxEvent(z,h)* ZonalTripSens(k,z,h)
+
RegImpact * { Σ ZMinRegReq(z1,h) * ZonalRegDepSens(k,z1,h)
z1
+
SpinImpact * { Σ ZMinSpinReq(z1,h) * ZonalSpinDepSens(k,z1,h)
z1
+
{ PMaxEvent(z,h) - SpinImpact * [MWRegSpinReq(h)-MWRegReq(h)]
÷ {[MWOpResReq(h)-MWRegSpinReq(h)]
* { SuppImpact * Σ ZminSuppReq(z1,h) * ZonalSuppDepSens(k,z1,h)}
z1
≤
FGLimit_CREvent(k,h)
+ TransLimitViolationCREvent(k,h)

END IF

ELSE

No constraint is modeled for that transmission constraint and that zone.

END IF

WHERE

PMaxEvent(z,h) is the size of the largest resource in zone z;

PmaxThreshold is a tuning parameter, a threshold on the size of the largest resource in a zone that triggers the modeling of a Reserve Procurement Contingency Reserve constraint for transmission constraints in the zone;

ZonalTripSens(k,z,h), or the zonal trip sensitivity, is a capacity-weighted average of the sensitivities of the resources available for commitment in the zone during hour h;

ZonalSpinDepSens(k,z,h), or the zonal spin deployment sensitivity, is a ramp-rate weighted average of either 1) the sensitivities of the regulation or spin qualified resources in the zone, or 2) the sensitivities of the committed, spin qualified resources in the zone and the resources scheduled to potentially provide regulating reserves in the zone during hour h;

ZonalSuppDepSens(k,z,h), or the zonal supplemental deployment sensitivity, is a weighted average of either 1) the sensitivities of resources in the zone that are qualified to provied off-line supplemental reserves, weighted by the ramp rate and the offline response capabilities of each resource, or 2) the weighted sensitivities just described, except applied to resources in the zone based on their actual commitment status (scheduled to potentially provide regulating reserves, committed but not scheduled to potentially provide regulating reserves, uncomitted but available for offline supplemental reserves) during hour h;

RegImpact is a tuning parameter that adjusts the impact on the constraint from regulating reserves;

SpinImpact is a tuning parameter that adjusts the impact on the constraint from spinning reserves;

SuppImpact is a tuning parameter that adjusts the impact on the constraint from supplemental reserves;

FGLimit_CREvent(k,h) is the flow limit on the transmission constraint given the post-contingency system topology.

One Reserve Procurement Contingency Reserve Event constraint exists for each transmission constraint and each reserve zone, provided that the size of the largest contingent event in the zone is greater than a threshold, and only for transmission constraints that have been selected to be reserve procurement contingency constraints prior to the market processes (this statement is represented by the outer “IF” statement in the logic above). The constraints ensure that reserves are deliverable during a contingency reserve event by enforcing that the pre-contingency system flow on the constraint, modified by several terms representing the impacts of regulating reserves, spinning reserves, and supplemental reserves, is less than the limit of the transmission constraint. The modifying terms are slightly different, depending on whether the size of the largest contingent event in the zone is greater than the amount of spinning reserves required for the zone (this statement is represented by the inner “IF” statement in the logic above.

6.2.7.22 Reserve Procurement Short Term Reserve Event Constraints

Constraint Classification: Reliability

Constraint Type: Logic-Based Penalized LE

Reserve Procurement Short Term Reserve Event constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when a Short Term Reserve event takes place for the loss of the largest resource in the zone.

Flow_SystenEnergy(k,e,t)
=
Flow_SystemEnergySCED (k,h)
-
ZonalSTRNeed (e,h)* ZonalTripSens(k,e,h)
+
$\sum_{z}$ STRResponse(z,e,h) * ZonalSTRDepSens(k,z,h)
≤
STRTransLimit (k,h)
+ TransLimitViolationSTREvent(k,z,h)

WHERE

ZonalSTRNeed (e,h) is the possible deployment MW for Short Term Reserveif event e happens at hour h. Event e is defined as the largest generation contingency MW for a Reserve Zone. e is the collection for max events for each zone.

ZonalTripSens(k,e,h), zonal Short Term Reservetrip sensitivity, the sensitivite of the largest generation which is tripped in event e for transmission constraint k in hour h.

STRResponse(z,e,h), Short Term Reserveresponse provided by resources for constraint *k* in zone *z* at hour h. STR Response is less than sum of all cleared Short Term Reservein zone z excluding cleared STR on the event contingency generation.

ZonalSTRDepSens(k,z,h), Zonal Short Term Reserveresponse sensitivity from zone z to constraint k at hour h, calculated as a weighted average of the constraint flow sensitivities of resources in the zone that are qualified to provide Short Term Reserve, weighted by the up ramp rate of online resources and maximum offline STR response of offline resources.

STRTransLimit (k,h), Short Term Reservetransmission constraint maximum flow allowed after Short Term Reserveresponse for constraint k at hour h .

One Reserve Procurement Short Term Reserve Event constraint exists for each transmission constraint and each Reserve Zone, provided that the size of the largest Short Term Reserve event in the zone is greater than a threshold, and only for transmission constraints that have been selected to be reserve procurement Short Term Reserve constraints prior to the market processes. The constraints ensure that reserves are deliverable during a Short Term Reserve event by enforcing the limitation that the pre-contingency system flow on the constraint, modified by several terms representing the impacts of Short Term Reserves, is less than the limit of the transmission constraint.

6.2.7.23 Short Term Reserve Post-Deployment Power Balance Constraint

Constraint Classification: Reliability

Constraint Type: Penalized LE

Post-event power balance constraints maintain power balance with the consideration of Short Term Reserve deployment and zonal events. The post-event power balance will be enforced for each Short Term Reserve event.

$$\sum_{z} \mathrm{STRResponse(z,e,h)} + \mathrm{ZNeedViolSTRPos(e,h)} - \mathrm{ZNeedViolSTRNeg(e,h)} = \mathrm{ZonalSTRNeed\ (e,h)}\ \forall e$$

$$\mathrm{ZNeedViolSTRPos(e,h)}, \mathrm{ZNeedViolSTRNeg(e,h)} \geq 0$$

6.2.7.24 Maximum Zonal Short Term Reserve Deployment Constraint

Constraint Classification: Reliability

Constraint Type: Hard LE

STR response provided by resources in zone *z* for contingency event at time h has to be less than the dynamically calculated zonal requirement.

$$STRResponse_{z,e,h} \leq ZminSTR_{z,h}$$

6.2.7.25 Ramp Procurement Up Ramp Capability Post Deployment Transmission Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Ramp Procurement Up Ramp Capability constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Up Ramp Capability are deployed in the upward direction.

FG_SystemEnergySCED(k,h)

$+ \sum_{z}$ ZMinRCUpReq(z,h) * ZonalRCUpDepSens(k,z,h)

≤

FGLimit(k,h)

+ TransLimitViolationRCUp(k,h)

One Ramp Procurement Up Ramp Capability post deployment transmission constraint exists for each transmission constraint that is selected to be a ramp procurement ramp capability constraint prior to the market processes. The constraint ensures that the total flow on the flowgate because of the system cleared energy, as defined in Section **Error! Reference source not found.**, plus the sum of the minimum zonal up ramp capability requirements multiplied by the zonal up ramp capability deployment sensitivities, is less than or equal to the flowgate limit. The zonal up ramp capability deployment sensitivity is a ramp-rate weighted average of the sensitivities of the ramp capability qualified resources in the zone.

6.2.7.26 Ramp Procurement Down Ramp Capability Post Deployment Transmission Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Ramp Procurement Down Ramp Capability post deployment transmission constraints are used to ensure that for a specific subset of transmission constraints, the flow across the transmission constraint will be within limits under circumstances when all cleared Ramp Capability are deployed in the downward direction.

$$FG\_SystemEnergySCED(k,h)$$

$$- \sum_{z} ZMinRCDownReq(z,h) * ZonalRCDownDepSens(k,z,h)$$

$$\leq$$

$$FGLimit(k,h)$$

$$+ TransLimitViolationRCDown(k,h)$$

One Ramp Procurement Down Ramp Capability constraint exists for each transmission constraint that is selected to be a ramp procurement ramp capability constraint prior to the market processes. The constraint ensures that the total flow on the flowgate as a result of the system cleared energy, as defined in Section **Error! Reference source not found.**, plus the sum of the minimum zonal down ramp capability requirements multiplied by the zonal down ramp capability deployment sensitivities, is less than or equal to the flowgate limit. The zonal down ramp capability deployment sensitivity is a ramp-rate weighted average of the sensitivities of the Ramp Capability qualified resources in the zone.

6.2.7.27 Transmission Contingency Analysis Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

Transmission contingency analysis transmission flowgate constraints represent the set of transmission constraints identified by the hourly transmission contingency analysis process (described in detail in Section 7) as potential problems and are enforced in the second hourly SCED execution (post-contingency analysis SCED execution).

Σ {[ClearedEnergy(r,h) - ClearedEnergy(r,h)|$_{\text{First SCED Execution}}$]
r * [∂Flow(k,h)/∂P(r,h)]}
+ Σ {[ClearedImportSeg(tr,h) - ClearedImportSeg(r,h)|$_{\text{First SCED Execution}}$]
tr * ∂Flow(k,h)/∂P(tr,h)}
+ Σ {[ClearedVirtualSupSeg(tr,h) - ClearedVirtualSupSeg(r,h)|$_{\text{First SCED Execution}}$]
tr * ∂Flow(k,h)/∂P(tr,h)}
+ Σ {[ClearedUpToTUCSeg(tr,h) - ClearedUpToTUCSeg(r,h)|$_{\text{First SCED Execution}}$]
tr * ∂Flow(k,h)/∂P(tr,h)}
+ Σ { FixedImportMW(tr,h) * ∂Flow(k,h)/∂P(tr,h)} tr
+ Σ { LoopFlowInjectionMW(i,h) * ∂Flow(k,h)/∂P(i,h)} i
- Σ {[ClearedDemSeg(tr,h) - ClearedDemtSeg(tr,h)|$_{\text{First SCED Execution}}$]
tr * ∂Flow(k,h)/∂P(tr,h)}
- Σ {[ClearedExportSeg(tr,h) - ClearedExportSeg(r,h)|$_{\text{First SCED Execution}}$]
tr * ∂Flow(k,h)/∂P(tr,h)}
- Σ { ClearedVirtualDemSeg(tr,h) - ClearedVirtualDemSeg(r,h)|$_{\text{First SCED Execution}}$]
tr * ∂Flow(k,h)/∂P(tr,h)}
- Σ { FixedExportMW(tr,h) * ∂Flow(k,h)/∂P(tr,h)}
tr
- Σ { LoopFlowWithdrawalMW(i,h) * ∂Flow(k,h)/∂P(i,h)}
i
+ ACFlow(k,h)
≤
FGLimit(k,h)
+ Σ TransLimitStepViolation(st,k,h)
st

6.2.8 Tie-Breaking Constraints

6.2.8.1 Cleared Energy Tie-Breaking Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Hard Equality

The cleared Energy tie-breaking constraints ensure equitable clearing of energy between two or more resources / transactions when there are multiple optimal solutions.

EnergyTieBreak1(e1,e2,h)
- EnergyTieBreak2(e1,e2,h)
=
MaxLimit(e1,h) * ClearedEnergy(e2,h)
- MaxLimit(e2, h)* ClearedEnergy(e1,h)

The cleared Energy tie-breaking constraints distribute the clearing of energy among price-tied resources and/or transactions in proportion to the maximum limit offered by those resources or transactions for the hour.

6.2.8.2 Cleared Regulating Reserve Tie-Breaking Constraints

Constraint Classification: Good Utility Practice

Constraint Type: Hard Equality

The cleared Regulating Reserve tie-breaking constraint ensures equitable clearing of regulating reserve between two or more resources when there are multiple optimal solutions.

RegResTieBreak1(r1,r2,h)
- RegResTieBreak2(r1,r2,h)
=
InputRampRate(r1,h) * {ClearedRegRes1(r2,h) + ClearedRegRes2(r2,h)}
- InputRampRate (r2, h)* {ClearedRegRes1(r2,h) + ClearedRegRes2(r2,h)}

The cleared Regulating Reserve tie-breaking constraints distribute the clearing of regulating reserve among price-tied resources in proportion to the ramp rate offered by those resources for the hour.

6.2.8.3 Cleared Contingency Reserve Tie-Breaking Constraints - Committed Resources

Constraint Classification: Good Utility Practice

Constraint Type: Hard Equality

The cleared Contingency Reserve tie-breaking constraints ensure equitable clearing of contingency reserve between two or more committed resources when there are multiple optimal solutions.

ContResTieBreak1(r1,r2,h)
– ContResTieBreak2(r1,r2,h)
=
InputRampRate(r1,h) * ClearedContRes(r2,h)
- InputRampRate (r2, h)* ClearedContRes(r1,h)

The cleared Contingency Reserve tie-breaking constraints distribute the clearing of contingency reserve among price-tied resources in proportion to the ramp rate offered by those resources for the hour.

6.2.8.4 Cleared Contingency Reserve Tie-Breaking Constraints – Uncommitted Resources

Constraint Classification: Good Utility Practice

Constraint Type: Hard Equality

The cleared Contingency Reserve tie-breaking constraints ensure equitable clearing of contingency reserve between two or more uncommitted resources when there are multiple optimal solutions.

6.2.8.5 Cleared Offline Short Term Reserve Tie-Breaking Constraints – Not Committed Resources

Constraint Classification: Good Utility Practice

Constraint Type: Hard Equality

The cleared Offline Short Term Reserve tie-breaking constraints ensure equitable clearing of Short Term Reserve between two or more non-committed resources when there are multiple optimal solutions.

