**Manual No. 002**

# Business Practices Manual

# Energy and Operating Reserve Markets

## Attachment C

## Reliability Assessment Commitment

## Software Formulations and Business Logic

## Disclaimer

This document is prepared for informational purposes only to support the application of the provisions of the Tariff and the services provided thereunder. MISO may revise or terminate this document at any time at its discretion without notice. While every effort will be made by MISO to update this document and inform its users of changes as soon as practicable, it is the responsibility of the user to ensure use of the most recent version of this document in conjunction with the Tariff and other applicable documents, including, but not limited to, the applicable NERC Standards. Nothing in this document shall be interpreted to contradict, amend, or supersede the Tariff. MISO is not responsible for any reliance on this document by others, or for any errors or omissions or misleading information contained herein. In the event of a conflict between this document, including any definitions, and either the Tariff, NERC Standards, or NERC Glossary the Tariff, NERC Standards, or NERC Glossary shall prevail. In the event of a conflict between the Tariff and the NERC Standards, or NERC Glossary, the Tariff shall prevail until or unless the Federal Energy Regulatory Commission orders otherwise. Any perceived conflicts or questions should be directed to the Legal Department.

## TABLE OF CONTENTS

**List of Exhibits:**

# 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 1.3) 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 C to the *BPM for Energy and Operating Reserve Markets* covers the rules, design, and operational elements of the Reliability Assessment Commitment (RAC) process in MISO's Day-Ahead Energy and Operating Reserve Market and Real-Time Energy and Operating Reserve Market.

This BPM 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 Reliability Assessment Commitment software consists of the following processes:

- Pre-SCUC Processing
- SCUC Engine
- Transmission Contingency Analysis

Attachment C outlines the software formulation and business requirements for the Reliability Assessment Commitment.

# 3. Pre-SCUC Processing

Pre-SCUC processing includes the data calculations and data processing performed just prior to execution of the SCUC engine. Pre-SCUC processing establishes the following:

## 3.1 Commitment Availability

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

### 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Commitment Status for the generation resource or Demand Response Resource - Type II during the commitment interval is not set to ***Not Participating***.
    - **NOTE 1:** If a Resource is designated as a Network Resource, the Commitment Status cannot be set to ***Not Participating*** in any RAC process executed prior to the Operating Day.
    - **NOTE 2:** If a Resource has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, the Commitment Status cannot be set to ***Not Participating*** for that resource during that commitment interval.
- The Commitment Status for the generation resource or Demand Response Resource - Type II during the commitment interval is not set to ***Outage***.
- The Commitment Status for the generation resource or Demand Response Resource - Type II during the commitment interval is not set to ***Emergency***.
    - **NOTE 1:** This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode,*** of SCUC.
    - **NOTE 2:** If a resource has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, this condition will not apply.

- The Outage Scheduler outage type listed for the generation resource or Demand Response Resource - Type II during the commitment interval is not set to ***Out of Service***.
- The resource  has not been decommitted due to a forced outage. This condition applies only to IRAC and LAC studies.

### 3.1.2 Commitment Availability – Aggregate Combined-Cycle Generation Resources

An aggregate combined-cycle generation resource will be available for commitment in the Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Commitment Status for the aggregate combined-cycle generation resource during the commitment interval is not set to ***Not Participating***.
  - **NOTE 1:** If a resource  is designated as a network resource , the Commitment Status cannot be set to ***Not Participating*** in any RAC process executed prior to the Operating Day.
  - **NOTE 2:** If a resource  has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, the Commitment Status cannot be set to ***Not Participating*** for that resource during that commitment interval.

The Commitment Status for the aggregate combined-cycle generation resource during the commitment interval is not set to ***Outage***.

- The Commitment Status for the aggregate combined-cycle generation resource during the commitment interval is not set to ***Emergency***.
  - **NOTE 1:** This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
  - **NOTE 2:** If a resource  has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, this condition will not apply.
- The Outage Scheduler outage type listed for at least one of the individual generation resource s that make up the aggregate combined-cycle generation resource during the commitment interval is not set to ***Out of Service***.
- The Combined Cycle Status for the resource is set to ***Aggregate*** for the day.

- The resource has not been decommitted due to a forced outage. This condition applies only to IRAC and LAC studies.

### 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 Reliability Assessment Commitment as an individual generation resource during a specific commitment interval as long as the following conditions apply:

- The Commitment Status for the individual generation resource during the commitment interval is not set to ***Not Participating***.
  - **NOTE 1:** If a resource is designated as a network resource , the Commitment Status cannot be set to ***Not Participating*** in any RAC process executed prior to the Operating Day.
  - **NOTE 2:** If a resource has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, the Commitment Status cannot be set to ***Not Participating*** for that resource during that commitment interval.
- The Commitment Status for the individual generation resource during the commitment interval is not set to ***Outage***.
- The Commitment Status for the individual generation resource during the commitment interval is not set to ***Emergency***.
  - **NOTE 1:** This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
  - **NOTE 2:** If a resource has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, this condition will not apply.
- The Outage Scheduler outage type listed for the individual generation resource during the commitment interval 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.
- The resource  has not been decommitted due to a forced outage. This condition applies only to IRAC and LAC studies.

### 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Commitment Status for the Demand Response Resource - Type I during the commitment interval is not set to ***Not Participating***.
    - **NOTE:** If a resource  has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, the Commitment Status cannot be set to ***Not Participating*** for that resource during that commitment interval.
- The resource  has not been decommitted due to a forced outage. This condition applies only to IRAC and LAC studies.
- The Commitment Status for the Demand Response Resource - Type I during the commitment interval is not set to ***Emergency***.
    - **NOTE 1:** This condition applies in the ***Normal Mode*** of SCUC but not in the ***Emergency Mode*** of SCUC.
    - **NOTE 2:** If a resource  has been committed for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or a previous Reliability Assessment Commitment process, this condition will not apply.

### 3.1.5 Commitment Availability – External Asynchronous Resources

An External Asynchronous Resource will be available in the Reliability Assessment Commitment during a specific commitment interval 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 and/or Export Schedule for the commitment interval.
- The resource  has not been decommitted due to a forced outage. This condition applies only to IRAC and LAC studies.

### 3.1.6 Commitment Availability – Electric Storage Resources

Electric Storage Resource will be available for commitment in the Reliability Assessment Commitment during a specific commitment interval 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 commitment interval is not set to ***Out of Service***.
- The resource has not been decommitted due to a forced outage. This condition applies only to IRAC and LAC studies.

## 3.2 Off-Line Supplemental Reserve Availability

The off-line Supplemental Reserve availability is determined for each resource and commitment interval 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 commitment interval. 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 commitment interval in order to be dispatched for off-line Supplemental Reserve by SCUC or cleared for off-line Supplemental Reserve by SCED for that commitment interval. The off-line Supplemental Reserve availability is designated in the formulations as **OffLineSupAvailability(r,ci)** and will be set to 1 whenever a specific resource is available to clear off-line supplemental reserve in a specific commitment interval.

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

Generation resource s (other than combined-cycle generation resource s) and Demand Response Resources - Type II will be available to provide off-line Supplemental Reserve in the Reliability Assessment Commitment during a specific commitment interval 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 commitment interval is not set to ***Not Participating***.

- **NOTE 1:** If a resource is designated as a network resource , the Off-Line Supplemental Reserve Dispatch Status cannot be set to ***Not Participating*** in any RAC process executed prior to the Operating Day.
- **NOTE 2:** If a resource has been cleared for off-line supplemental reserve for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market, the Off-Line Supplemental Reserve Dispatch Status cannot be set to ***Not Participating*** for that resource during that commitment interval.

- The Off-Line Supplemental Reserve Dispatch Status for the generation resource or Demand Response Resource - Type II during the commitment interval 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 commitment interval is not set to ***Not Qualified***.
- The Commitment Status for the generation resource or Demand Response Resource - Type II during the commitment interval is not set to ***Outage***.
- The Outage Scheduler outage type listed for the generation resource or Demand Response Resource - Type II during the commitment interval 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Off-Line Supplemental Reserve Dispatch Status for the aggregate combined-cycle generation resource during the commitment interval is not set to ***Not Participating***.