STRResTieBreak1(r1,r2,h)
– STRResTieBreak2(r1,r2,h)
=
MaxOfflineSTR (r1,h) * ClearedOfflineSTR (r2,h)
- MaxOfflineSTR (r2, h)* ClearedOfflineSTR (r1,h)

The cleared Offline Short Term Reserve tie-breaking constraints distribute the clearing of short term reserve among price-tied resources in proportion to the Short Term Reserve Offline max limit offered by those resources for the hour.

ContResTieBreak1(r1,r2,h)
– ContResTieBreak2(r1,r2,h)
=
MaxOffLineResponse(r1,h) * ClearedContRes(r2,h)
- MaxOffLine Reponse(r2,h)* ClearedContRes(r1,h)

NOTE: The maximum off-line response limit is replaced by the targeted demand reduction level if the uncommitted resource is a Demand Response Resource - Type I.

The cleared Contingency Reserve tie-breaking constraints distribute the clearing of contingency reserve among price-tied resources in proportion to the ramp rate offered by those resources for the hour.

6.3 SCED Constraint Relaxation Logic

There are instances when opposing constraints cause a non-zero value for one or more violation variables. When this occurs, LMPs and MCPs become impacted by arbitrary penalty prices. Unless these penalty prices have been specified in the Tariff in the form of a demand curve (which is the case for operating reserve, regulating reserve constraints, and regulating plus spinning reserve constraints), it is necessary to employ constraint relaxation techniques and re-execute the SCED algorithm with the goal of generating the same primal solution (i.e., same clearing results), but removing the impacts of penalty pricing and instead relying on the maximum value of the supply curve to set prices.

After SCED executes, automatic constraint relaxation logic identifies constraints that have violation variable values greater than zero (i.e., violated constraints with penalty pricing impacts). The constraint limits are then adjusted (up for LE constraints and down for GE constraints) by an amount equal to the violation amount plus a small configurable percentage and SCED is re-executed with the adjusted limits. The idea is that the second SCED execution will generate the same primal solution (i.e., cleared energy, cleared Regulating Reserve and cleared Contingency Reserve should be the same or very close to the same as the first SCED iteration). However, with the adjusted limits, constraints that violated in the first SCED iteration will not violate in the second SCED iteration. LMPs and MCPs will no longer be impacted by arbitrary penalty prices. Instead, prices will be based on the maximum supply curve price, where the supply curve is a function of both offers and opportunity costs.

It is important to note that while the LP solvers used to implement the SCED algorithm are very accurate, relaxation of a constraint by an amount exactly equal to the violation may not totally eliminate the constraint violation. Therefore, it is generally necessary to over-relax the violated constraint by a small over-relaxation percentage (generally 1% of the violation amount). The automatic constraint relaxation logic contains user-configurable over-relaxation percentage settings to accomplish this.

The following constraints can be automatically relaxed by the Day-Ahead SCED algorithm, and the relaxation is prioritized based on the magnitude of the penalty price:

- Generation-Based Operating Reserve Constraint
- Generation-Based Regulating plus Spinning Reserve Constraint
- Generation-Based Regulating Reserve Constraint
- Maximum Resource Regulating Reserve Constraints
- Maximum Resource Contingency Reserve Constraints
- Maximum Resource Short Term Reserve Constraints
- Self-Scheduled Energy Constraints
- Self-Scheduled Regulating Reserve Constraints
- Self-Scheduled Contingency Reserve Constraints

It is sometimes necessary to relax transmission constraints as well, but relaxation of transmission constraints in the Day-Ahead Energy and Operating Reserve Market is a manual process and not included in the automatic SCED constraint relaxation logic.

6.4 SCED Output

The following output is generated by the SCED algorithm:

- Cleared hourly energy volumes for resources
- Cleared hourly energy volumes for non-resource transactions
- Cleared hourly regulating reserve volumes for resources
- Cleared hourly spinning reserve volumes for resources
- Cleared hourly supplemental reserve volumes for resources
- Cleared hourly Short Term Reserve volumes for resources
- Current Energy Storage Level for Electric Storage Resource
- Transmission constraint hourly shadow prices
- Sub-Regional Power Balance constraint hourly shadow prices
- Market-wide operating reserve constraint hourly shadow prices
- Market-wide regulating plus spinning reserve constraint hourly shadow prices

- Market-wide regulating reserve constraint hourly shadow prices
- Market-Wide Non-Sustainable Regulating Reserve constraint shadow prices
- Market-wide Short Term Reserve constraint hourly shadow prices
- Reserve Procurement Minimum Reserve Zone Regulating Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Regulating plus Spinning Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Operating Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Short Term Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Ramp Capability Up Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Ramp Capability Down Reserve Requirement shadow prices
- Generation-based operating reserve constraint hourly shadow prices

7. SCED-Pricing Formulations

The Day-Ahead SCED-Pricing algorithm is executed for each hour of the operating day after completion of the Day-Ahead SCED algorithm to:

- Calculate Ex Post Locational Marginal Prices (LMPs) for Energy
- Calculate Ex Post Market Clearing Prices (MCPs) for Regulating Reserve, Spinning Reserve, Supplemental Reserve, Up and Down Ramp Capability and Short Term Reserve.

The Day-Ahead SCED-Pricing algorithm uses a Linear Programming (LP) solver as described in Schedule 29A of the Tariff. The SCED-Pricing algorithm extends the concept of LMP and MCP by allowing the cost of committing Fast Start Resources, the Energy cost of Fast Start Resources dispatched at limits, and Emergency Demand Response Resources to set Energy and reserve prices. Fast Start Resources are a generation resource that can be started, synchronized and inject energy or a demand response resource that can reduce energy consumption within 10 minutes of notification, has a minimum run time of one hour or less and is not a fuel limited resources. Under Capacity shortage conditions, Proxy Offers will be established for the emergency capacity that is designated as available during the shortage condition only. The Proxy Offer is the maximum of the Emergency Tier I Offer Floor and the Energy Offer of the applicable capacity block. The Emergency Tier I Offer Floor is established for hours with shortage conditions as the maximum of $500 and the highest available economic offer in the Energy Emergency Area with the costs of committing and dispatching Fast Start Resources considered in the same way as that specified in section 7.1.2. As such, a Proxy Offer is allowed to exceed the Energy Offer Price Cap, which is for incremental energy cost only. The Proxy Offer will be used in the SCED-Pricing algorithm specified below for resources' emergency dispatch range above the economic maximum limit or the entire range for emergency commitments.

In the formulations that follow, continuous primal variables are shown in a red font and constraint violation variables are shown in a blue font. See Attachment A on Market Optimization Techniques for background information on LP SCED formulations.

7.1 SCED-Pricing Objective Function

The overall objective function of the SCED-Pricing algorithm, the same as the SCED algorithm with the exceptions for treatment of Fast Start Resources, is to minimize the following cost function over a single hour in the operating day:

MINIMIZE { Resource Energy Costs
+ Fast Start Resources Commitment Cost
- Price Sensitive Demand Value
+ Dispatchable Import Costs
- Dispatchable Export Value
+ Virtual Supply Costs
- Virtual Demand Value
- Up-to-TUC Transaction Costs
+ Regulating Reserve Costs
+ Contingency Reserve Costs
+ Off-Line Short Term Reserve Costs
- Market-Wide Operating Reserve Value
- Market-Wide Regulating Reserve Value
- Market-Wide Regulating plus Spinning Reserve Value
- Market-Wide Short Term Reserve Value
+ Proxy Offer Costs of External Resource that Qualifies as Planning Resource, Load Modifying Resource or Emergency Energy Purchase
+ Constraint Violation Penalty Costs**
+ Energy Balance Scaling Penalty Costs***
+ Tie-Breaking Penalty Costs**}**

*Note: Under Capacity shortage conditions, a Proxy Offer will be used for resources' emergency dispatch range above the economic maximum limit or the entire range for emergency only commitments
**Note: Applies only when there are opposing constraints
***Note: Applies only under an energy surplus or energy deficit

The cost terms in the objective function above are described as follows.

7.1.1 SCED-Pricing Objective Function Cost Terms Shared with SCED Objective Function

A number of the cost terms of the SCED-Pricing objective function are calculated identically to cost terms in the SCED objective function that can be found in section 6.1 of this Attachment. Those cost terms are:

- Resource Energy Costs,
- Price Sensitive Demand Value,

- Dispatchable Import Costs,
- Dispatchable Export Value,
- Virtual Supply Cost,
- Virtual Demand Value,
- Up-to-TUC Transaction Value,
- Regulating Reserve Costs,
- Contingency Reserve Costs,
- Off-Line Short Term Reserve Costs,
- Market-Wide Operating Reserve Value,
- Market-Wide Regulating Reserve Value,
- Market-Wide Regulating plus Spinning Reserve Value,
- Market-Wide Short Term Reserve Value,
- Opposing Constraint Violation Penalty Costs,
- Energy Balance Scaling Penalty Costs,
- Tie-Breaking Penalty Costs
- Emergency Purchases Cost*
- External Resources that are Planning Resources Cost*

* Under Capacity shortage conditions, the Proxy Offer Cost for a resource's emergency capacity is the maximum of the Emergency Tier I Offer Floor and the Energy Offer of the applicable capacity block. The Emergency Tier I Offer Floor is established for hours of generation scarcity as the maximum of $500 and the highest available economic offer with the costs of committing and dispatching Fast Start Resources considered in the same way as that specified in Section 7.1.2. As such, a Proxy Offer is allowed to exceed the Energy Offer Price Cap, which is for incremental energy cost only.

7.1.2 Fast Start Resources Commitment Costs

Fast Start Resources Commitment Costs are the sum of the Start-Up offer and No-Load offer for generation resources and DRR type II or shut down offer and hourly curtailment offer for DRR type I that would be incurred by all Fast Start Resources available for commitment by the Transmission Provider, based on their submitted Start-Up, No-Load Offer Costs, Shut-down offer and hourly curtailment offer if SCED-Pricing determines their possible commitment best meets the objective function.

The Day-Ahead Pricing formulation considers the costs of committing and the costs of keeping on-line those Fast Start Resources that are committed by the Transmission Provider to be on line in the Hour. It also considers the costs of committing and dispatching off-line Fast Start Resources if either or both of the following conditions hold:

(a) The SCED algorithm finds a solution that does not meet energy and/or reserve requirements in the Hour except for the Surplus Conditions;
(b) The SCED algorithm finds a solution that violates a transmission constraint for which the Transmission Provider is the monitoring entity and the Transmission Provider determines that commitment of the Fast Start Resource provides significant relief to the violation. For purposes of this provision, offline resources with Generation Shift Factors either greater than or equal to 6% or less than or equal to – 6% are deemed to be providing significant relief to the transmission constraint violation.

7.1.2.1 Online Resources

The SCED-Pricing algorithm allocates a share of the Start-Up Cost or Shut-Down Cost of the Fast Start Resource to the hour for which prices are being calculated. The following costs are different from those in the SCED algorithm and for those costs N is the minimum run time for generation resources or DRR – Type II, or the Minimum Interruption Duration for DRR – Type I.

On-line Fast Start Resources Commitment Costs are expressed mathematically in the SCED-Pricing objective function as follows:

Generation resources and DRR type II:

$$= \sum_{r} \{On(r,h) * \{AllocatedShareStartUpCost(r,h) + NoLoadCost(r,h)\}\}$$

where AllocatedShareStartUpCost(r,h) = StartUpCost(r) / N if hour is within N hours of the time the Generation or DRR type II resource was committed, or 0 if hour is later than N hours after the resource was committed

DRR type I

$$= \sum_{r1} \{On(r1, h) * \{(AllocatedShareShutdownCost(r1, h) + HourlyCurtailmentOffer(r1, h\}\}$$

Where AllocatedShareShutDownCost(r1, h) = ShutDownCost(r1) / N if hour is within N hours of the time the DRR - Type I was committed, or 0 if hour is later than N hours after the DRR - Type I was committed.

7.1.2.2 Offline Resources

The SCED-Pricing algorithm allocates a share of the Start-Up Cost or Shut-Down cost for the Fast Start Resource to the Hour for which prices are being calculated. The following costs are different than in the SCED algorithm and for those costs N is the minimum run time for generation resources or DRR - Type II, or the Minimum Interruption Duration for DRR - Type I, offered by the Fast Start Resource in hours, where N is rounded up to the nearest hour.

Off-line Fast Start Resources Commitment Costs are expressed mathematically in the SCED-Pricing objective function as follows:

Generation resources and DRR type II:

$$= \sum_{r} \{On(r,h) * \{StartUpCost(r) / N + NoLoadCost(r,h)\}\}$$

DRR type I

$$= \sum_{r1} \{On(r1, h) * \{(ShutdownCost(r1) / N + HourlyCurtailmentOffer(r1, h\}\}$$

7.2 SCED-Pricing Constraints

The overall objective function of the SCED-Pricing algorithm is minimized subject to the following constraints.

7.2.1 Generation Resource and Demand Response Resource - Type II Constraints

The constraints of the SCED-Pricing objective function related to non-fast start generation resource and Demand Response Resource Type II are calculated identically to constraints in the

SCED objective function that can be found in section 7.1 of this BPM. For fast start generation resource and Demand Response Resource Type II, a number of the constraints of the SCED-Pricing objective function related to generation resource and Demand Response Resource Type II are calculated identically to constraints in the SCED objective function that can be found in section 6.2.1 of this Attachment. Those constraints are:

- Energy Step Clearing Constraints,
- Cleared Energy Constraints,
- Cleared Regulating Reserve Constraints,
- Cleared Contingency Reserve Constraints,
- Cleared Short Term Reserve Constraints,
- Maximum Energy Limit Constraints,
- Long-Term Ramp-Up Constraints,
- Long-Term Ramp-Down Constraints,
- Contingency Reserve Ramp Constraints,
- Regulating Reserve Ramp Constraints,
  - Up Ramp Capability Ramp Constraints,
  - Down Ramp Capability Ramp Constraints
- Short Term Reserve Ramp Constraints,
- Maximum Resource Regulating Reserve Constraints,
- Maximum Resource Contingency Reserve Constraints,
  - Maximum Resource Up Ramp Capability Constraints,
  - Maximum Resource Down Ramp Capability Constraints,
- Maximum Resource Short Term Reserve Constraints,
- Self-Scheduled Energy Constraints,
- Self-Scheduled Regulating Reserve Constraints,
- Self-Scheduled Contingency Reserve Constraints

The additional constraints for fast start generation resource and Demand Response Resource Type II are described in the sections below.

7.2.1.1 Partial commitment constraint

To allow Fast Start Resource set price, SCED-Pricing represents the fraction of the Fast Start Resource committed by the SCED-Pricing algorithm in the hour h by the continuous decision variable $on(r,h)$. SCED-Pricing algorithm requires that $on(r,h)$ satisfy $0 \leq on(r,h) \leq 1$.

7.2.1.2 Maximum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

Maximum Limit Constraints in the SCED-Pricing algorithm for non-Fast Start Resources follow the SCED algorithm and can be found in section 6.2.1 of this Attachment.

The following maximum limit constraints apply to on line Fast Start resources during the hour.

ClearedEnergy(r,h) + ContResCleared(r,h) + ClearedRegRes1(r,h) + ClearedRegRes2(r,h)≤
On(r,h)*MaxLimit(r,h) + MaxLimitViolation(r,h)

7.2.1.3 Maximum Short Term Reserve Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

Maximum Limit Constraints in the SCED-Pricing algorithm for non-Fast Start Resources follow the SCED algorithm and can be found in section 6.2.1 of this Attachment.

The following maximum limit constraints apply to on line Fast Start resources during the hour.

ClearedEnergy(r,h) + STRResCleared(r,h) + ClearedRegRes1(r,h)
≤
On(r,h)*MaxLimit(r,h) + MaxLimitViolation(r,h)

7.2.1.4 Minimum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

Minimum Limit Constraints in the SCED-Pricing algorithm for non-Fast Start Resources follow the SCED algorithm and can be found in section 6.2.1 of this Attachment.

The following minimum limit constraints apply to on line Fast Start resources during the hour.

ClearedEnergy(r,h) − ClearedRegRes1(r,h)

≥

On(r,h)*MinLimit(r,h) - MinLimitViolation(r,h)

7.2.1.5 General Ramp-Down Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

The following constraints are used to ensure the change in the Energy dispatch target can be accommodated by the ramp-down rate.

EnergyDispatchTarget(r,di)

≥

InitialEnergyOutput(r,di)

- 5 * RampDownRate(r,di)

- GeneralRampDownViolation(r,di)

Under both normal condition and emergency condition, online Fast Start Resources, which are dispatched at their Economic Minimum (EcoMin) in previous interval, in the Day-Ahead Market will be allowed to back down to 0 by not enforcing Ramp-Down constraint. This also applies to External Asynchonous Resources.

7.2.1.6 Offline Fast Start Resource Maximum Limit Constraint

Constraint Classification: Physical

Constraint Type: Penalized LE

The following offline fast start resource maximum limit constraints apply to Fast Start Resources while a scarcity condition exists or a transmission constraint is in violation.

ClearedEnergy(r,h)

<

On(r,h)*MaxLimit(r,h) + MaxLimitViolation(r,h)

Offline Fast Start Resource Minimum Limit Constraint
Constraint Classification: Physical

Constraint Type: Penalized LE

The following offline fast start resource minimum limit constraints apply to Fast Start Resources while a scarcity condition exists or a transmission constraint is in violation.

ClearedEnergy(r,h)

≥

On(r,h)*MinLimit(r,h) - MinLimitViolation(r,h)

7.2.1.7 Offline Fast Start Resource Contingency Reserve Constraint

Constraint Classification: Physical

Constraint Type: Penalized LE

The following offline fast start resource contingency reserve constraints apply to Fast Start Resources while a scarcity condition exists or a constraint is in violation.

ConResCleared(r,h)

≤

{1− On(r,h)}

* Min[MaxOffLineResponse(r,h), Maxlimt(r,h)]] + MaxLimitViolation(r,h)

7.2.1.8 Offline Fast Start Resource Short Term Reserve Constraint

Constraint Classification: Physical

Constraint Type: Penalized LE

The following offline Fast Start Resource maximum limit constraints apply to Fast Start Resources while a scarcity condition exists or a transmission constraint is in violation.

ClearedOffLineSTR (r,h)

<
(1-On(r,h))*min(MaxLimit(r,h), MaxOffLineSTR(r,h))

7.2.2 Demand Response Resource - Type I Constraints

The constraints of the SCED-Pricing objective function related to non-fast start Demand Response Resource Type I are calculated identically to constraints in the SCED objective function that can be found in section 6.2.2 of this Attachment. For fast start Demand Response Resource Type I, a number of the constraints of the SCED-Pricing objective function related to Demand Response Resource Type I are calculated identically to constraints in the SCED objective function that can be found in section 6.2.2 of this Attachment. Those constraints are:

Cleared Regulating Reserve Constraints,
Maximum Resource Contingency Reserve Constraints,
Maximum Resource Short Term Reserve Constraints,
Self-Scheduled Contingency Reserve Constraints

The additional constraints for fast start Demand Response Resource Type I are described in the sections below.

7.2.2.1 Partial commitment constraint

To allow Fast Start Resource set price, SCED-Pricing represents the fraction of the Fast Start Resource committed by the SCED-Pricing algorithm in the hour *h* by the continuous decision variable *on(r,h)*. SCED-Pricing algorithm requires that *on(r,h)* satisfy *0* ≤ *on(r,h)* ≤ *1*.

7.2.2.2 Cleared Energy Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following cleared energy constraints apply to Fast Start Resources while a scarcity condition exists or a constraint is in violation.

The following constraints apply to Fast Start DRR type I Resources
ClearedEnergy(r,h) =
On(r,h)* TargetDemRedLevel (r,h)

7.2.2.3 Offline Fast Start Cleared Contingency Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following cleared energy constraints apply to Offline Fast Start DRR type I Resources while a scarcity condition exists or a constraint is in violation.

The following constraints apply to Fast Start DRR type I Resources

ClearedContRes(r,h) =
(1-On(r,h))* TargetDemRedLevel (r,h)

7.2.2.4 Offline Fast Start Cleared Short Term Reserve Constraints

Constraint Classification: Physical

Constraint Type: Hard Equality

The following cleared energy constraints apply to Offline Fast Start Resources while a scarcity condition exists or a constraint is in violation.

The following constraints apply to Offline Fast Start DRR type I Resources

ClearedOfflineSTR (r,h) =
(1-On(r,h))* TargetDemRedLevel (r,h)

7.2.3 External Asynchronous Resource Constraints

The constraints of the SCED-Pricing objective function related to External Asynchronous Resource Constraints are calculated identically to constraints in the SCED objective function that can be found in section 6.2.3 of this Attachment.

7.2.4 Electric Storage Resource Constraints

The constraints of the SCED-Pricing objective function related to Electric Storage Resource Constraints are calculated identically to constraints in the SCED objective function that can be found in section **Error! Reference source not found.** of this Attachment.

7.2.5 Energy Transaction Constraints

The constraints of the SCED-Pricing objective function related to Energy Transaction Constraints are calculated identically to constraints in the SCED objective function that can be found in section 6.2.5 of this Attachment.

7.2.6 Optimal Power Flow Constraints

The constraints of the SCED-Pricing objective function related to Optimal Power Flow Constraints are calculated identically to constraints in the SCED objective function that can be found in section 6.2.6 of this Attachment.

7.2.7 Reliability Constraints

The constraints of the SCED-Pricing objective function related to Reliability Constraints are calculated identically to constraints in the SCED objective function that can be found in section 6.2.7 of this Attachment.

7.2.8 Tie-Breaking Constraints

The constraints of the SCED-Pricing objective function related to Tie-Breaking Constraints are calculated identically to constraints in the SCED objective function that can be found in section 6.2.8 of this Attachment.

7.3 SCED-Pricing Constraint Relaxation Logic

The SCED-Pricing Constraint Relaxation Logic is identical to the SCED Constraint Relaxation Logic which can be found in section 6.3 of this Attachment.

7.4 SCED-Pricing Output

The following output is generated by the SCED-Pricing algorithm:

- Cleared hourly energy volumes for resources
- Cleared hourly energy volumes for non-resource transactions
- Cleared hourly regulating reserve volumes for resources
- Cleared hourly spinning reserve volumes for resources

- Cleared hourly supplemental reserve volumes for resources
- Cleared hourly Short Term Reserve volumes for resources
- Global power balance constraint hourly shadow prices or **Globalλ(i, h)**
- Transmission constraint hourly shadow prices
- Sub-Regional Power Balance constraint hourly shadow prices
- Market-wide operating reserve constraint hourly shadow prices
- Market-wide regulating plus spinning reserve constraint hourly shadow prices
- Market-wide regulating reserve constraint hourly shadow prices
- Market-Wide Non-Sustainable Regulating Reserve constraint shadow prices
- Market-wide Short Term Reserve constraint hourly shadow prices
- Reserve Procurement Minimum Reserve Zone Regulating Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Regulating plus Spinning Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Operating Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Short Term Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Ramp Capability Up Reserve Requirement shadow prices
- Reserve Procurement Minimum Reserve Zone Ramp Capability Down Reserve Requirement shadow prices
- Generation-based operating reserve constraint hourly shadow prices
- Fast Start Resource Partial Commitment
- Fast Start Marginal Resources

8. Transmission Contingency Analysis

There are two main SCED executions every hour. The first SCED execution considers only the watch list and basecase transmission constraints. At the end of the first SCED execution, the SCED cleared energy outputs are forwarded to a transmission contingency analysis engine. The transmission contingency analysis engine uses a decoupled AC power flow algorithm to perform contingency analysis on the proposed SCED solution and identify potential transmission contingencies (both contingency and basecase) that could be an issue based on the energy injections and withdrawals associated with the first SCED execution. Based on the results of the transmission contingency analysis, additional transmission constraints are formulated and passed back to SCED for a second iteration (See Section 6.2.7.27 on Transmission Contingency Analysis Constraints). The transmission contingency analysis constraints are formulated to take advantage of the more accurate AC power flow formulation. These constraints are delta constraints guiding the second SCED iteration to make adjustments as necessary to enforce these constraints.

It is important to note that while the transmission contingency analysis engine is a decoupled AC power flow engine, all branch resistances continue to be set to zero and losses continue to be modeled at the load distributed reference bus. In addition, VAR injections and withdrawals are allowed at each bus as necessary to maintain 1.0 per unit voltage magnitudes at all buses.

9. Post-SCED Processing

The SCUC algorithm sets hourly resource commitment flags and hourly execution of the SCED algorithm generates cleared volumes that are communicated to market participants when the Day-Ahead Energy and Operating Reserve Market results are posted. The shadow prices generated by the hourly SCED executions must be used to calculate final LMPs and MCPs to be posted. These calculations are outlined below.

9.1 LMP Calculations

The nodal LMP for a specific hour is defined as the incremental cost to serve an incremental increase in load at that node, and is influenced by the shadow price of the global power balance constraint and the shadow price of watch list and contingency transmission constraints that are not directly modeled by the global power balance constraints. However, it is necessary to decompose these shadow prices into the three components of LMP, and then use these nodal LMP components to determine the commercial pricing node LMPs, all as discussed in Section 5 of the Energy and Operating Reserve Market Business Practices Manual as well as in Section 39 of the Tariff.

Mathematically, the nodal LMP is calculated as follows for a specific node and hour;

$$LMP(i,h) = Global\lambda(i,h) + \sum_{k \notin \text{basecase constraints}} \partial Flow(h)/\partial P(i,h) * \mu(k,h)$$

Additional reserve procurement constraints have been added which place new limits on resource energy and operating reserve clearings, to ensure that cleared reserves are deliverable as needed. The shadow prices of these constraints are additive to the marginal congestion component of LMPs. Thus, the nodal LMP is expressed as follows for a specific node and hour:

$$\begin{aligned} LMP(i,h) = {} & Global\lambda(i,h) + \sum_{k \notin \text{basecase constraints}} \partial Flow(h)/\partial P(i,h) * \mu(k,h) \\ & + \sum_{k \notin \text{basecase constraints}} \{[\partial Flow(k,h)/\partial P(i,h)] * RPRegUp\lambda(i,h) \\ & + \sum_{k \notin \text{basecase constraints}} \{[\partial Flow(k,h)/\partial P(i,h)] * RPRegDown\lambda(i,h) \\ & + \sum_{z,\, k \notin \text{basecase constraints}} \{[\partial Flow(k,h)/\partial P(i,h)] * RPCRDep\lambda(i,z,h) \\ & + \sum_{z,\, k \notin \text{basecase constraints}} \{[\partial Flow(k,h)/\partial P(i,h)] * RPSTRDep\lambda(i,z,h) \end{aligned}$$

9.1.1 Calculation of the LMP at the Reference Bus (MEC_r)

The marginal energy component of the LMP at the reference bus, designated as **$MEC_r(h)$**, is one of the three components of LMP and is the same for all nodes in a specific hour. The marginal energy component of LMP at the reference bus is calculated as follows for an hour:

$MEC_r(h) = \Sigma$ { RefBusDF(i) * LMP(i,h) i

9.1.2 Calculation of the Marginal Loss Component of Nodal LMPs (MLCs)

The marginal loss component of the LMP at a specific node, designated as **MLC(i, h)**, is one of the three components of the LMP and is calculated as follows for each node for an hour:

$MLC(i,h) = - \partial Loss(h)/\partial P(i,h) * MEC_r(h)$

9.1.3 Calculation of Commercial Pricing Node LMPs

The LMP at a specific commercial pricing node, including LMPs at resources, load zones, hubs and interfaces, is calculated as follows for each commercial pricing node for an hour:

LMP(cpn,h) = Σ { WF(i,cpn) * LMP(i,h) i

9.1.4 Calculation of Commercial Pricing Node Marginal Loss Component of LMP (MLCs)

The marginal loss component of the LMP at a specific commercial pricing node MLCs, including MLCs at resource, load zones, hubs and interfaces, are calculated as follows for each commercial pricing node for an hour:

MLC(cpn,h) = Σ { WF(i,cpn) * MCL(i,h) i

9.1.5 Calculation of Commercial Pricing Node Marginal Congestion Component of LMP (MCCs)

The commercial pricing node Marginal Congestion Component of LMP (MCCs), including MCCs at resources, load zones, hubs and interfaces, are calculated as follows for each commercial pricing node for an hour:

$MCC(cpn,h) = LMP(cpn,h) - MEC_r(h) - MLC(cpn,h)$

9.1.6 LMP Capping Logic

Per the Tariff, LMPs must be capped at the Value of Lost Load (VOLL). The following capping logic is incorporated into the LMP calculations:

9.1.6.1 Global Energy Deficit

In the unlikely event of a global energy deficit where all LMPs exceed the VOLL, all commercial node LMPs for the hour will be set equal to the VOLL. In addition, the MECr will be set equal to the VOLL and the marginal loss component and marginal congestion component of all LMPs will be set to zero.