- **NOTE 1:** If a resource is designated as a network resource , the Off-Line Supplemental Reserve Dispatch Status cannot be set to ***Not Participating*** in any RAC process executed prior to the Operating Day.

    - **NOTE 2:** If a resource has been cleared for off-line supplemental reserve for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market, the Off-Line Supplemental Reserve Dispatch Status cannot be set to ***Not Participating*** for that resource during that commitment interval.
- The Off-Line Supplemental Reserve Dispatch Status for the aggregate combined-cycle generation resource during the commitment interval 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 commitment interval is not set to ***Not Qualified***.
- The Commitment Status for the aggregate combined-cycle generation resource during the commitment interval is not set to ***Outag***e.
- The Outage Scheduler outage type listed for at least one of the individual generation resource s that make up the aggregate combined-cycle generation resource during the commitment interval 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 Reliability Assessment Commitment as an individual generation resource during a specific commitment interval as long as the following conditions apply:

- The Off-Line Supplemental Reserve Dispatch Status for the individual generation resource during the commitment interval is not set to ***Not Participating***.
    - **NOTE 1:** If a resource is designated as a network resource , the Off-Line Supplemental Reserve Dispatch Status cannot be set to ***Not Participating*** in any RAC process executed prior to the Operating Day.

- **NOTE 2:** If a resource has been cleared for off-line supplemental reserve for a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market, the Off-Line Supplemental Reserve Dispatch Status cannot be set to ***Not Participating*** for that resource during that commitment interval.

- The Off-Line Supplemental Reserve Dispatch Status for the individual generation resource during the commitment interval 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 commitment interval is not set to ***Not Qualified***.
- The Commitment Status for the individual generation resource during the commitment interval is not set to ***Outage***.
- The Outage Scheduler outage type listed for the individual generation resource during the commitment interval 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 Resource

An Electric Storage Resource will be available to provide off-line Supplemental Reserve in the Reliability Assessment Commitment during a specific commitment interval as long as the Commitment Status is Available.

## 3.3 Regulating Reserve Availability

The Regulating Reserve availability is determined for each resource and commitment interval 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 commitment interval in order to be dispatched for Regulating Reserve by SCUC or cleared for Regulating Reserve by SCED for that commitment interval. The Regulating

Reserve availability is designated in the formulations as **RegAvailability(r,ci)** and will be set to 1 whenever a specific resource is available to provide Regulating Reserve in a specific commitment interval.

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

Generation resource s and Demand Response Resources - Type II will be available to provide Regulating Reserve in the Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The generation resource or Demand Response Resource - Type II is available for commitment during the commitment interval 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 commitment interval is not set to ***Not Participating***.
- The Regulating Reserve Dispatch Status for the generation resource or Demand Response Resource - Type II during the commitment interval 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The External Asynchronous Resource **CommitAvailability** flag is set to 1 during the commitment interval per Section 3.1 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 commitment interval is not set to ***Not Participating***.
- The Regulating Reserve Dispatch Status for the External Asynchronous Resource during the commitment interval is not set to ***Not Qualified***.

### 3.3.3 Regulating Reserve Availability – Electric Storage Resources

An Electric Storage Resource will be available to provide Regulating Reserve in the Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Electric Storage Resource **CommitAvailability** flag is set to 1 during the commitment interval per Section 3.1.7 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 the Electric Storage Resource during the commitment interval is not set to ***Not Participating***.
- The Regulating Reserve Dispatch Status for the Electric Storage Resource during the commitment interval is not set to ***Not Qualified***.

## 3.4 Spinning Reserve Availability

The Spinning Reserve availability is determined for each resource and commitment interval 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 commitment interval in order to be dispatched for Spinning Reserve by SCUC or cleared for Spinning Reserve by SCED for that commitment interval. The Spinning Reserve availability is designated in the formulations as **SpinAvailability(r,ci)** and will be set to 1 whenever a specific resource is available to provide Spinning Reserve in a specific commitment interval.

### 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The generation resource or Demand Response Resource - Type II is available for commitment during the commitment interval 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 commitment interval 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The External Asynchronous Resource **CommitAvailability** flag is set to 1 during the commitment interval per Section 3.1 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 commitment interval 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 Reliability Assessment Commitment during a specific commitment interval 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 commitment interval is not set to ***Not Qualified***.
- The Spinning Reserve Dispatch Status for the Demand Response Resource - Type I during the commitment interval 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 commitment interval 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 Resources

An Electric Storage Resource will be available to provide Spinning Reserve in the Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Electric Storage Resource **CommitAvailability** flag is set to 1 during the commitment interval per Section 3.1.7 above.
- The Electric Storage Resources 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 Resource during the commitment interval is not set to ***Not Qualified***.

## 3.5 Supplemental Reserve Availability

The Supplemental Reserve availability is determined for each resource and commitment interval 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 commitment interval in order to be dispatched for Supplemental Reserve by SCUC or cleared for Supplemental Reserve by SCED for that commitment interval. The Supplemental Reserve availability is designated in the formulations as **SupAvailability(r,ci)** and will be set to 1 whenever a specific resource is available to provide Supplemental Reserve in a specific commitment interval.

### 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The generation resource or Demand Response Resource - Type II is available for commitment during the commitment interval 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 commitment interval 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The External Asynchronous Resource **CommitAvailability** flag is set to 1 during the commitment interval per Section 3.1 above.
- 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 commitment interval 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 Reliability Assessment Commitment during a specific commitment interval 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 commitment interval is not set to ***Not Qualified***.
- The Supplemental Reserve Dispatch Status for the Demand Response Resource - Type I during the commitment interval 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 commitment interval 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 Resources

An Electric Storage Resource will be available to provide Supplemental Reserve in the Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Electric Storage Resource **CommitAvailability** flag is set to 1 during the commitment interval per Section 3.1.7 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 commitment interval is not set to ***Not Qualified***.

## 3.6 On-Line Short Term Reserve Availability

The On-Line Short Term Reserve availability is determined for each resource and commitment interval prior to executing the SCUC algorithm. A resource must meet certain conditions in order to be considered available to provide On-Line Short Term Reserve. Intermittent Resources and Dispatchable Intermittent Resources are not available to provide Short Term Reserve. A resource must be available to provide On-Line Short Term Reserve in a specific commitment interval in order to be dispatched for Short Term Reserve by SCUC or cleared for Short Term Reserve by SCED for that commitment interval. The on-line Short Term Reserve availability is designated in the formulations as **OnlineSTRAvailability(r,ci)** and will be set to 1 whenever a specific resource is available to provide on-line Short Term Reserve in a specific commitment interval.

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

Generation Resources and Demand Response Resources - Type II will be available to provide On-Line Short Term Reserve in Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The generation resource or Demand Response Resource - Type II is available for commitment during the commitment interval per Section 3.1 above.
- The On-Line Supplemental Reserve Dispatch Status for the generation resource or Demand Response Resource - Type II during the commitment intervalmust 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 Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The External Asynchronous Resource **CommitAvailability** flag is set to 1 during the commitment interval per Section 3.1 above.
- The On-Line Short Term Reserve Dispatch Status for the External Asynchronous Resource during the commitment interval must be set to Economic.

### 3.6.3 On-Line Short Term Reserve Availability – Electric Storage Resources

An Electric Storage Resource will be available to provide On-Line Short Term Reserve in Reliability Assessment Commitment during a specific commitment interval as long as the following conditions apply:

- The Electric Storage Resource CommitAvailability flag is set to 1 during the commitment interval per Section 3.1.7 above.
- The On-Line Short Term Reserve Dispatch Status for the Electric Storage Resource during the commitment interval must be set to ***Economic***.

## 3.7 Off-Line Short Term Reserve Availability

The Off-Line Short Term Reserve availability is determined for each resource and commitment interval 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 Resources, Intermittent Resources and Dispatchable Intermittent Resources are not available to provide Off-Line Short Term Reserve. A resource must be available to provide off-Line Short Term Reserve in a specific commitment interval in order to be dispatched for Short Term Reserve by SCUC or cleared for Short Term Reserve by SCED for that commitment interval. The off-line Short Term Reserve availability is designated in the formulations as **OfflineSTRAvailability(r,ci)** and will be set to 1 whenever a specific resource is available to provide off-line Short Term Reserve in a specific commitment interval

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

Generation Resources (other than Intermittent Resources and Dispatchable Intermittent Resources) and Demand Response Resources - Type II will be available to provide Off-Line Short Term Reserve in Reliability Assessment Commitment during a specific commitment interval 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 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 commitment interval 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 Reliability Assessment Commitment during a specific commitment interval 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 constraint is met.

## 3.8 Must Run Status

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

- If the Commitment Status for a specific resource and commitment interval is set to ***Must Run***, then the Must Run Status is set to 1 for that resource and commitment interval.
- If the resource was committed during a specific commitment interval in the Day-Ahead Energy and Operating Reserve Market or during any prior Reliability Assessment Commitment process, then the Must Run Status is set to 1 for that resource and commitment interval.
- If the Commitment Status for a specific resource and commitment interval is not set to ***Must Run*** and the resources was not committed during that commitment interval in the Day-Ahead Energy and Operating Reserve Market, then the Must Run Status is set to 0 for that resource and commitment interval.

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,ci)**, is determined as follows for each resource (except for External Asynchronous) and commitment interval based on the submitted Commitment Status for that resource and commitment interval:

- If the Commitment Status for a specific resource and commitment interval is set to ***Emergency***, then the Emergency Status is set to 1 for that resource and commitment interval.
  If the Commitment Status for a specific resource and commitment interval is not set to ***Emergency***, then the Emergency Status is set to 0 for that resource and commitment interval.

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.

The Intermittent Resource status is used in the Ramp-Up and Ramp-Down Capability constraints in SCUC.

## 3.11 Self-Scheduled Energy Status

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

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

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,ci)**, is determined as follows for each resource (except Demand Response Resources - Type I) and commitment interval based on the submitted Regulating Reserve Dispatch Status for that resource and commitment interval:

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

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,ci)**, is determined as follows for each resource and commitment interval based on the submitted Spinning Reserve Dispatch Status for that resource and commitment interval:

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

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,ci)**, is determined as follows for each External Asynchronous Resource and Demand Response Resource - Type I and for each commitment interval based on the submitted Supplemental Reserve Dispatch Status for that resource and commitment interval:

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

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,ci)**, is determined as follows for each Generation Resource, Demand Response Resource - Type II and Electric Storage Resource and for each commitment interval based on the submitted On-Line Supplemental Reserve Dispatch Status for that resource and commitment interval:

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

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,ci)**, is determined as follows for each Generation Resource, Demand Response Resource - Type II and Electric Storage Resource and for each commitment interval based on the submitted Off-Line Supplemental Reserve Dispatch Status for that resource and commitment interval:

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

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

## 3.17 Reliability Assessment Commitment Resource Limit Set

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

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

If the resource is an Electric Storage Resource, the Reliability Assessment Commitment 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, Economic 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 |

### 3.17.1 Reliability Assessment Commitment Resource Limit Sets – Generation Resources and Demand Response Resources – Type II

If a valid hourly Real-Time resource limit Set has been submitted by the market participant for a specific resource and commitment interval, that limit set is used for that resource during that commitment interval in the Reliability Assessment Commitment. If a valid hourly Real-Time resource limit Set has not been submitted by the market participant for a specific resource and commitment interval (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 Real-Time resource limit set is used for that resource during that commitment interval. The processed limit set is denoted as EmerMinLimit(r,ci), EcoMinLimit(r,ci), RegMinLimit(r,ci) (if applicable), RegMaxLimit(r,ci) (if applicable), EcoMaxLimit(r,ci) and EmerMaxLimit(r,ci).

### 3.17.2 Reliability Assessment Commitment Resource Limit Sets – External Asynchronous Resources

If a valid hourly Real-Time resource limit set has been submitted by the market participant for a specific External Asynchronous Resource and commitment interval, that limit set is used for that resource during that commitment interval in the Reliability Assessment Commitment. If a valid hourly Real-Time resource limit set has not been submitted by the market participant for a specific External Asynchronous Resource and commitment interval (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 Real-Time resource limit set is used for that External Asynchronous Resource during that commitment interval. 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,ci), EcoMinLimit(r,ci), RegMinLimit(r,ci) (if applicable), RegMaxLimit(r,ci) (if applicable), EcoMaxLimit(r,ci) and EmerMaxLimit(r,ci).

### 3.17.3 Reliability Assessment Commitment Resource Limit Sets – Electric Storage Resource

If a valid hourly Real-Time 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 Reliability Assessment Commitment. If a valid hourly Real-Time 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 Real-Time 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 Reliability Assessment Commitment Input Ramp Rates

An input ramp rate is determined for each generation resource , Demand Response Resource - Type II and External Asynchronous Resource for each commitment interval prior to executing the SCUC 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 algorithm

### 3.18.1 Reliability Assessment Commitment Ramp Rates – Generation Resources, External Asynchronous Resources and Demand Response Resources – Type II

For FRAC and IRAC studies, if a valid Real-Time Hourly Ramp Rate has been submitted by the market participant for a specific resource and commitment interval, that ramp rate is used for that resource during that commitment interval in the Reliability Assessment Commitment. If a valid Real-Time Hourly Ramp Rate has not been submitted by the market participant for a specific resource and commitment interval (e.g., a null value has been submitted for the Real-Time Hourly Ramp Rate, etc.), the Real-Time Default Ramp Rate is used for that resource during that commitment interval.

For LAC studies, each of the three Real-Time Ramp Rates are modeled: Up Ramp Rate, Down Ramp Rate, and Bi-directional Ramp Rate. If valid ramp rates have been submitted by the market participant for a specific resource and commitment interval, then that ramp rate is used for that resource during that commitment interval in LAC studies. If valid ramp rates have not been submitted by the market participant for a specific resource and commitment interval (e.g., a null value has been submitted for one or more of the modeled ramp rates, etc.), the default ramp rate is used for that ramp rate for that resource during that commitment interval.

### 3.18.2 Reliability Assessment Commitment Ramp Rates – Electric Storage Resource

If a valid Real-Time 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 Reliability Assessment Commitment. If either a valid Real-Time 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 Real-Time Hourly Charge Ramp Rate, etc.), the Real-Time Default Charge Ramp Rate or Discharge Ramp Rate will be used for that Resource during that hour.

## 3.19 Reliability Assessment Commitment 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 Reliability Assessment Commitment:

### 3.19.1 Long-Term SCUC Ramp-Up Rates

Long-term ramp-up rates, which are designated in the formulations as **LTSCUCRampUpRate(r,ci)**, 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 commitment interval (except for the first commitment interval 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. For LAC studies, the Long-Term SCUC ramp-up rate accounts for the full set of ramp rates (up, down, and bi-directional).

### 3.19.2 Long-Term SCUC Ramp-Down Rates

Long-term SCUC ramp-down rates, which are designated in the formulations as **LTSCUCRampDownRate(r,ci)**, 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 commitment interval (except for the first commitment interval 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. For LAC studies, the Long-Term SCUC ramp-up rate accounts for the full set of ramp rates (up, down, and bi-directional).

### 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,ci)**, 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 commitment interval. 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,ci)**. For LAC studies, the Long-Term SCUC start-up ramp rate accounts for the full set of ramp rates (up, down, and bi-directional), as well as a time-based start-up profile that is specified by resource type and resource fuel-type.