9.1.6.2 MEC_r Exceeds VOLL

When $MEC_r(h)$ exceeds VOLL but there is no global energy deficit, $MEC_r(h)$ is adjusted to VOLL and MCC(cpn,h) and MLC(cpn,h) are adjusted as necessary to maintain the LMP(cpn,h) at the lesser of VOLL or the value calculated above.

9.1.6.3 MEC_r Does Not Exceed VOLL

When $MEC_r(h)$ does not exceed VOLL, MCC(cpn,h) is adjusted as necessary to maintain the LMP(cpn,h) at the lesser of VOLL or the value calculated above.

9.2 MCP Calculations

Regulating Reserve MCPs, Spinning Reserve MCPs, and Supplemental Reserve MCPs are calculated for each reserve zone and hour. Regulation Mileage MCPs are calculated in the Real-Time Market only, and hence, are not included below.

9.2.1 Regulating Reserve MCPs for Generation Resources, Demand Response Resources – Type II, Electric Storage Resources and External Asynchronous Resources

The Regulating Reserve MCPs for Generation Resources, Demand Response Resources - Type II, Electric Storage Resources and External Asynchronous Resources in a specific hour and reserve zone are calculated as the sum of the following, but capped at VOLL:

- Applicable off-line studies Reserve zone operating reserve constraint hourly shadow price
- Applicable off-line studies Reserve zone regulating plus spinning reserve constraint hourly shadow price
- Applicable off-line studies Reserve zone regulating reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone operating reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone regulating plus spinning reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone regulating reserve constraint hourly shadow price
- Generation-based operating reserve constraint hourly shadow price
- Generation-based regulating plus spinning reserve constraint hourly shadow price

9.2.2 Spinning Reserve MCPs for Generation Resources, Demand Response Resources – Type II, Electric Storage Resources and External Asynchronous Resources

The Spinning Reserve MCPs for Generation Resources, Demand Response Resources - Type II, Electric Storage Resources and External Asynchronous Resources in a specific hour and reserve zone are calculated as the sum of the following, but capped at VOLL:

- Applicable off-line studies Reserve zone operating reserve constraint hourly shadow price
- Applicable off-line studies Reserve zone regulating plus spinning reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone operating reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone regulating plus spinning reserve constraint hourly shadow price
- Generation-based operating reserve constraint hourly shadow price
- Generation-based regulating plus spinning reserve constraint hourly shadow price

9.2.3 Spinning Reserve MCPs Demand Response Resources – Type I

The Spinning Reserve MCPs for Demand Response Resources – Type I in a specific hour and reserve zone are calculated as the sum of the following, but capped at VOLL:

- Applicable off-line studies Reserve zone operating reserve constraint hourly shadow price
- Applicable off-line studies Reserve zone regulating plus spinning reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone operating reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone regulating plus spinning reserve constraint hourly shadow price

9.2.4 Supplemental Reserve MCPs for Generation Resources, Demand Response Resources – Type II, Electric Storage Resources and External Asynchronous Resources

The Supplemental Reserve MCPs for Generation Resources, Demand Response Resources - Type II, Electric Storage Resources and External Asynchronous Resources in a specific hour and reserve zone are calculated as the sum of the following, but capped at VOLL:

- Applicable off-line studies Reserve zone operating reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone operating reserve constraint hourly shadow price
- Generation-based operating reserve constraint hourly shadow price

9.2.5 Supplemental Reserve MCPs for Demand Response Resources – Type I

The Supplemental Reserve MCPs for Demand Response Resources in a specific hour and reserve zone are equal to the sum of the following, but capped at VOLL:

- Applicable off-line studies Reserve zone operating reserve constraint hourly shadow price
- Reserve Procurement Minimum Reserve zone operating reserve constraint hourly shadow price

9.2.6 Short Term Reserve MCPs for for All Resources

The Short Term Reserve MCPs for all resources in a specific hour and Reserve Zone are calculated as the sum of the following, but capped at VOLL:

- Reserve Procurement Minimum Reserve Zone operating reserve constraint hourly shadow price

10. Current Tuning Parameter Settings

Listed below are the current tuning parameter settings for the Day-Ahead SCUC algorithm:

- ContResRampMult = 1.0
- ContResDeployTime = 10 Minutes
- MaxContResFactor = 0.2
- MaxRegResFactor = 0.2
- MaxRCUpFactor = 0.2
- MaxRCDownFactor = 0.2
- RegRampMult = 1.0
- STRRampMult = 1.0
- RegResponseTime = 5 Minutes
- STRResponseTime = 30 Minutes
- MaxSTRResFactor = 1.0
- RCUpResponseTime = 10 Minutes
- RCDownResponseTime = 10 Minutes
- RCUpRampMult = 1.0
  RCDownRamp Mult = 1.0

Listed below are the current tuning parameter settings for the Day-Ahead SCED algorithm:

- ContResRampMult = 1.0
- ContResDeployTime = 10 Minutes
- MaxContResFactor = 0.2
- MaxRegResFactor = 0.2
- MaxRCUpFactor = 0.2
- MaxRCDownFactor = 0.2
- RegRampMult = 1.0

- STRRampMult = 1.0
- RegResponseTime = 5 Minutes
- STRResponseTime = 30 Minutes
- MaxSTRResFactor = 1.0
- RCUpResponseTime = 10 Minutes
- RCDownResponseTime = 10 Minutes
- RegStorageUseFactor = 0
- SpinStorageUseFactor = 0
- SuppStorageUseFactor = 0
- STRStorageUseFactor = 0
- RegUpStorageReliabilityFactor = 1.0
- RegDnStorageReliabilityFactor = 1.0
- SpinStorageReliabilityFactor = 1.0
- SuppStorageReliabilityFactor = 1.0
- STRStorageReliabilityFactor = 1.0

11. Glossary of Variables, Arrays and Parameters

11.1 Array Indices

- **cpn:** Index of commercial pricing nodes
- **d:** Index of days in SCUC period
- **e1, e2:** Index of resources and energy transactions
- **h:** Index of hours
- **i, j:** Index of buses or electrical nodes
- **k:** Index of transmission branches, constraints or flowgates
- **r, r1, r2:** Index of resources
- **sg:** Index of offer or bid segments
- **st:** Index of offer curve or demand curve steps
- **tr:** Index of energy transactions (including price sensitive demand bids, virtual supply offers, virtual demand bids, dispatchable imports, dispatchable exports, fixed imports, fixed exports and up-to-TUC transactions - excluding resources)
- **z:** Index of reserve zones

11.2 MISO Input Data

- **BranchLimit(k,h):** A floating point array. The limit of branch k in hour h. Expressed in MW.
- **DF(i,r):** A floating point array. The percent of resource r output allocated to bus i, or the normalized distribution factor for bus i and resource r.
- **DF(i,tr):** A floating point array. The percent of energy transaction tr allocated to bus i, or the normalized distribution factor for bus i and energy transaction tr.

- **FGLimit(k,h):** A floating point array. The limit of flowgate constraint k in hour h. Expressed in MW.
- **FGLimit_CREvent(k,h):** A floating point array. The limit of flowgate constraint k in hour h used for Reserve Procurement Contingency Reserve Event Constraints. Expressed in MW.
- **InyC(k,r,h)**: A floating point array. Injection Coefficient for resource r over Sub-Regional Power Balance Constraint k during hour h. Expressed in MW.
- **LoopFlowInjectionMW(i,h):** A floating point array. The loop flow MWs injected at external bus i during hour h to model the impact of external generation serving external load. Expressed in MW. Established by MISO staff ahead of time.
- **LoopFlowWithdrawalMW(i,h):** A floating point array. The loop flow MWs withdrawn at external bus i during hour h to model the impact of external generation serving external load. Expressed in MW. Established by MISO staff ahead of time.
- **∂Loss(h)/∂P(i,h):** A floating point array. The marginal loss sensitivity factor for injections at bus i during hour h calculated with respect to the load distributed reference bus. Established by MISO staff ahead of time.
- **MTLF(h):** A floating point variable. The medium term load forecast for hour h for market footprint. Expressed in MW.
- **MWContResReq(h):** A floating point array. The Market-Wide Contingency Reserve requirement for hour h. Expressed in MW.
- **MWOpResDemandCurve(h,MW):** A floating point array. The market-wide operating reserve demand curve for hour h. Expressed in $ per MW.
- **MWRampDnReq(h)**: A floating point array. The Market-Wide Ramp-Down requirement for hour h. Expressed in MW/hr.
- **MWRampDnReqScaleFactor(h):** A floating point array. The factor by which the Market-Wide Ramp-Down Requirement is scaled in hour h, modified as necessary to ensure an adequate commitment.
- **MWRampUpReq(h)**: A floating point array. The Market-Wide Ramp-Up requirement for hour h. Expressed in MW/hr.
- **MWRampUpReqScaleFactor(h):** A floating point array. The factor by which the Market-Wide Ramp-Up Requirement is scaled in hour h, modified as necessary to ensure an adequate commitment.
- **MWRegReq(h):** A floating point array. The Market-Wide Regulating Reserve requirement for hour h. Expressed in MW.
- **MWRegResDemandCurve(h,MW):** A floating point array. The market-wide regulating reserve demand curve for hour h. Expressed in $ per MW.
- **Posting Period:** A floating point variable. The length of the period between the time Day-Ahead Energy and Operating Reserve Market results are posted and the operating day begins (typically 7 hours based on a projected posting time of 16:00 the day prior).
- **RefBusDF(i):** A floating point array. The percent of the load distributed reference bus allocated to bus i, or the normalized reference bus distribution factor for bus i.

- **RegResDemandPrice:** A floating point variable. The regulating reserve demand curve price updated monthly by MISO in accordance with the tariff.
- **RZOpResDemandCurve(z,h,MW):** A floating point array. The reserve zone operating reserve demand curve for reserve zone z and hour h. Expressed in $ per MW.
- **RZRegResDemandCurve(z,h,MW):** A floating point array. The reserve zone regulating reserve demand curve for reserve zone z and hour h. Expressed in $ per MW.
- **SinkDF(i,tr):** A floating point array. The percent of the Up-to-TUC transaction tr sink MW allocated to bus i, or the normalized sink distribution factor for bus i and Up-to-TUC transaction tr.
- **SourceDF(i,tr):** A floating point array. The percent of the Up-to-TUC transaction tr source MW allocated to bus i, or the normalized source distribution factor for bus i and Up-to-TUC transaction tr.
- **MWSTRReq(h):** A floating point array. The Market-Wide Short Term Reserve requirement for hour h. Expressed in MW.
- **STRDCPriceStep(st,h)** : Price of system (market-wide) STR demand curve for price step st at hour h
- **STRDCMaxStep(st,h)** : MW width of the demand curve step which is the maximum market-wide STR cleared at the associated demand curve step price at hour h.

11.3 Market Participant Input Data

- **DemSegMW(tr,h,sg):** A floating point array. The bid MW for segment sg of price sensitive demand bid tr for hour h. Expressed in MW.
- **DemSegPrice(tr,h,sg):** A floating point array. The bid price for segment sg of price sensitive demand bid tr for hour h. Expressed in $ per MWh.
- **EnergyOfferPrice(r,h):** A floating point array. The energy offer price for resource r for hour h. Expressed in $ per MWh. Applies only to Demand Resource Resources - Type I.
- **EnergyOfferCurve(r,h,MW):** A floating point array. The energy offer curve, piece-wise linear or stepped, submitted for resource r for hour h. Expressed in $ per MWh.
- **ExportSegMW(tr,h,sg):** A floating point array. The bid MW for segment sg of dispatchable export transaction tr for hour h. Expressed in MW.
- **ExportSegPrice(tr,h,sg):** A floating point array. The bid price for segment sg of dispatchable export transaction tr for hour h. Expressed in $ per MWh.
- **FixedDemBidMW(tr,h):** A floating point array. The MW for fixed demand bid tr for hour h. Expressed in MW.
- **FixedExportMW(tr,h):** A floating point array. The MW for fixed export transaction tr for hour h. Expressed in MW.
- **FixedImportMW(tr,h):** A floating point array. The MW for fixed import transaction tr for hour h. Expressed in MW.
- **HotToColdTime(r):** A floating point array. The amount of time required for resource r to cool down from a hot state to a cold state after a shutdown. Expressed in hours.

- **HotToIntTime(r):** A floating point array. The amount of time required for resource r to cool down from a hot state to an intermediate state after a shutdown. Expressed in hours.
- **HourCurtOfferPrice(r,h):** A floating point array. The hourly curtailment offer price for resource r for hour h. Expressed in $ per hour. Applies only to Demand Resource Resources - Type I.
- **ImportSegMW(tr,h,sg):** A floating point array. The offer MW for segment sg of dispatchable import transaction tr for hour h. Expressed in MW.
- **ImportSegPrice(tr,h,sg):** A floating point array. The offer price for segment sg of dispatchable import transaction tr for hour h. Expressed in $ per MWh.
- **InitialOffHours(r):** A floating point array. The number of hours resource r is off-line prior to the beginning of the SCUC period. Expressed in hours.
- **InitialOnHours(r):** A floating point array. The number of hours resource r is on-line prior to the beginning of the SCUC period. Expressed in hours.
- **MaxDailyEnergyLimt(r, d):** A floating point array. The maximum amount of energy that can be supplied by resource r during day d. Expressed in MWh.
- **MaxDailyStarts(r, d):** An integer array. The maximum number of times resource r may be started in a day d. For a Demand Response Resource – Type I, this parameter is the maximum number of times that a load can be interrupted in a day.
- **MaxIntTime(r):** A floating point array. The maximum amount of time a Demand Response Resource - Type I may be in an interrupted (i.e., committed) state. Analogous to the maximum run time. Expressed in hours.
- **MaxOffLineResponse(r,h):** A floating point array. The maximum off-line response limit of resource r during hour h. Expressed in MW.
- **MaxRunTime(r):** A floating point array. The maximum amount of time resource r can be committed following a start-up. Expressed in hours.
- **MinDownTime(r):** A floating point array. The minimum amount of time resource r must be uncommitted following a shut-down. Expressed in hours.
- **MinIntTime(r):** A floating point array. The minimum amount of time a Demand Response Resource - Type I may be in an interrupted (i.e., committed) state. Analogous to the minimum run time. Expressed in hours.
- **MinNonIntTime(r):** A floating point array. The minimum amount of time a Demand Response Resource - Type I must be in a non-interrupted state (i.e., decommitted) between two interrupted states. Analogous to the minimum down time. Expressed in hours.
- **MinRunTime(r):** A floating point array. The minimum amount of time resource r must be committed following a start-up. Expressed in hours.
- **NLOfferPrice(r,h):** A floating point array. The no-load offer price for resource r for hour h. Expressed in $ per hour. Applies to Generation Resources and Demand Resource Resources - Type II.
- **OffLineSupResOfferPrice(r,h):** A floating point array. The off-line supplemental reserve offer price for resource r for hour h. Expressed in $ per MWh.

- **RegCapOfferPrice(r,h,):** A floating point array. The regulating reserve capacity offer price for resource r for hour h. Expressed in $ per MWh.
- **RegMileOfferPrice(r,h,):** A floating point array. The regulating reserve mileage offer price for resource r for hour h. Expressed in $ per MW.
- **RegResOfferPrice(r,h,):** A floating point array. The regulating reserve offer price for resource r for hour h. Expressed in $ per MWh.
- **SDOfferPrice(r,d):** A floating point array. The start-up offer for resource r for day d. Expressed in $ per start. Applies only to Demand Resource Resources - Type I.
- **SSEnergyMW(r,h):** A floating point array. The energy self-schedule for resource r during hour h. Expressed in MW.
- **SSRegResMW(r,h):** A floating point array. The regulating reserve self-schedule for resource r during hour h. Expressed in MW.
- **SSSpinResMW(r,h):** A floating point array. The spinning reserve self-schedule for resource r during hour h. Expressed in MW.
- **SSSupResMW(r,h):** A floating point array. The supplemental reserve self-schedule for resource r during hour h. Expressed in MW. Applies only to Demand Response Resources - Type I and External Asynchronous Resources.
- **SSOffLineSupResMW(r,h):** A floating point array. The off-line supplemental reserve self-schedule for resource r during hour h. Expressed in MW. Applies only to Generation Resource and Demand Response Resources - Type II.
- **SSOnLineSupResMW(r,h):** A floating point array. The on-line supplemental reserve self-schedule for resource r during hour h. Expressed in MW. Applies only to Generation Resource and Demand Response Resources - Type II.
- **SUCNotTime(r,h):** A floating point array. The cold start-up notification time used to evaluate a start-up for resource r in hour h. Expressed in hours.
- **SUCOfferPrice(r,d):** A floating point array. The cold start-up offer for resource r for day d. Expressed in $ per start.
- **SUCTime(r,h):** A floating point array. The cold start-up time used to evaluate a start-up for resource r in hour h. Expressed in hours.
- **SUHNotTime(r,h):** A floating point array. The hot start-up notification time used to evaluate a start-up for resource r in hour h. Expressed in hours.
- **SUHOfferPrice(r,d):** A floating point array. The hot start-up offer for resource r for day d. Expressed in $ per start.
- **SUHTime(r,h):** A floating point array. The hot start-up time used to evaluate a start-up for resource r in hour h. Expressed in hours.
- **SUINotTime(r,h):** A floating point array. The intermediate start-up notification time used to evaluate a start-up for resource r in hour h. Expressed in hours.
- **SUIOfferPrice(r,d):** A floating point array. The intermediate start-up offer for resource r for day d. Expressed in $ per start.
- **SUITime(r,h):** A floating point array. The intermediate start-up time used to evaluate a start-up for resource r in hour h. Expressed in hours.

- **SUNotTime(r,h):** A floating point array. The single start-up notification time used to evaluate a start-up for resource r in hour h. Expressed in hours. Applies only to Demand Response Resources - Type I, and is associated with the notification time needed to interrupt load.
- **SUTime(r,h):** A floating point array. The single start-up time used to evaluate a start-up for resource r in hour h. Expressed in hours. Applies only to Demand Response Resources - Type I , and is associated with the time needed to interrupt load.
- **TargetDemRedLevel(r,h):** A floating point array. The targeted demand reduction level for resource r during hour h. Expressed in MW. Applies only to Demand Resource Resources - Type I.
- **UpToTUCSegMW(tr,h,sg):** A floating point array. The bid MW for segment sg of Up-to-TUC transaction tr for hour h. Expressed in MW.
- **UpToTUCSegPrice(tr,h,sg):** A floating point array. The bid price for segment sg of Up-to-TUC transaction tr for hour h. Expressed in $ per MWh.
- **VirtualDemSegMW(tr,h,sg):** A floating point array. The bid MW for segment sg of virtual demand bid tr for hour h. Expressed in MW.
- **VirtualDemSegPrice(tr,h,sg):** A floating point array. The bid price for segment sg of virtual demand bid tr for hour h. Expressed in $ per MWh.
- **VirtualSupSegMW(tr,h,sg):** A floating point array. The offer MW for segment sg of virtual supply offer tr for hour h. Expressed in MW.
- **VirtualSupSegPrice(tr,h,sg):** A floating point array. The offer price for segment sg of virtual supply offer tr for hour h. Expressed in $ per MWh.
- **OfflineSTRMaxMinRunTimeHours(r,h):** A GEN or DRR2 resource MinimumRunTime must be less than this many hours in order to be offline STR qualified.
- **OfflineSTRDRR1MaxMinInterruptTimeHours(r,h):** A DRR1 resource MinimumInterruptTime must be less than this many hours in order to be offline STR qualified.
- **MaxOfflineSTR(r,h):** Maximum offline STR response of resource *r* at hour h within the STR response time h
- **OffLineSTROfferPrice (r,h)**: Offline STR offer Price for resource r at hour h
- **InitialEnergyStorage(r,d) :** A floating point array. The initial state of charge level of resource r for day d. Expressed in MWh. Applies only to Electric Storage Resource.
- **MaxEnergyStorageLevel(r,h):** A floating point array. Maximum Energy Storage Level of resource r at hour h. Experssed in MWh. Applies only to Electric Storage Resource.
- **MinEnergyStorageLevel(r,h):** A floating point array. Minimum Energy Storage Level of resource r at hour h. Experssed in MWh. Applies only to Electric Storage Resource.
- **EmerMaxEnergyStorageLevel(r,h):** A floating point array. Maximum Energy Storage Level of resource r at hour h under emergency condition. Experssed in MWh. Applies only to Electric Storage Resource.
- **EmerMinEnergyStorageLevel(r,h):** A floating point array. Minimum Energy Storage Level of Resource r at hour h under emergency condition. Expressed in MWh. Applies only to Electric Storage Resource.

- **EfficiencyFactor(r,h):** A floating point array. Electric Storage Resource charge efficiency factor. Applies only to Electric Storage Resource.
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11.4 Pre-SCUC Processing Variables

- **B(i,j,h):** A floating point array. The bus admittance matrix for hour h.
- **BranchB(k,h):** A floating point array. The series admittance for transmission branch k during hour h.
- **CertainMustRunStartup(r,h):** A Boolean array. A flag that indicates whether a start-up issued for the resource in hour h is a start-up associated with a Must-Run commitment interval. Set to 1 if an issued start-up for resource r in hour h will be a Must-Run commitment, with no associated start-up costs to the system.
- **CommitAvailability(r,h):** A Boolean array. The commitment availability of resource r during hour h. Set to 1 if resource r is available for commitment during hour h. Set to 0 if resource r is not available for commitment during hour h.
- **ContResOfferPrice(r,h):** A floating point array. The contingency reserve offer price used in the SCUC algorithm to dispatch contingency reserve on committed resource r during hour h. Expressed in $ per MW.
- **EcoMaxLimit(r,h):** A floating point array. The economic maximum limit for resource r during hour h. Expressed in MW.
- **EcoMinLimit(r,h):** A floating point array. The economic minimum limit for resource r during hour h. Expressed in MW.
- **EmerMaxLimit(r,h):** A floating point array. The emergency maximum limit for resource r during hour h. Expressed in MW.
- **EmerMinLimit(r,h):** A floating point array. The emergency minimum limit for resource r during hour h. Expressed in MW.
- **EmerStatus(r,h):** A Boolean array. The emergency status of resource r during hour h. Set to 1 if resource r has a commitment status of ***Emergency*** during hour h, otherwise set to 0.
- **EnergyStepPrice(r,h,st):** A floating point array. The energy offer curve step price for resource r and offer curve step st during hour h. Expressed in $ per MWh.
- **EnergyStepWidth(r,h,st):** A floating point array. The energy offer curve step width for resource r and offer curve step st during hour h. Expressed in MW.
- **∂Flow(k,h)/∂P(i,h):** A floating point array. The shift factor for transmission constraint k and bus i during hour h, which represents the incremental flow on transmission constraint k for an incremental injection at bus i coupled with an incremental withdrawal at the load distributed reference bus.
- **∂Flow(k,h)/∂P(r,h):** A floating point array. The shift factor for transmission constraint k and resource r during hour h, which represents the incremental flow on transmission constraint k for an incremental increase in resource r output coupled with an incremental withdrawal at the load distributed reference bus.

- **∂Flow(k,h)/∂P(tr,h):** A floating point array. The shift factor for transmission constraint k and energy transaction r during hour h, which represents the incremental flow on transmission constraint k for an incremental increase in energy transaction tr coupled with an incremental withdrawal at the load distributed reference bus.
- **GenORReqFactor(h):** A floating point array. The percentage of Operating Reserve that must be supplied by Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources for hour h based on reliability standards.
- **InitialOnStatus(r):** A Boolean array. The initial-on status of the resource. Set to 1 if the resource is initially on-line. Set to 0 if the resource is initially off-line.
- **InpurRampRate(r,h):** A floating point array. The ramp rate used for resource r during hour h (hourly if available, else default). Expressed in MW per Minute.
- **LTSCUCRampDownRate(r,h):** A floating point array. A ramp rate used in the SCUC long-term ramp-down constraints. Expressed in MW per Minute.
- **LTSCUCRampUpRate(r,h):** A floating point array. A ramp rate used in the SCUC long-term ramp-up constraints. Expressed in MW per Minute.
- **LTSCUCSDRampRate(r,h):** A floating point array. A ramp rate used in the SCUC long-term ramp-down constraints. Expressed in MW per Minute.
- **LTSCUCSURampRate(r,h):** A floating point array. A ramp rate used in the SCUC long-term ramp-up constraints. Expressed in MW per Minute.
- **MinCommitTime(r,h):** A floating point array. The minimum amount of time resource r must be committed if started in hour h. Expressed in hours.
- **MinDecommitTime(r,h):** A floating point array. The minimum amount of time resource r must be decommitted if shut-down in hour h. Expressed in hours.
- **MustRunStatus(r,h):** A Boolean array. The must run status of resource r during hour h. Set to 1 if resource r has commitment status of ***Must Run*** during hour h, otherwise set to 0.
- **MWORReq(h):** A floating point array. The Market-Wide Operating Reserve requirement for hour h. Expressed in MW.
- **MWRegSpinReq(h):** A floating point array. The Market-Wide Regulating plus Spinning Reserve requirement for hour h. Expressed in MW.
- **NextMustRunPeriod(r,h):** A floating point array. This value indicates for a given resource r and hour h, the next hour (greater than h) for which the resource is considered a Must-Run resource.
- **OffLineSupAvailability(r,h):** A Boolean array. The off-line supplemental reserve availability of resource r during hour h. Set to 1 if resource r is available to provide off-line supplemental reserve during hour h. Set to 0 if resource r is not available to provide off-line supplemental reserve during hour h.
- **PF(i,h):** A floating point array. The marginal loss penalty factor for energy injections at bus i during hour h. If i is replaced with r or tr, the marginal loss penalty factor applies to a resource or transaction at a specific commercial pricing node.
- **PossibleMustRunStartup(r,h):** A Boolean array. A flag that indicates whether a start-up issued for the resource in hour h could possibly be a start-up associated with a Must-Run

commitment interval. Set to 1 if an issued start-up for resource r in hour h may be a Must-Run commitment, with no associated start-up costs to the system**.**