### 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,ci)**, 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 commitment interval (except for the first commitment interval 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. For LAC studies, the Long-Term SCUC shut-down rate accounts for the full set of ramp rates (up, down, and bi-directional), as well as a time-based shut-down profile that is specified by resource type and resource fuel-type.

## 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 commitment interval prior to the start of the Reliability Assessment Commitment SCUC period, the Initial On Status for the resource is set to 1.
- If the resource is not scheduled to be on-line during the commitment interval prior to the start of the Reliability Assessment Commitment SCUC period, 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 Reliability Assessment Commitment SCUC period 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, ci)**, captures the condition such that if a resource r starts up in commitment interval ci, 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,ci) will be set to one for the entire first hour where the resource r offers the Must-Run Commit Status, as well as the commitment interval 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 Commit 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, ci)**, captures the condition such that if a resource r starts up in commitment interval ci, 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,ci) will be set to one for sequential commitment intervals with offered Commit Status of Economic, that immediately precede a commitment interval with offered Commit Status of Must-Run.

If the SCUC starts a resource during a commitment interval where PossibleMustRunStartupPeriod(r, ci) = 1 and, and if the startup initiates a commitment period contiguous to an commitment interval 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 commitment interval ci describes the commitment interval in which the resource next has a Must Run status, after commitment interval ci, and is referred to as **NextMustRunPeriod(r,ci)**

NextMustRunPeriod(r, ci) = first ci1 such that
ci1 > = ci and MustRunStatus(r,ci1)]

## 3.24 Minimum Commitment Time

The minimum commitment time, which is designated in the formulations as **MinCommitTime(r,ci)**, represents the minimum amount of time a resource must be committed if started in commitment interval ci.

For FRAC and IRAC studies, 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 commitment interval ci. Mathematically, the minimum commitment time is determined as follows:

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

where H = SCUC Period Duration

For LAC studies, the minimum commitment time is simply the minimum run time for resource r:

MinCommitTime(r,ci)= MinRunTime(r)

## 3.25 Minimum Decommitment Time

The minimum decommitment time, which is designated in the formulations as **MinDecommitTime(r,ci)**, represents the minimum amount of time a resource must be decommitted if shut down in commitment interval ci.

For FRAC and IRAC studies, 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 commitment interval ci. Mathematically, the minimum decommitment time is determined as follows:

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

where H = SCUC Period Duration

For LAC studies, the minimum decommitment time is simply the minimum down time for resource r:

MinDecommitTime(r,ci)= MinDownTime(r)

## 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 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 resource s
- 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 resource s 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,ci)**.

### 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 resource s and Demand Response Resources - Type II for use in the SCUC algorithm.

- If 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 Real-Time Spinning Reserve offer price for the commitment interval.
- 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 Real-Time On-Line Supplemental Reserve offer price for the commitment interval.

### 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 Real-Time Spinning Reserve offer price for the commitment interval.
- 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 Real-Time Supplemental Reserve offer price for the commitment interval.

### 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 commitment interval.
- 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 commitment interval.

### 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 Real-Time Spinning Reserve offer price for the commitment interval.
- 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 Real-Time Supplemental Reserve offer price for the commitment interval.

## 3.28 SCUC Off-Line Short Term Reserve Offer Price

The Off-Line Short Term Reserve offer price is determined for each qualified resource, prior to executing the SCUC algorithm. The Off-Line Short Term Reserve 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 resource s 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 commitment interval prior to executing the SCUC algorithm. The Market-Wide Operating Reserve Requirement for a specific commitment interval is set equal to the sum of the Market-Wide Regulating Reserve Requirement for that commitment interval plus the Market-Wide Contingency Reserve Requirement for that commitment interval. The Market-Wide Operating Reserve Requirement for a specific commitment interval is designated in the formulations as **MWORReq(ci)**.

## 3.30 Market-Wide Regulating Reserve Requirement

The Market-Wide Regulating Reserve Requirement is calculated for each commitment interval prior to executing the SCUC and SCED algorithm. The Market-Wide Regulating Reserve Requirement for a specific commitment interval is designated in the formulations as **MWRegReq(ci)**. This requirement may be scaled up by a reliability margin factor to ensure Market-Wide reliability.

## 3.31 Market-Wide Regulating plus Spinning Reserve Requirement

The Market-Wide Regulating plus Spinning Reserve Requirement is calculated for each commitment interval prior to executing the SCUC algorithm. The Market-Wide Regulating plus Spinning Reserve Requirement for a specific commitment interval is set equal to the sum of the Market-Wide Regulating Reserve Requirement for that commitment interval plus the Market-Wide Spinning Reserve Requirement for that commitment interval. The Market-Wide Regulating plus Spinning Reserve Requirement for a specific commitment interval is designated in the formulations as **MWRegSpinReq(ci)**.

## 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(ci)**.

## 3.33 Market-Wide Ramp-Up Capacity Requirement

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

MWRampUpReq(ci) =

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

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

## 3.34 Market-Wide Ramp-Down Capacity Requirement

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

MWRampDnReq(ci)=

**MAX {** BaseRampDownReq,
**[-** NetLoadForecastChange(ci)
- (NetFixedNSIChange(ci) * NSIMultiplier(ci))
+ NetWindGenerationChange(ci)]
* NetLoadVariationFactor(ci)
*(RampMinutes/60)
- NetLoadUncertaintyDown(ci)**}**

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

## 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, and 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

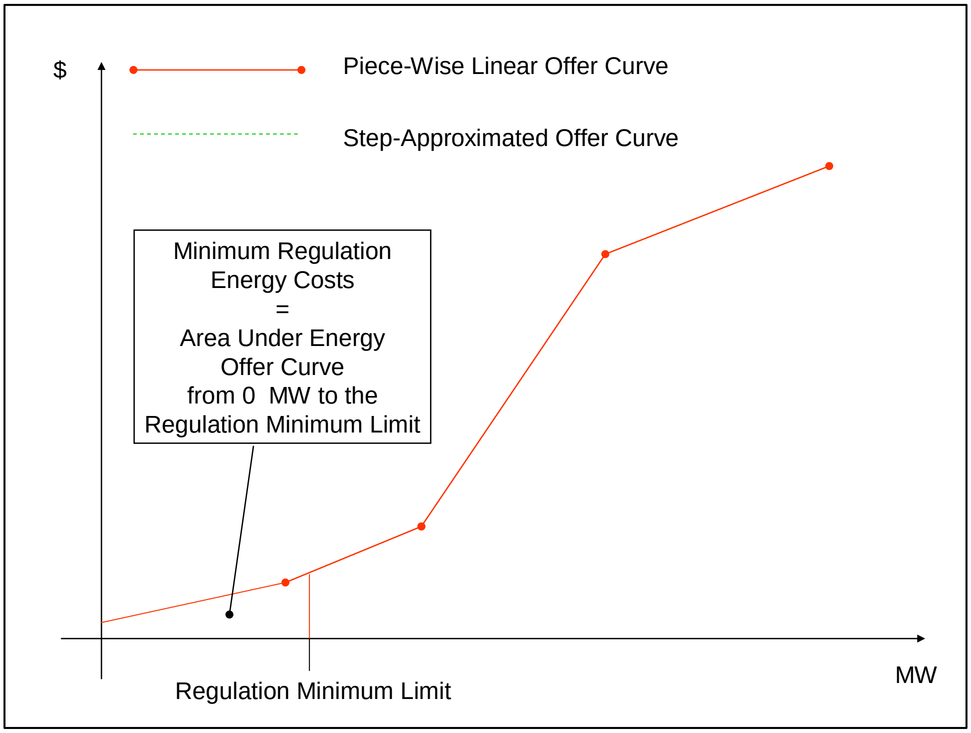
The Generation-Based Operating Reserve Requirement Factor, designated in the formulations as **GenORReqFactor(ci)**, represents the minimum percentage of the Market-Wide Operating Reserve Requirement that must be satisfied by generation resource s, Demand Response Resources - Type II and External Asynchronous 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 commitment interval as follows:

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

## 3.37 Minimum Regulation Energy Costs

Minimum regulation energy costs, designated in the formulations as **MinRegEnergyCost(r,ci)**, represents the total energy costs incurred to operate resource r at the regulation minimum limit during commitment interval ci. The minimum regulation energy costs are determined for resource r during commitment interval ci by calculating the area under the energy offer curve from 0 MW to the regulation minimum limit as illustrated in Exhibit 3-1 below:

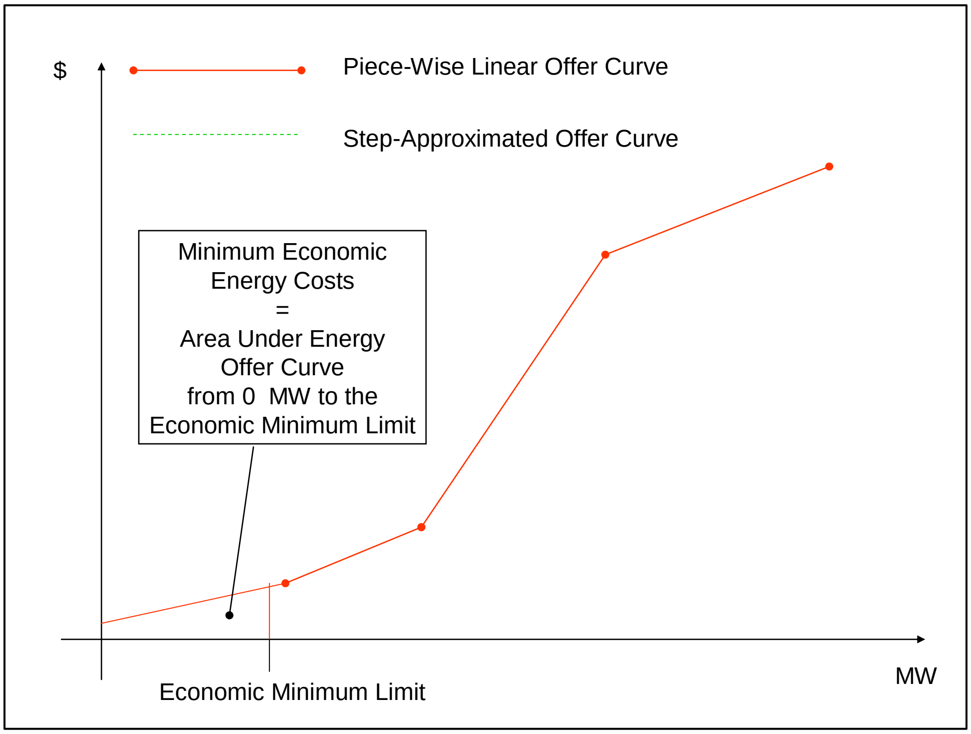
**Exhibit 3-1: Calculation of Regulation Minimum Energy Costs**




## 3.38 Minimum Economic Energy Costs

Minimum economic energy costs, designated in the formulations as **MinEconEnergyCost(r,ci)**, represents the total energy costs incurred to operate resource r at the economic minimum limit during commitment interval ci. The minimum economic energy costs are determined for resource r during commitment interval ci by calculating the area under the energy offer curve from 0 MW to the economic minimum limit as illustrated in Exhibit 3-2 below:

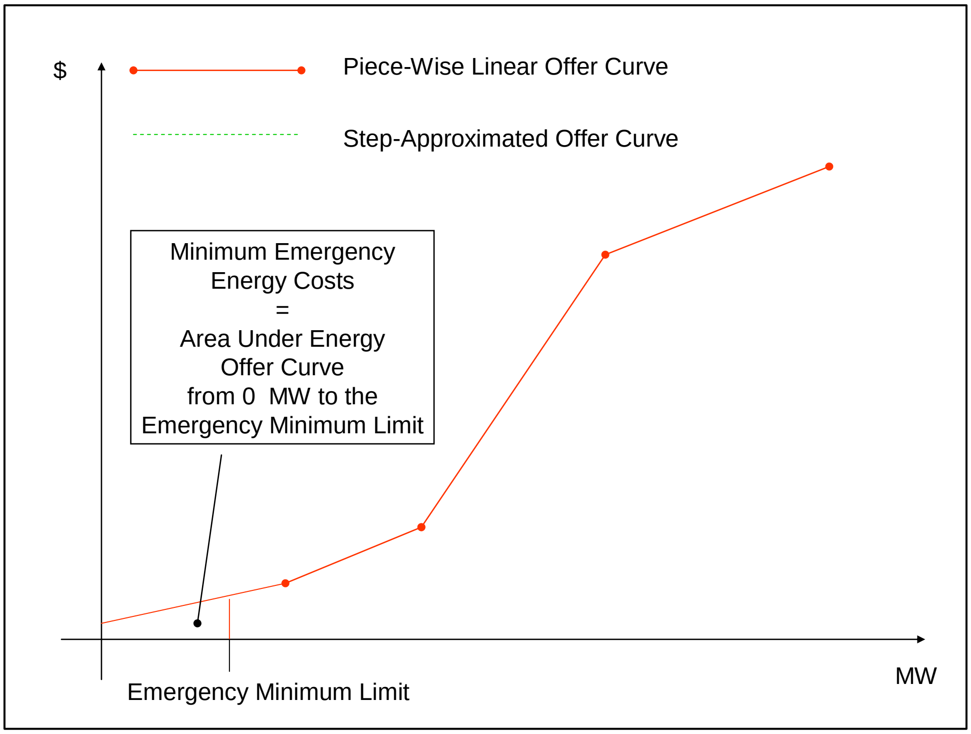
**Exhibit 3-2: Calculation of Economic Minimum Energy Costs**




## 3.39 Minimum Emergency Energy Costs

Minimum emergency energy costs, designated in the formulations as **MinEmerEnergyCost(r,ci)**, represents the total energy costs incurred to operate resource r at the emergency minimum limit during commitment interval ci. The minimum emergency energy costs are determined for resource r during commitment interval ci by calculating the area under the energy offer curve from 0 MW to the emergency minimum limit as illustrated in Exhibit 3-3 below:

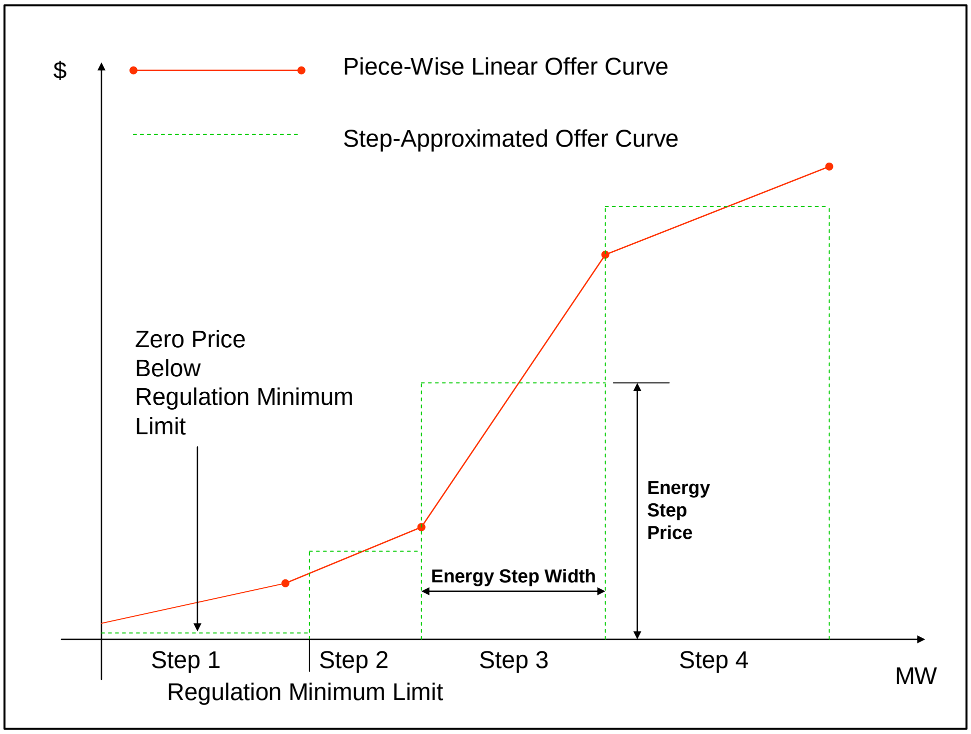
**Exhibit 3-3: Calculation of Emergency Minimum Energy Costs**




## 3.40 SCUC Energy Offer Curve Linearization

For each resource and commitment interval, 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 each piece-wise linear segment. The portion of the energy offer curve below the regulation minimum limit is set to zero. Exhibit 3-4 below provides a graphical illustration of the SCUC offer curve linearization:

**Exhibit 3-4: 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,ci,st)** and **EnergyStepPrice(r,ci,st)** respectively.