- **RegAvailability(r,h):** A Boolean array. The regulating reserve availability of resource r during hour h. Set to 1 if resource r is available to provide regulating reserve during hour h. Set to 0 if resource r is not available to provide regulating reserve during hour h.
- **RegMaxLimit(r,h):** A floating point array. The regulation maximum limit for resource r during hour h. Expressed in MW.
- **RegMinLimit(r,h):** A floating point array. The regulation minimum limit for resource r during hour h. Expressed in MW.
- **RZORReq(z,h):** A floating point array. The Reserve Zone Operating Reserve requirement for reserve zone z during hour h. Expressed in MW.
- **RZRegSpinReq(z,h):** A floating point array. The Reserve Zone Regulating plus Spinning Reserve requirement for reserve zone z during hour h. Expressed in MW.
- **SpinAvailability(r,h):** A Boolean array. The spinning reserve availability of resource r during hour h. Set to 1 if resource r is available to provide spinning reserve during hour h. Set to 0 if resource r is not available to provide spinning reserve during hour h.
- **SSEnergyStatus(r,h):** A Boolean array. The energy self-schedule status of resource r during hour h. Set to 1 if energy is being self-scheduled on resource r during hour h. Set to 0 if energy is not being self-scheduled on resource r during hour h.
- **SSOnLineSupResStatus(r,h):** A Boolean array. The one-line supplemental reserve self-schedule status of resource r during hour h. Set to 1 if on-line supplemental reserve is being self-scheduled on resource r during hour h. Set to 0 if on-line supplemental reserve is not being self-scheduled on resource r during hour h.
- **SSRegResStatus(r,h):** A Boolean array. The regulating reserve self-schedule status of resource r during hour h. Set to 1 if regulating reserve is being self-scheduled on resource r during hour h. Set to 0 if regulating reserve is not being self-scheduled on resource r during hour h.
- **SSSpinResStatus(r,h):** A Boolean array. The spinning reserve self-schedule status of resource r during hour h. Set to 1 if spinning reserve is being self-scheduled on resource r during hour h. Set to 0 if spinning reserve is not being self-scheduled on resource r during hour h.
- **SSSupResStatus(r,h):** A Boolean array. The supplemental reserve self-schedule status of resource r during hour h. Set to 1 if supplemental reserve is being self-scheduled on resource r during hour h. Set to 0 if supplemental reserve is not being self-scheduled on resource r during hour h.
- **SupAvailability(r,h):** A Boolean array. The supplemental reserve availability of resource r during hour h. set to 1 if resource r is available to provide supplemental reserve during hour h. Set to 0 if resource r is not available to provide supplemental reserve during hour h.
- **OnlineSTRAvailability(r,h):** A Boolean array. The Short Term Reserve availability of resource r during hour h. set to 1 if resource r is available to provide Short Term Reserve

during hour h. Set to 0 if resource r is not available to provide Short Term Reserve during hour h.

- **OfflineSTRAvailability(r,h):** A Boolean array. The Short Term Reserve availability of resource r during hour h. set to 1 if resource r is available to provide Short Term Reserve during hour h. Set to 0 if resource r is not available to provide Short Term Reserve during hour h.

11.5 SCUC Parameters

- **BaseRampDnReq:** The minimum ramp-down requirement for any hour of the Operating Day. Used in the calculation of the Market-Wide Ramp-Down Capacity Requirement. Expressed in MW.
- **BaseRampUpReq:** The minimum ramp-up requirement for any hour of the Operating Day. Used in the calculation of the Market-Wide Ramp-Up Capacity Requirement. Expressed in MW.
- **ContResDeployTime:** The maximum amount of time in which Contingency Reserve must be deployed after notification. Expressed in Minutes.
- **ContResRampMult:** The amount of cleared contingency reserve a resource must be able to deploy within the Contingency Reserve Deployment Time assuming no regulating reserve deployment.
- **EmerPenPrice:** The emergency release penalty price. Used in ***Emergency Mode*** only. Expressed in $ per MW.
- **EnergyShortagePenPrice:** The global power balance constraint deficit penalty price. Expressed in $ per MW.
- **EnergySurplusPenPrice:** The global power balance constraint surplus penalty price. Expressed in $ per MW.
- **GenORReqFactor:** The percentage of operating reserve that must be supplied by Generation Resources, Demand Response Resources - Type II, External Asynchronous Resources and Electric Storge Resources based on applicable reliability standards.
- **GenOpResShortagePenPrice:** The generation-based operating reserve constraint penalty price. Expressed in $ per MW.
- **GenRegReqFactor:** The percentage of regulating reserve that must be supplied by Generation Resources, Demand Response Resources - Type II, External Asynchronous Resources and Electric Storge Resources based on applicable reliability standards.
- **GenRegShortagePenPrice:** The generation-based regulating reserve constraint penalty price. Expressed in $ per MW.
- **GenRegSpinReqFactor:** The percentage of regulating plus spinning reserve that must be supplied by Generation Resources, Demand Response Resources - Type II, External Asynchronous Resources and Electric Storge Resources based on applicable reliability standards.
- **GenRegSpinShortagePenPrice:** The generation-based regulating plus spinning reserve constraint penalty price. Expressed in $ per MW.

- **LimitPenPrice:** The limit constraint penalty price. Expressed in $ per MW.
- **LossRate:** The loss rate, expressed as a percent of the fixed demand bids, used to calculate actual losses within the SCUC algorithm.
- **MaxContResFactor:** The maximum percentage of the market-wide contingency reserve requirement that can be supplied by a single resource.
- **MaxRegResFactor:** The maximum percentage of the market-wide regulating reserve requirement that can be supplied by a single resource.
- **MaxResourceContResPenPrice:** The maximum resource contingency reserve constraint penalty price. Expressed in $ per MW.
- **MaxResourceRegPenPrice:** The maximum resource regulating reserve constraint penalty price. Expressed in $ per MW.
- **MWCRReqFactor:** The percentage of the hourly market-wide contingency reserve requirement that should be modeled in SCUC to ensure a sufficient number of resources are committed to supply contingency reserve. This factor does not impact the amount of contingency reserve actually cleared by SCED.
- **MWRegReqFactor:** The percentage of the hourly market-wide regulating reserve requirement that should be modeled in SCUC to ensure a sufficient number of resources are scheduled to regulate. This factor does not impact the amount of regulating reserve actually cleared by SCED.
- **MWSpinReqFactor:** The percentage of the hourly market-wide spinning reserve requirement that should be modeled in SCUC to ensure a sufficient number of resources are committed to supply spinning reserve. This factor does not impact the amount of spinning reserve actually cleared by SCED.
- **OpResShortagePenPrice:** The operating reserve constraint penalty price. Expressed in $ per MW.
- **PmaxEvent(z,h):** The size of the largest resource in zone z during hour h.
- **PMaxThreshold**: A tuning parameter. A threshold on the size of the largest resource in a zone that triggers the modeling of a Reserve Procurement Contingency Reserve constraint for transmission constraints.
- **RampCapContRes:** A Boolean which indicates whether cleared contingency reserve is considered in the resource ramp capacity calculation.
- **RampCapReg:** A Boolean which indicates whether cleared regulation is considered in the resource ramp capacity calculation.
- **RampMinutes:** The time length used in defining each resource’s ramp capacity. Expressed in minutes.
- **RampPenPrice:** The ramp constraint penalty price. Expressed in $ per MW.
- **RampDnPenPrice:** The ramp-down constraint penalty price. Expressed in $/MW/hr.
- **RampUpPenPrice:** The ramp-up constraint penalty price. Expressed in $/MW/hr.
- **RegImpact:** A tuning parameter that adjusts the impact from regulating reserves on Reserve Procurement Contingency Reserve Event constraints.

- **RegRampMult:** The amount of cleared regulating reserve a resource must be able to deploy within the Regulation Response Time assuming no contingency reserve deployment.
- **RegResponseTime:** The maximum amount of time allowed for a resource to deploy cleared Regulating Reserve in either direction. Expressed in Minutes.
- **RegShortagePenPrice:** The regulating reserve constraint penalty price. Expressed in $ per MW.
- **RegSpinShortagePenPrice:** The regulating plus spinning reserve constraint penalty price. Expressed in $ per MW.
- **RZCRReqFactor:** The percentage of the hourly reserve zone contingency reserve requirement that should be modeled in SCUC to ensure a sufficient number of resources are committed to supply contingency reserve. This factor does not impact the amount of contingency reserve actually cleared by SCED.
- **RZRegReqFactor:** The percentage of the hourly reserve zone regulating reserve requirement that should be modeled in SCUC to ensure a sufficient number of resources are scheduled to regulate. This factor does not impact the amount of regulating reserve actually cleared by SCED.
- **RZSpinReqFactor:** The percentage of the hourly reserve zone spinning reserve requirement that should be modeled in SCUC to ensure a sufficient number of resources are committed to supply spinning reserve. This factor does not impact the amount of spinning reserve actually cleared by SCED.
- **SpinImpact:** A tuning parameter that adjusts the impact from spinning reserves on Reserve Procurement Contingency Reserve Event constraints.
- **SSContResPenPrice:** The self-scheduled contingency reserve constraint penalty price. Expressed in $ per MW.
- **SSEnergyPenPrice:** The self-scheduled energy constraint penalty price. Expressed in $ per MW.
- **SSRegPenPrice:** The self-scheduled regulating reserve constraint penalty price. Expressed in $ per MW.
- **SubRegLimitPenPrice:** The Sub-Regional Power Balance constraint penalty price. Expressed in $ per MW.
- **SuppImpact:** A tuning parameter that adjusts the impact from supplemental reserves on Reserve Procurement Contingency Reserve Event constraints.
- **TransLimitCREventPenPrice:** The reserve procurement transmission constraint Contingency Reserve event penalty price. Expressed in $ per MW.
- **TransLimitRegDownPenPrice:** The reserve procurement transmission constraint regulation down penalty price. Expressed in $ per MW.
- **TransLimitRegUpPenPrice:** The reserve procurement transmission constraint regulation up penalty price. Expressed in $ per MW.
- **TransLimitPenPrice:** The transmission constraint penalty price. Expressed in $ per MW.
- **ZonalRegDepSens(k,z,h):** The zonal regulation deployment sensitivity for transmission constraint k and reserve zone z during hour h is the average sensitivity to the constraint for

all resources qualified to provide regulating reserves in the zone, weighted by the ramp rate of each resource. ZonalRegDepSens(k,z,h) is described further in Section 4.2.5.19.

- **ZonalSpinDepSens(k,z,h):** The zonal spin deployment sensitivity for transmission constraint k and reserve zone z during hour h is a ramp-rate weighted average of the sensitivities of the regulation or spin qualified resources in the zone.
- **ZonalSuppDepSens(k,z,h):** The zonal supplemental deployment sensitivity for transmission constraint k and reserve zone z during hour h is a weighted average of the sensitivities of resources in the zone that are qualified to provied off-line supplemental reserves, weighted by the ramp rate and the offline response capabilities of each resource.
- **ZonalSTRDepSens(k,z,h):** The zonal Short Term Reserve deployment sensitivity for transmission constraint k and Reserve Zone z during commitment hour h is a weighted average of the sensitivities of resources in the zone that are qualified to provide off-line supplemental reserves, weighted by the ramp rate and the offline response capabilities of each resource.
- **ZonalTripSens(k,z,h):** The zonal trip sensitivity for transmission constraint k and reserve zone z during hour h is a capacity-weighted average of the sensitivities of the resources available for commitment in the zone.
- **MaxResourceSTRPenPrice**: Maximum single resource STR clearing constraint violation penalty price
- **STRDeployTime** : STR deployment time. This is a configurable option.
- **STRRampMult** : STR ramp multiplier, a tuning parameter that determines the percentage of cleared STR that should be deployable within the STR response period.
- **TransLimitSTRPenPrice** : STR post-deployment transmission constraint violation penalty price.
- **ZNeedSTRPenPrice** : Zonal STR deployment power balance constraint violation penalty price.

11.6 SCUC Primal Variables and Output Data

- **CF(r,h):** A Boolean array. The commitment flag for resource r during hour h. Set to 1 if resource r is committed during hour h, otherwise 0.
- **ContResDispatch(r,h):** A floating point array. The contingency reserve dispatched by SCUC on resource r during hour h. Expressed in MW.
- **ContResRampViolation(r,h):** A floating point array. The contingency reserve ramp constraint violation variable for resource r during hour h. Expressed in MW.
- **DemSegDispatch(tr,h,sg):** A floating point array. The energy dispatched by SCUC on segment sg of price sensitive demand bid tr during hour h. Expressed in MW or MWh.
- **EmerCond(h):** An integer array. Represents the emergency condition for hour h as determined by the SCUC.
- **EmerMaxFlag(r,h):** An integer array. Set to 1 for resource r in hour h if the emergency maximum operating range has been released on resource r during hour h, otherwise set to 0.

- **EmerMaxRelease(r,h):** A floating point array. The percentage of the emergency maximum operating range released by SCUC on resource r during hour h. Applies in ***Emergency Mode*** only. Expressed in per unit.
- **EmerMinFlag(r,h):** An integer array. Set to 1 for resource r in hour h if the emergency minimum operating range has been released on resource r during hour h, otherwise set to 0.
- **EmerMinRelease(r,h):** A floating point array. The percentage of the emergency minimum operating range released by SCUC on resource r during hour h. Applies in ***Emergency Mode*** only. Expressed in per unit.
- **EnergyDispatch(r,h):** A floating point array. The energy dispatched by SCUC on resource r during hour h. Expressed in MW or MWh.
- **EnergyStepDispatch(r,h,st):** A floating point array. The energy dispatched by SCUC on offer curve step st for resource r during hour h. Expressed in MW or MWh.
- **ExportSegDispatch(tr,h,sg):** A floating point array. The energy dispatched by SCUC on segment sg of dispatchable export transaction tr during hour h. Expressed in MW or MWh.
- **FirstSU(r,h):** A Boolean array. The first start-up flag for resource r during hour h. Set to 1 if resource r has a first start-up during hour h, otherwise 0.
- **Flow_SystemEnergySCUC(k,h):** A floating point array. The transmission flow on transmission constraint k during hour h from entire set of system energy clearings across all market activities, both injections and withdrawals. Flow_**SystemEnergySCUC(k,h)** is not a variable in itself, but is the sum of several variables, and is defined for ease of explanation of Reserve Procurement constraints. The definition of Flow_**SystemEnergySCUC(k,h)** is given in Section 4.2.5.17.
- **GenOpResShortage(h):** A floating point array. The generation-based operating reserve constraint deficit violation variable during hour h. Expressed in MW.
- **GenRegShortage(h):** A floating point array. The generation-based regulating reserve constraint deficit violation variable during hour h. Expressed in MW.
- **GenRegSpinShortage(h):** A floating point array. The generation-based regulating plus spinning reserve constraint deficit violation variable during hour h. Expressed in MW.
- **GlobalEnergyShortage(h):** A floating point array. The global power balance constraint deficit violation variable during hour h. Expressed in MW.
- **GlobalEnergySurplus(h):** A floating point array. The global power balance constraint surplus violation variable during hour h. Expressed in MW.
- **ImportSegDispatch(tr,h,sg):** A floating point array. The energy dispatched by SCUC on segment sg of dispatchable import transaction tr during hour h. Expressed in MW or MWh.
- **LTRampDownViolation(r,h):** A floating point array. The long-term ramp-down constraint violation variable for resource r during hour h. Expressed in MW.
- **LTRampUpViolation(r,h):** A floating point array. The long-term ramp-up constraint violation variable for resource r during hour h. Expressed in MW.
- **MaxLimitViolation(r,h):** A floating point array. The maximum limit constraint violation variable for resource r during hour h. Expressed in MW.

- **MaxResourceContResViolation(r,h):** A floating point array. The maximum resource contingency reserve constraint violation variable for resource r during hour h. Expressed in MW.
- **MaxResourceRegViolation(r,h):** A floating point array. The maximum resource regulating reserve constraint violation variable for resource r during hour h. Expressed in MW.
- **MinLimitViolation(r,h):** A floating point array. The minimum limit constraint violation variable for resource r during hour h. Expressed in MW.
- **MRSU(r,h):** A floating point array. The Must-Run start-up flag for resource r during hour h. Set to 1 if resource r has a Must-Run start-up during hour h, otherwise 0.
- **MWHourlyRampDnViolation(h):** A floating point array. The market-wide ramp-down constraint violation variable for hour h. Expressed in MW/hr.
- **MWHourlyRampUpViolation(h):** A floating point array. The market-wide ramp-up constraint violation variable for hour h. Expressed in MW/hr.
- **MWOpResShortage(h):** A floating point array. The market-wide operating reserve constraint violation variable for hour h. Expressed in MW.
- **MWRegShortage(h):** A floating point array. The market-wide regulating reserve constraint violation variable for hour h. Expressed in MW.
- **MWRegSpinShortage(h):** A floating point array. The market-wide regulating plus spinning reserve constraint violation variable for hour h. Expressed in MW.
- **OffLineSupResDispatch(r,h):** A floating point array. The off-line supplemental reserve dispatched by SCUC on resource r during hour h. Expressed in MW.
- **RampDnCap(r,h):** A floating point array. The ramp-down capacity of resource r for hour h. Expressed in MW/hr.
- **RampUpCap(r,h):** A floating point array. The ramp-up capacity of resource r for hour h. Expressed in MW/hr.
- **RegResDispatch1(r,h):** A floating point array. The regulating reserve dispatched by SCUC on resource r during hour h. Expressed in MW. This portion of dispatched Regulating Reserve is a result of a consideration of the resource's regulating reserve total offer cost (that is, both the regulation capacity offer cost and the regulating mileage offer cost).
- **RegResDispatch2(r,h):** A floating point array. The regulating reserve dispatched by SCUC on resource r during hour h. Expressed in MW. This portion of dispatched Regulating Reserve is a result of consideration of the resource's regulating capacity offer cost only.
- **RF(r,h):** A Boolean array. The regulation flag for resource r during hour h. Set to 1 if resource r is selected to regulate during hour h, otherwise 0.
- **SSContResDeficit(r,h):** A floating point array. The self-scheduled contingency reserve constraint violation variable for resource r during hour h. Expressed in MW.
- **SSEnergyDeficit(r,h):** A floating point array. The self-scheduled energy constraint violation variable for resource r during hour h. Expressed in MW.
- **SSRegDeficit(r,h):** A floating point array. The self-scheduled regulating reserve constraint violation variable for resource r during hour h. Expressed in MW.

- **SD(r,h):** A Boolean array. The shut-down flag for resource r during hour h. Set to 1 if resource r has is shut down during hour h, otherwise 0. Note: For DRR Type I Resources, this variable indicates the return of load.
- **SU(r,h):** A Boolean array. The start-up flag for resource r during hour h. Set to 1 if resource r has a start-up during hour h, otherwise 0. Note: For DRR Type I Resources, this variable indicates the interruption of load.
- **SubRegLimitStepViolation(st,k,h):** A floating point array. The Sub-Regional Power Balance constraint violation variable for constraint k during hour h. Expressed in MW.
- **SUC(r,h):** A Boolean array. The cold start-up flag for resource r during hour h. Set to 1 if resource r has a cold start-up during hour h, otherwise 0.
- **SUH(r,h):** A Boolean array. The hot start-up flag for resource r during hour h. Set to 1 if resource r has a hot start-up during hour h, otherwise 0.
- **SUI(r,h):** A Boolean array. The intermediate start-up flag for resource r during hour h. Set to 1 if resource r has an intermediate start-up during hour h, otherwise 0.
- **TransLimitStepViolation(st,k,h):** A floating point array. The transmission constraint violation variable for constraint k during hour h. Expressed in MW.
- **TransLimitViolationCREvent(k,z,h):** A floating point array. The reserve procurement transmission constraint contingency reserve event violation variable for constraint k under the event of loss the largest resource in zone z during hour h. Expressed in MW.
- **TransLimitViolationRegDown(k,h):** A floating point array. The reserve procurement transmission constraint regulation down violation variable for constraint k during hour h. Expressed in MW.
- **TransLimitViolationRegUp(k,h):** A floating point array. The reserve procurement transmission constraint regulation up violation variable for constraint k during hour h. Expressed in MW.
- **UpToTUCSegDispatch(tr,h,sg):** A floating point array. The energy dispatched by SCUC on segment sg of Up-to-TUC transaction tr during hour h. Expressed in MW or MWh.
- **VirtualDemSegDispatch(tr,h,sg):** A floating point array. The energy dispatched by SCUC on segment sg of virtual demand bid tr during hour h. Expressed in MW or MWh.
- **VirtualSupSegDispatch(tr,h,sg):** A floating point array. The energy dispatched by SCUC on segment sg of virtual supply offer tr during hour h. Expressed in MW or MWh.
- **ZMinRegReq(z,h):** A floating point array. The solved minimum zonal regulating reserve requirement for zone z during hour h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements (regulation, spinning, and supplemental) ensure the deliverability of procured reserves intra-zonally, as needed.
- **ZMinSpinReq(z,h):** A floating point array. The solved minimum zonal spinning reserve requirement for zone z during hour h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements (regulation, spinning, and supplemental) ensure the deliverability of procured reserves intra-zonally, as needed.
- **ZMinSuppReq(z,h):** A floating point array. The solved minimum zonal supplemental reserve requirement for zone z during hour h, expressed in MW. Together, the inclusion of the

minimum zonal reserve requirements (regulation, spinning, and supplemental) ensure the deliverability of procured reserves intra-zonally, as needed.

- **MaxResourceSTRViol(r,h):** Maximum single resource STR clearing constraint for resource at location r and hour h
- **OfflineSTRResDispatch(r,h):** Cleared offline STR MW value for resource r at hour h
- **OnlineSTRResDispatch(r,h):** STRonlineMW(r,h): Cleared online STR MW value for resource r at hour h
- **STRResDispatch (r,h)** : Cleared STR MW value for resource r at hour h
- **STRTransLimit(k,h) :** STR transmission constraint maximum flow allowed after STR response for constraint k at hour h
- **STRResponse(z,e,h)** : STR response provided by resources for constraint k in zone z at hour h.

11.7 Pre-SCED Processing Variables

- **ContResOfferPrice(r,h):** A floating point array. The contingency reserve offer price used in the SCED algorithm to dispatch contingency reserve on resource r during hour h. Expressed in $ per MW.
- **EnergyStepPrice(r,h,st):** A floating point array. The energy offer curve step price for resource r and offer curve step st during hour h. Expressed in $ per MWh.
- **EnergyStepWidth(r,h,st):** A floating point array. The energy offer curve step width for resource r and offer curve step st during hour h. Expressed in MW.
- **InvB(i,j,h):** A floating point array. The inverted bus admittance matrix for hour h.
- **LTSCEDRampDownRate(r,h):** A floating point array. The ramp-down rate used in the long-term ramp-down constraints for resource r during hour h.
- **LTSCEDRampUpRate(r,h):** A floating point array. The ramp-up rate used in the long-term ramp-up constraints for resource r during hour h.
- **MaxEnergyLimit(r,h):** A floating point array. The maximum energy limit for resource r during hour h.
- **MaxLimit(r,h):** A floating point array. The maximum limit for resource r during hour h.
- **MinLimit(r,h):** A floating point array. The minimum limit for resource r during hour h.
- **MWOpResStepPrice(st,h):** A floating point array. The market-wide operating reserve demand curve step price for step st and hour h. Expressed in $ per MW.
- **MWOpResStepWidth(st,h):** A floating point array. The market-wide operating reserve demand curve step width for step st and hour h. Expressed in MW.

11.8 SCED Parameters

- **ContResDeployTime:** The maximum amount of time in which Contingency Reserve must be deployed after notification. Expressed in Minutes.

- **ContResRampMult:** The amount of cleared contingency reserve a resource must be able to deploy within the Contingency Reserve Deployment Time assuming no regulating reserve deployment.
- **EnergyShortagePenPrice:** The global power balance constraint deficit penalty price. Expressed in $ per MW.
- **EnergySurplusPenPrice:** The global power balance constraint surplus penalty price. Expressed in $ per MW.
- **FixedDemScalePenPrice:** The fixed demand scale-down penalty price. Expressed in $ per MW.
- **GenORReqFactor:** The percentage of operating reserve that must be supplied by Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources based on applicable reliability standards.
- **GenOpResShortagePenPrice:** The generation-based operating reserve constraint penalty price. Expressed in $ per MW.
- **GenRegReqFactor:** The percentage of regulating reserve that must be supplied by Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources based on applicable reliability standards.
- **GenRegShortagePenPrice:** The generation-based regulating reserve constraint penalty price. Expressed in $ per MW.
- **GenRegSpinReqFactor:** The percentage of regulating plus spinning reserve that must be supplied by Generation Resources, Demand Response Resources - Type II and External Asynchronous Resources based on applicable reliability standards.
- **GenRegSpinShortagePenPrice:** The generation-based regulating plus spinning reserve constraint penalty price. Expressed in $ per MW.
- **LimitPenPrice:** The limit constraint penalty price. Expressed in $ per MW.
- **LossDemandFactor:** The loss offset factor is the projected percentage of the medium term load forecast that will clear in the day ahead market.
- **LossOffsetFactor:** The loss offset factor is an estimate of the difference between actual losses and marginal losses expressed as a percentage of the projected cleared day ahead demand. Since actual losses are less than marginal losses, this factor is typically negative.
- **MaxConResFactor:** The maximum percentage of the market-wide contingency reserve requirement that can be supplied by a single resource.
- **MinLimitScalePenPrice:** The minimum limit scale-down penalty price. Expressed in $ per MW.
- **MaxRegResFactor:** The maximum percentage of the market-wide regulating reserve requirement that can be supplied by a single resource.
- **MaxResourceContResPenPrice:** The maximum resource contingency reserve constraint penalty price. Expressed in $ per MW.
- **MaxResourceRegPenPrice:** The maximum resource regulating reserve constraint penalty price. Expressed in $ per MW.
- **RampPenPrice:** The ramp constraint penalty price. Expressed in $ per MW.

- **RegRampMult:** The amount of cleared regulating reserve a resource must be able to deploy within the Regulation Response Time assuming no contingency reserve deployment.
- **RegResponseTime:** The maximum amount of time allowed for a resource to deploy cleared Regulating Reserve in either direction. Expressed in Minutes.
- **RegSpinShortagePenPrice:** The regulating plus spinning reserve constraint penalty price. Expressed in $ per MW.
- **SSContResPenPrice:** The self-scheduled contingency reserve constraint penalty price. Expressed in $ per MW.
- **SSEnergyPenPrice:** The self-scheduled energy constraint penalty price. Expressed in $ per MW.
- **SSRegPenPrice:** The self-scheduled regulating reserve constraint penalty price. Expressed in $ per MW.
- **SubRegLimitPenPrice:** The Sub-Regional Power Balance constraint penalty price. Expressed in $ per MW.
- **TransLimitPenPrice:** The transmission constraint penalty price. Expressed in $ per MW.

11.9 SCED Primal Variables and Output Data

- **ClearedContRes(r,h):** A floating point array. The contingency reserve cleared by SCED on resource r during hour h. Expressed in MW.
- **ClearedDemSeg(tr,h,sg):** A floating point array. The energy cleared by SCED on segment sg of price sensitive demand bid tr during hour h. Expressed in MW or MWh.
- **ClearedEnergy(r,h):** A floating point array. The energy cleared by SCED on resource r during hour h. Expressed in MW or MWh.
- **ClearedExportSeg(tr,h,sg):** A floating point array. The energy cleared by SCED on segment sg of dispatchable export transaction tr during hour h. Expressed in MW or MWh.
- **ClearedImportSeg(tr,h,sg):** A floating point array. The energy cleared by SCED on segment sg of dispatchable import transaction tr during hour h. Expressed in MW or MWh.
- **ClearedMWOpRes(h):** A floating point array. The market-wide operating reserve cleared by SCED for hour h. Expressed in MW.
- **ClearedMWRegRes(h):** A floating point array. The market-wide regulating reserve cleared by SCED for hour h. Expressed in MW.
- **ClearedRegRes1(r,h):** A floating point array. The regulating reserve cleared by SCED on resource r during hour h, considering the resource's total regulating reserve offer cost. Expressed in MW.
- **ClearedRegRes2(r,h):** A floating point array. The regulating reserve cleared by SCED on resource r during hour h, considering just the resource's regulating capacity offer cost. Expressed in MW
- **ClearedRZOpRes(z,h):** A floating point array. The reserve zone operating reserve cleared by SCED for reserve zone z during hour h. Expressed in MW.
- **ClearedRZRegRes(z,h):** A floating point array. The reserve zone regulating reserve cleared by SCED for reserve zone z during hour h. Expressed in MW.