## 3.41 Topology Processing

For FRAC and IRAC studies, a topology processor executes for each commitment interval of the Reliability Assessment Commitment SCUC period. The topology uses an hourly network model (based on outage scheduler data applied to the quarterly network model) to calculate hourly shift factors for use in the watch list set of transmission constraints to be enforced in the SCUC algorithm. The shift factors are designated in the formulations as **∂Flow(k,ci)/∂P(i, ci)**.

Topology processing in LAC studies is similar to what is described above, with the following exceptions: instead of an hourly network model, the Real-Time network model based on State Estimation, supplemented by outage schedules for forward-looking intervals, is used.

## 3.42 Marginal Loss Penalty Factor Calculation

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

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

# 4. SCUC Formulations

The SCUC algorithm is used to

- Recommend resource commitments on an hourly (for FRAC and IRAC), or sub-hourly (for LAC) basis.
- For FRAC and IRAC studies, schedule resources for regulation on an hourly basis.
- Detect a shortage condition or surplus condition for each commitment interval.
- Release emergency maximum operating ranges on selected resources for given commitment intervals if a shortage condition exists.
- Release emergency minimum operating ranges on selected resources for given commitment intervals if a surplus condition exists.

Notes for LAC:

LAC studies do not schedule resources for regulation; instead, all previously-scheduled regulation resources are respected.

LAC studies analyze and provide results using sub-hourly granularity.

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 self-committed 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 Resources will clear reserves 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 offers 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 conditions is detected in one or more commitment intervals 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 Commitment Interval Curtailment Costs
+ Minimum Energy Costs
+ Scaled Resource Energy Costs
+ Scaled Regulating Reserve Costs
+ Scaled Contingency Reserve Costs
+ Scaled Off-Line Supplemental Reserve Costs
+ Scaled 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

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

### 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

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

### 4.1.3 No-Load Costs

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

No-Load Costs

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

### 4.1.4 DRR Type – I Commitment interval Curtailment Costs

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

CurtailmentCosts

$$= \sum \sum \{ CF(r,ci) * [HourlyCurtOffer(r,ci)$$

r ci

+ TargetDemRedLevel(r,ci) * EnergyOffer(r,ci)]}

### 4.1.5 Minimum Energy Costs

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

Minimum Energy Costs

=

+ CF(r,ci) * MinEcoEnergyCost(r,ci)

EmerMinRelease(r,ci)
* [MinEcoEnergyCost(r,ci
- MinEmerEnergyCost(r,ci)]

### 4.1.6 Scaled Resource Energy Costs

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

Scaled Resource Energy Costs

$$= \sum_{r} \sum_{ci} \left\{ \int_{0}^{EnergyDispatch(r,ci)} PF(r,ci) * PriceScaleFactor * EnergyOfferCurve(r,ci,MW)dMW \right\}$$

**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. The portion of the offer curve below the regulation minimum limit is set to zero. Therefore, the following mathematical expression for Energy Costs is incorporated into the actual SCUC objective function:

Energy Costs

= Σ Σ Σ { PF(r,ci) * PriceScaleFactor * EnergyStepPrice(r,ci,st)
r ci st
* EnergyStepDispatch(r,ci,st)}

where

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

### 4.1.7 Scaled 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:

Regulating Reserve Costs

= Σ Σ { PriceScaleFactor* [RegResOfferPrice(r,ci)*RegResDispatch1(r,ci)
r ci +RegCapOfferPrice(r,ci)*RegResDispatch2(r,ci)]}

**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 Scaled Resource Energy Costs Section 4.1.6.

### 4.1.8 Scaled 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

= Σ Σ { ContResOfferPrice(r,ci) * PriceScaleFactor * ContResDispatch(r,ci)} r ci

**NOTE:** DRR-Type I and 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 Scaled Resource Energy Costs Section 4.1.6.

### 4.1.9 Scaled Off-Line Supplemental Reserve Costs

Off-Line Supplemental Reserve costs apply to uncommitted Generation Resources and 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

$$= \sum_{r} \sum_{ci} \{ OffLineSupResOfferPrice(r,ci) * PriceScaleFactor * OffLineSupResDispatch(r,ci) \}$$

### 4.1.10 Scaled 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

$$= \sum_{r} \sum_{ci} \{ OffLineSTROfferPrice(r,ci) * PriceScaleFactor * OffLineSTRResDispatch(r,ci) \}$$

### 4.1.11 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 commitment interval where there was a shortage condition in the initial normal mode SCUC iteration:

Emergency Maximum Release Penalty Cost

= Σ Σ {[EmerMaxLimit(r,ci) - EcoMaxLimit(r,ci)]
r ci * EmerPenPrice
ci∈H * EmerMaxRelease(r,ci)}

Where

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

### 4.1.12 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 commitment interval where there was a surplus condition in the initial normal mode SCUC iteration:

Emergency Minimum Release Penalty Cost

= Σ Σ {[EcoMinLimit(r,ci) - EmerMinLimit(r,ci)]
r ci * EmerPenPrice
ci∈H' * EmerMinRelease(r,ci)}

Where

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

### 4.1.13 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 commitment interval of the SCUC period.

#### 4.1.13.1 Generation Resources and Demand Response Resources – Type II

Emergency Commitment Penalty Cost

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

#### 4.1.13.2 Demand Response Resources – Type I

Emergency Commitment Penalty Cost

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

### 4.1.14 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 commitment intervals 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.

#### 4.1.14.1 Generation Resources and Demand Response Resources – Type II

Emergency Contingency Reserve Penalty Cost

= Σ Σ { EmerStatus(r,ci) * EmerPenPrice *
OffLineSupResDispatch(r,ci)}
r ci

#### 4.1.14.2 Demand Response Resources – Type I

Emergency Contingency Reserve Penalty Cost

= Σ Σ { EmerStatus(r,ci) * EmerPenPrice * ConResDispatch(r,ci)}
r ci

### 4.1.15 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:

#### 4.1.15.1 Resource Maximum Limit Violation Cost:

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

Resource Maximum Limit Violation Cost

= Σ Σ { LimitPenPrice * MaxLimitViolation(r,ci)}
r ci

#### 4.1.15.2 Resource Minimum Limit Violation Cost:

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

Resource Minimum Limit Violation Cost

= Σ Σ { LimitPenPrice * MinLimitViolation(r,ci)}
r ci

#### 4.1.15.3 Resource Ramp Rate Violation Cost:

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

Resource Ramp Rate Violation Cost

= Σ Σ { RampPenPrice * ContResRampViolation(r,ci)}
r ci

+ Σ Σ { RampPenPrice * RegRampViolation(r,ci)}
r ci

#### 4.1.15.4 Global Power Balance Violation Cost:

Applies to the entire market.

Global Power Balance Violation Cost

= Σ {[EnergyShortagePenPrice * GlobalEnergyShortage(ci)]
ci
+ [EnergySurplusPenPrice* GlobalEnergySurplus(ci)]

#### 4.1.15.5 Market-Wide Regulating Reserve Violation Cost:

Applies to the entire market

Market Wide Regulating Reserve Violation Cost

= Σ {[RegShortagePenPrice * MWRegShortage(ci)]}
ci
z ci

#### 4.1.15.6 Market-Wide Regulating plus Spinning Reserve Violation Cost:

Applies to the entire market

Market Wide Regulating plus Spinning Reserve Violation Cost

$$= \sum_{ci} \{[RegSpinShortagePenPrice * MWRegSpinShortage(ci)]\}$$

#### 4.1.15.7 Market-Wide Operating Reserve Violation Cost:

Applies to the entire market

Market Wide Operating Reserve Violation Cost

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

#### 4.1.15.8 Market-Wide Short Term Reserve Violation Cost:

Applies to the entire market

Market Wide Short Term Reserve Violation Cost

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

#### 4.1.15.9 Market-Wide Ramp-Up Violation Cost:

Applies to the entire market

Market Wide Ramp-Up Violation Cost

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

#### 4.1.15.10 Market-Wide Ramp-Down Violation Cost:

Applies to the entire market

Market Wide Ramp-Down Violation Cost

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

#### 4.1.15.11 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

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

#### 4.1.15.12 Generation-Based Operating Reserve Violation Cost:

Applies to the entire market

Generation Based Operating Reserve Violation Cost

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

#### 4.1.15.13 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

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

#### 4.1.15.14 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

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

#### 4.1.15.15 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

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

#### 4.1.15.16 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

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

#### 4.1.15.17 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

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

#### 4.1.15.18 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

$$= \Sigma\ \Sigma\ TotalSTRPenaltyCost(k,ci)$$

k ci

,where

TotalSTRPenaltyCost(k,ci)

>=

TransLimitSTRPenPrice(k,ci)*[TransLimitViolSTR(k,e,ci) + TransLimitSurplusSTR(k,e,ci)]

#### 4.1.15.19 Maximum Resource Regulating Reserve Violation Cost:

Applies to each resource

Maximum Resource Regulating Reserve Violation Cost

$$= \sum_{r} \sum_{ci} \{[\text{MaxResourceRegPenPrice} * \text{MaxResourceRegViolation}(r,ci)]\}$$

#### 4.1.15.20 Maximum Resource Contingency Reserve Violation Cost:

Applies to each resource

Maximum Resource Contingency Reserve Violation Cost

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

#### 4.1.15.21 Maximum Resource Short Term Reserve Violation Cost:

Applies to each resource

Maximum Resource Short Term Reserve Violation Cost

$$= \sum_{r} \{ \text{MaxResourceSTRResPenPrice} * \text{MaxResourceSTRResViolation}(r,ci)\}$$

#### 4.1.15.22 Resource Self-Scheduled Energy Violation Cost:

Applies to each resource

Resource Self Scheduled Energy Violation Cost

$$= \Sigma\, \Sigma \{[\text{SSEnergyPenPrice} * \text{SSEnergyDeficit}(r,ci)]\}$$

r ci

#### 4.1.15.23 Resource Self-Scheduled Regulating Reserve Violation Cost:

Applies to each resource

Resource Self Scheduled Regulating Reserve Violation Cost

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

#### 4.1.15.24 Resource Self-Scheduled Contingency Reserve Violation Cost:

Applies to each resource

Resource Self Scheduled Contingency Reserve Violation Cost

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

## 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 commitment interval in order to be committed in that commitment interval.

CF(r,ci)

≤

CommitAvailability(r,ci)

If the commitment availability of a specific resource is 0 during a specific commitment interval, the commitment flag for that resource and commitment interval must also be 0. If the commitment availability for a specific resource is 1 during a specific commitment interval, the commitment flag for that resource and commitment interval 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 a resource be available for regulation a specific commitment interval in order to be selected for regulation during that commitment interval.

RF(r,ci)

≤

RegAvailability(r,ci)

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

This constraint does not apply to LAC studies.

#### 4.2.1.3 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 commitment interval in order to be dispatched for Contingency Reserve during that commitment interval.

ContResDispatch(r,ci)

≤

[EmerMaxLimit(r,ci) - EmerMinLimit(,ci)] *
SpinAvailability(r,ci)

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

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during a specific commitment interval, the contingency reserve dispatched on that resource during that commitment interval must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a specific resource are 1 during a specific commitment interval, 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 a commitment interval 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 commitment intervals when contingency reserve is available from the resource.

#### 4.2.1.4 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 commitment interval in order to be dispatched for off-line Supplemental Reserve during that commitment interval.

OffLineSupResDispatch(r,ci)

≤

MaxOffLineResponse(r,ci) * OffLineSupAvailability(r,ci)

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

#### 4.2.1.5 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 interval in order to be dispatched for on-line Short Term Reserve during that interval.

OnlineSTRResDispatch (r,ci)

≤

{ - EnergyDispatch (r,ci) - RegResDispatch1 (r,ci)
+ CF(r,ci)* EcoMaxLimit (r,ci) - RF(r,ci)*[EcoMaxLimit(r,ci) – RegMaxLimit(r,ci)]}
* OnLineSTRAvailability(r,ci)

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

OnlineSTRResDispatch (r,ci)

≤

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

#### 4.2.1.6 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,ci)

<=

[1 – CF(r,ci)] * InputRampRate(r,ci)

#### 4.2.1.7 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 commitment interval in order to be dispatched for off-line Short Term Reserve during that commitment interval.

OffLineSTRResDispatch(r,ci)

≤

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

#### 4.2.1.8 Must-Run Commitment Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

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

CF(r,ci)

≥

CommitAvailability(r,ci) * MustRunStatus(r,ci)

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

#### 4.2.1.9 Regulation Commitment Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

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

RF(r,ci)

≤

CF(r,ci)

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

This constraint does not exist for LAC studies, since regulation scheduling is not considered.

#### 4.2.1.10 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 commitment interval 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 commitment interval in order for the resource to be selected for regulation or the release of the emergency maximum operating range during that commitment interval.

RF(r,ci)

+ EmerMaxRelease(r,ci)

≤

CF(r,ci)

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

This constraint does not exist for LAC studies, since regulation scheduling is not considered.

#### 4.2.1.11 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 commitment interval 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 commitment interval in order for the resource to be selected for regulation or the release of the emergency minimum operating range during that commitment interval.

RF(r,ci)

\+ EmergMinRelease(r,ci)

≤

CF(r,ci)

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

This constraint does not exist for LAC studies, since regulation scheduling is not considered.

#### 4.2.1.12 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.

This constraint does not exist for LAC studies; instead, Real-Time conditions are considered.

#### 4.2.1.13 Start-Up/Shut-Down Commitment Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to all commitment intervals subsequent to the first commitment interval 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 commitment interval to be equal to the Commitment Flag for the resource and commitment interval less the Commitment flag for the resource in the previous commitment interval.

SU(r,ci) – SD(r,ci)

=

CF(r,ci)

- CF(r,ci-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, ci) between two adjacent commitment intervals will set either the SU(r, ci) or the SD(r, ci) flag to the value 1.

#### 4.2.1.14 Hourly Start-Up/Shut-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

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

SU(r, ci) + SD(r, ci) ≤ 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, ci) between two adjacent commitment intervals will set either the SU(r, ci) or the SD(r, ci) flag to the value 1.

#### 4.2.1.15 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.

This constraint does not exist for LAC studies; instead, Real-Time conditions are considered

#### 4.2.1.16 Hot Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard Equality

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

**IF {** ci > HotToIntTime(r)}

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

**ELSE IF {** InitialOnHours (r) > 0 }

$SUH(r, ci) = SU(r, ci)$

**ELSE IF {** InitialOnHours (r) <= 0 }

**AND {** ci – 1 – InitialOnHours(r) < HotToIntTime(r)}
$SUH(r, ci) = SU(r, ci)$

**ELSE IF {** InitialOnHours (r) <= 0 } and { ci =1 }

**AND {** – InitialOnHours(r) > = HotToIntTime(r)}
$SUH(r, ci) = 0$

**ELSE IF {** InitialOnHours (r) <= 0 } and {ci > 1}

**AND {** ci - 1 – InitialOnHours(r) >= HotToIntTime(r)}

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

**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.

#### 4.2.1.17 Intermediate Start-Up Constraint

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraint is applied to a resource r in any commitment interval ci of the SCUC study period.