- **ClearedUpToTUCSeg(tr,h,sg):** A floating point array. The energy cleared by SCED on segment sg of Up-to-TUC transaction tr during hour h. Expressed in MW or MWh.
- **ClearedVirtualDemSeg(tr,h,sg):** A floating point array. The energy cleared by SCED on segment sg of virtual demand bid tr during hour h. Expressed in MW or MWh.
- **ClearedVirtualSupSeg(tr,h,sg):** A floating point array. The energy cleared by SCED on segment sg of virtual supply offer tr during hour h. Expressed in MW or MWh.
- **ContResRampViolation(r,h):** A floating point array. The contingency reserve ramp constraint violation variable for resource r during hour h. Expressed in MW.
- **ContResTieBreak1(r1,r2,h):** A floating point array. The contingency reserve tie-breaking variable 1 between resource r1 and resource r2 for hour h.
- **ContResTieBreak2(r1,r2,h):** A floating point array. The contingency reserve tie-breaking variable 2 between resource r1 and resource r2 for hour h.
- **EnergyStepClearing(r,h,st):** A floating point array. The energy cleared by SCED on offer curve step st for resource r during hour h. Expressed in MW or MWh.
- **EnergyTieBreak1(e1,e2,h):** A floating point array. The energy tie-breaking variable 1 between resource or transaction e1 and resource or transaction e2 for hour h.
- **EnergyTieBreak2(e1,e2,h):** A floating point array. The energy tie-breaking variable 2 between resource or transaction e1 and resource or transaction e2 for hour h.
- **FixedDemScaleFactor(h):** A floating point array. The factor by which fixed demand bids and fixed exports are scaled down in hour h by SCED if and only if an energy shortage occurs.
- **GenOpResShortage(h):** A floating point array. The generation-based operating reserve constraint deficit violation variable during hour h. Expressed in MW.
- **GenRegShortage(h):** A floating point array. The generation-based regulating reserve constraint deficit violation variable during hour h. Expressed in MW.
- **GenRegSpinShortage(h):** A floating point array. The generation-based regulating plus spinning reserve constraint deficit violation variable during hour h. Expressed in MW.
- **Globalλ(i,h):** A floating point array. The shadow price (i.e., dual variable) of the global power balance constraint for bus i during hour h. Expressed in $ per MW.
- **GlobalEnergyShortage(i,h):** A floating point array. The global power balance constraint deficit violation variable for bus i during hour h. Expressed in MW.
- **GlobalEnergySurplus(i, h):** A floating point array. The global power balance constraint surplus violation variable for bus i during hour h. Expressed in MW.
- **LTRampDownViolation(r,h):** A floating point array. The long-term ramp-down constraint violation variable for resource r during hour h. Expressed in MW.
- **LTRampUpViolation(r,h):** A floating point array. The long-term ramp-up constraint violation variable for resource r during hour h. Expressed in MW.
- **MaxEnergyLimitViolation(r,h):** A floating point array. The maximum limit constraint violation variable for resource r during hour h. Expressed in MW.
- **MaxLimitViolation(r,h):** A floating point array. The maximum limit constraint violation variable for resource r during hour h. Expressed in MW.

- **MaxResourceContResViolation(r,h):** A floating point array. The maximum resource contingency reserve constraint violation variable for resource r during hour h. Expressed in MW.
- **MaxResourceRegViolation(r,h):** A floating point array. The maximum resource regulating reserve constraint violation variable for resource r during hour h. Expressed in MW.
- **ModeledLosses(h):** A floating point array. Actual losses modeled during hour h in the SCED algorithm. Expressed in MW.
- **MinLimitScaleFactor(h):** A floating point array. The factor by which minimum limits on non-regulating reserves and fixed imports are scaled down in hour h by SCED if and only if an energy surplus occurs.
- **MinLimitViolation(r,h):** A floating point array. The minimum limit constraint violation variable for resource r during hour h. Expressed in MW.
- **MWOpResStepClearing(st,h):** A floating point array. The market-wide operating reserve cleared by SCED for step st of the market-wide operating reserve demand curve during hour h. Expressed in MW
- **MWRegSpinShortage(h):** A floating point array. The market-wide regulating plus spinning reserve constraint violation variable for hour h. Expressed in MW.
- **MWRegResStep1Clearing(h):** A floating point array. The market-wide regulating reserve cleared by SCED for step 1 of the market-wide regulating reserve demand curve during hour h. Expressed in MW.
- **MWRegResStep2Clearing(h):** A floating point array. The market-wide regulating reserve cleared by SCED for step 2 of the market-wide regulating reserve demand curve during hour h. Expressed in MW
- **MWRegSpinResStep1Clearing(h):** A floating point array. The market-wide regulating plus spinning reserve cleared by SCED for step 1 of the market-wide regulating plus spinning reserve demand curve during hour h. Expressed in MW.
- **MWRegSpinResStep2Clearing(h):** A floating point array. The market-wide regulating plus spinning reserve cleared by SCED for step 2 of the market-wide regulating plus spinning reserve demand curve during hour h. Expressed in MW.
- **MWRegSpinResStep3Clearing(h):** A floating point array. The market-wide regulating plus spinning reserve cleared by SCED for step 3 of the market-wide regulating plus spinning reserve demand curve during hour h. Expressed in MW.
- **MWRCUpStep1Clearing(h):** A floating point array. The market-wide Up Ramp Capability cleared by SCED for step 1 of the market-wide Up Ramp Capability Demand Curve during the hour h. Expressed in MW.
- **MWRCUpStep2Clearing(h):** A floating point array. The market-wide Up Ramp Capability cleared by SCED for step 2 of the market-wide Up Ramp Capability Demand Curve during the hour h. Expressed in MW.
- **MWRCDownStep1Clearing(h):** A floating point array. The market-wide Down Ramp Capability cleared by SCED for step 1 of the market-wide Down Ramp Capability Demand Curve during the hour h. Expressed in MW.

- **MWRCDownStep2Clearing(h):** A floating point array. The market-wide Down Ramp Capability cleared by SCED for step 2 of the market-wide Down Ramp Capability Demand Curve during the hour h. Expressed in MW.
- **MWSTRResClearing(h):** A floating point array. The market-wide Short Term Reserve cleared by SCED of the market-wide Short Term Reserve Demand Curve during the hour. Expressed in MW.
- **PI(i,h):** A floating point array. Net energy injections at bus i during hour h including all energy injections less all energy withdrawals except for energy withdrawals due to fixed demand bids and modeled losses. Expressed in MW.
- **PW(i,h):** A floating point array. Energy withdrawals at bus i during hour h due to fixed demand bids and modeled losses (i.e., energy withdrawals modeled at the load distributed reference bus). Expressed in MW.
- **RegResTieBreak1(r1,r2,h):** A floating point array. The regulating reserve tie-breaking variable 1 between resource r1 and resource r2 for hour h.
- **RegResTieBreak2(r1,r2,h):** A floating point array. The Short Term reserve tie-breaking variable 2 between resource r1 and resource r2 for hour h.
- **STRResTieBreak1(r1,r2,h):** A floating point array. The Short Term Reserve tie-breaking variable 1 between resource r1 and resource r2 for hour h.
- **STRResTieBreak2(r1,r2,h):** A floating point array. The regulating reserve tie-breaking variable 2 between resource r1 and resource r2 for hour h.
- **RPRegUpλ(k,h):** A floating point array. The shadow price (i.e., dual variable) of the reserve procurement regulation up constraint for transmission constraint k during hour h. Expressed in $ per MW.
- **RPRegDownλ(k,h):** A floating point array. The shadow price (i.e., dual variable) of the reserve procurement regulation down constraint for transmission constraint k during hour h. Expressed in $ per MW.
- **RPCRDepλ(k,z,h):** A floating point array. The shadow price (i.e., dual variable) of the reserve procurement contingency reserve deployment constraint for transmission constraint k during hour h. Expressed in $ per MW.
- **MWRegSpinResStep1Clearing(h):** A floating point array. The reserve zone regulating plus spinning reserve cleared by SCED for step 1 of the reserve zone regulating plus spinning reserve demand curve in zone z during hour h. Expressed in MW.
- **MWRegSpinResStep2Clearing(h):** A floating point array. The reserve zone regulating plus spinning reserve cleared by SCED for step 2 of the reserve zone regulating plus spinning reserve demand curve in zone z during hour h. Expressed in MW.
- **MWRegSpinResStep3Clearing(h):** A floating point array. The reserve zone regulating plus spinning reserve cleared by SCED for step 3 of the reserve zone regulating plus spinning reserve demand curve in zone z during hour h. Expressed in MW.
- **SSContResDeficit(r,h):** A floating point array. The self-scheduled contingency reserve constraint violation variable for resource r during hour h. Expressed in MW.

- **SSEnergyDeficit(r,h):** A floating point array. The self-scheduled energy constraint violation variable for resource r during hour h. Expressed in MW.
- **SSRegDeficit(r,h):** A floating point array. The self-scheduled regulating reserve constraint violation variable for resource r during hour h. Expressed in MW.
- **Flow_SystemEnergySCED(k,h):** A floating point array. The transmission flow on transmission constraint k during hour h from entire set of system energy clearings across all market activities, both injections and withdrawals. Flow_**SystemEnergySCED** is not a variable in itself, but is the sum of several variables, and is defined for ease of explanation of Reserve Procurement constraints. The definition of Flow_**SystemEnergySCED** is given in Section 6.2.7.17.
- **ZMinRegReq(z,h):** A floating point array. The solved minimum zonal Regulating Reserve requirement for zone z during commitment interval h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed.
- **ZMinSpinReq(z,h):** A floating point array. The solved minimum zonal spinning reserve requirement for zone z during commitment interval h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed.
- **ZMinSuppReq(z,h):** A floating point array. The solved minimum zonal supplemental reserve requirement for zone z during commitment interval h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed.
- **ZMinRCUpReq(z,h):** A floating point array. The solved minimum zonal Up Ramp Capability reserve requirement for zone z during commitment interval h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed
- **ZMinRCDownReq(z,h):** A floating point array. The solved minimum zonal Down Ramp Capability reserve requirement for zone z during commitment interval h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed
- **ZMinSTRReq(z,h):** A floating point array. The solved minimum zonal short term reserve requirement for zone z during commitment interval h, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed
- **MaxResourceSTRViol(r,h):** Maximum single resource STR clearing constraint for resource at location r and hour h
- **ClearedOfflineSTR (r,h):** Cleared offline STR MW value for resource r at hour h
- **ClearedOnlineSTR (r,h):** STRonlineMW(r,h): Cleared online STR MW value for resource r at hour h
- **STRResDispatch (r,h)** : Cleared STR MW value for resource r at hour h

- **STRTransLimit(k,h) :** STR transmission constraint maximum flow allowed after STR response for constraint k at hour h
- **STRNeedSens(k,e,t) :** Constraint flow sensitivity of the STR event e for STR transmission constraint k at hour h
- **STRResponse(z,e,t)** : STR response provided by resources for constraint k in zone z at hour h.
- **θ(i,h):** A floating point array. The bus voltage angle for bus i during hour h calculated by the SCED algorithm. Expressed in Radians.

11.10 Transmission Contingency Analysis Output Data

- **ACFlow(k,h):** A floating point array. The flow calculated for transmission contingency analysis constraint k during hour h by the transmission contingency analysis algorithm.
- **∂Flow(k,h)/∂P(i,h):** A floating point array. The shift factor for transmission contingency analysis constraint k and bus i during hour h, which represents the incremental flow on transmission contingency analysis constraint k for an incremental injection at bus i coupled with an incremental withdrawal at the load distributed reference bus. If i is replaced with tr, then this variable represents the shift factor for the transaction tr, where tr could be allocated to more than on bus.
- **∂Flow(k,h)/∂P(i,h):** A floating point array. The shift factor for transmission contingency analysis constraint k and bus i during hour h, which represents the incremental flow on transmission contingency analysis constraint k for an incremental injection at bus i coupled with an incremental withdrawal at the load distributed reference bus.
- **∂Flow(k,h)/∂P(r,h):** A floating point array. The shift factor for transmission contingency analysis constraint k and resource r during hour h, which represents the incremental flow on transmission contingency analysis constraint k for an incremental increase in resource r output coupled with an incremental withdrawal at the load distributed reference bus.
- **∂Flow(k,h)/∂P(tr,h):** A floating point array. The shift factor for transmission contingency analysis constraint k and energy transaction r during hour h, which represents the incremental flow on transmission contingency analysis constraint k for an incremental increase in energy transaction tr coupled with an incremental withdrawal at the load distributed reference bus.

11.11 Post-SCED Processing Pricing Variables

- **LMP(cpn,h):** A floating point array. The LMP for commercial pricing node cpn during hour h.
- **LMP(i,h):** A floating point array. The LMP for bus i during hour h.
- **MCC(cpn, h):** A floating point array. The marginal congestion component of the LMP at commercial pricing node cpn during hour h.
- **MCC(i, h):** A floating point array. The marginal congestion component of the LMP at bus i during hour h.
- **MEC_r(h):** A floating point array. The marginal energy component of the LMP at the load-distributed reference bus during hour h.

- **MLC(cpn, h):** A floating point array. The marginal loss component of the LMP at commercial pricing node cpn during hour h.
- **MLC(i, h):** A floating point array. The marginal loss component of the LMP at bus i during hour h.
- **WF(i,cpn):** A floating point array. The weight factor for bus i and commercial pricing node cpn.