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

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

**ELSE IF {** InitialOnHours (r) <= 0 **}**

**AND {** ci – 1 – InitialOnHours(r) < HotToColdTime(r)**}**

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

**ELSE IF {** (InitialOnHours (r) <= 0 ) AND { ci=1 **}**

**AND {** – InitialOnHours(r) >= HotToColdTime(r)**}**
SUI(r, ci) = 0

**ELSE IF {** (InitialOnHours (r) <= 0 ) AND { ci > 1 **}**

**AND {** ci – 1 – InitialOnHours(r) >= HotToColdTime(r)**}**

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

**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.

#### 4.2.1.18 Must-Run Startup Constraint

Constraint Classification: Physical

Constraint Type: Hard LE

This constraint applies for all commitment intervals of the SCUC study period.

**IF {** PossibleMustRunStartupPeriod(r, ci) and ci1 > ci and ci1 < NextMustRunPeriod(r, ci)**}**

MRSU(r, ci) <= 1 - SD(r, ci1)

**END IF**

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

#### 4.2.1.19 Certain Must Run Startup Constraint

Constraint Classification: Physical

Constraint Type: Hard EQ

This constraint applies for all commitment intervals of the SCUC study period.

**IF {** CertainMustRunStartup(r, ci) = 1 **}**

MRSU(r, ci) = SU(r, ci)

**END IF**

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

#### 4.2.1.20 Possible Must-Run Start-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard EQ

This constraint applies for all commitment intervals of the SCUC study period.

**IF {** ssibleMustRunStartupPeriod(r, ci)**}**

MRSU(r, ci) = 0

**END IF**

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

#### 4.2.1.21 Cold Start-Up Constraints

Constraint Classification: Physical

Constraint Type: Hard EQ

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

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

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 commitment interval 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, ci)) is set to 1, SUH(r, ci), SUI(r, ci) and SUC(r, ci) are set to 0.

#### 4.2.1.22 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 {** ci + InitialOnHours(r) < MinRunTime(r)**}**

CF(r,ci)

≥

InitialOnStatus(r) +CommitAvailability(r,ci) - 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 commitment interval overrides this constraint.

This constraint does not exist for LAC studies.

#### 4.2.1.23 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 {** ci + InitialOffHours(r) < MinDownTime(r)**}**

CF(r,ci)

≤

InitialOnStatus(r) + MustRunStatus(r,ci)

**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 commitment interval overrides this constraint.

#### 4.2.1.24 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 commitment interval.

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

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.

#### 4.2.1.25 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 commitment interval.

SD(r,ci)

≤

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

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.

#### 4.2.1.26 Initial Maximum Run Time Constraint

Constraint Classification: Physical

Constraint Type: Hard Equality

The following constraints apply only in the first commitment interval of the SCUC period and are used to ensure a resource is not committed in the first commitment interval of the SCUC period if the initial on commitment intervals 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,ci)

**END IF**

#### 4.2.1.27 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 {** ci > MaxRunTime(r)**}**

$$\sum_{ci'=ci-MaxRunTime(r)}^{ci} \{ CF(r,ci') \} \le MaxRunTime(r)$$

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

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

**END IF**

This constraint ensures that a resource will not be committed in a specific commitment interval if commitment in that commitment interval 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.

#### 4.2.1.28 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) ≥ ci - InitialOnHours(r)**}**

OffLineSupResDispatch(r,ci)

≤

InitialOnStatus(r) * MaxOffLineResponse(r,ci)

**ELSE**

$$\sum_{ci'=ci}^{ci+MinDownTime(r)-1} OffLineSupResDispatch(r,ci')$$

≤

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

**END IF**

#### 4.2.1.29 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) ≥ ci - InitialOnHours(r)**}**

OffLineSTRResDispatch(r,ci)

≤
InitialOnStatus(r) * MaxOffLineSTR (r,ci)

**ELSE**

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

**END IF**

#### 4.2.1.30 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 commitment interval where the first start-up flag indicates the first start-up of the SCUC period.

**IF {** ci > 1 **}**

FirstSU(r,ci)

≥

SU(r,ci)

ci-1
- Σ { SU(r,ci')}
ci'=1

**ELSE**

FirstSU(r,1)

≥

SU(r,1)

**END IF**

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

#### 4.2.1.31 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 commitment interval 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 Reliability Assessment Commitment results.

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

SUC(r,ci)

≤

1

- FirstSU(r,ci)

**END IF**

If the number of commitment intervals from the Reliability Assessment Commitment posting time to the beginning of commitment interval ci 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 commitment interval, and this constraint will not allow both the cold start-up and first start-up flags to be set to 1.

#### 4.2.1.32 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 commitment interval 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 Reliability Assessment Commitment results.

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

SUI(r,ci)

≤

1

- FirstSU(r,ci)

**END IF**

If the number of commitment intervals from the Reliability Assessment Commitment posting time to the beginning of commitment interval ci 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 commitment interval, 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.

#### 4.2.1.33 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 commitment interval 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 Reliability Assessment Commitment results.

**IF {** SUHTime(r,ci) + SUHNotTime(r,ci) > ci + PostingPeriod - 1 **}**

SUH(r,ci)

≤

1

- FirstSU(r,ci)

**END IF**

If the number of commitment intervals from the Reliability Assessment Commitment posting time to the beginning of commitment interval ci 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 commitment interval, 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 commitment interval.

#### 4.2.1.34 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.

$\Sigma$ SU(r,ci)
ci$\in$ d

≤

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.

#### 4.2.1.35 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,ci,st)

≤

CF(r,ci) * EnergyStepWidth(r,ci,st)

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

#### 4.2.1.36 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,ci)

=

Σ { EnergyStepDispatch(r,ci,st)}
st

#### 4.2.1.37 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,ci)}
ci∈d

≤

MaxDailyEnergyLimit(r,d)

The sum of the energy dispatched on a specific resource across the period of study must be less than or equal to the maximum daily energy limit specified for that resource and day.

#### 4.2.1.38 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 a commitment interval 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,ci) + RegresDispatch2(r,ci)

≤

0.5 * RF(r,ci) * [RegMaxLimit(r,ci) - RegMinLimit(r,ci)]

If the regulation flag is set to 1 for a resource during a specific commitment interval, 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 commitment interval. If the regulation flag is set to 0 for a resource during a specific commitment interval, no regulating reserve may be dispatched on the resource during that commitment interval.

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

Note: For LAC studies, RF(r,ci) is not a binary variable; rather, it is a fixed input parameter.

#### 4.2.1.39 Maximum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized LE

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

EnergyDispatch(r,ci)

+ RegResDispatch1(r,ci) + RegResDispatch2(r,ci)

+ ContResDispatch(r,ci)

≤

RF(r,ci) * RegMaxLimit(r,ci)

+ [CF(r,ci) – RF(r,ci)] * EcoMaxLimit(r,ci)

+ MaxLimitViolation(r,ci)

If the commitment flag and the regulation flag are set to 1 for the resource during the commitment interval, 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 commitment interval, 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 commitment interval, then the energy, regulating reserve and contingency reserve dispatch must all sum to zero for the resource during the commitment interval. 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 commitment interval of an emergency mode SCUC execution when there was a shortage detected for that commitment interval during the initial normal mode SCUC iteration.

EnergyDispatch(r,ci)

+ RegResDispatch1(r,ci) + RegResDispatch2(r,ci)

+ ContResDispatch(r,ci)

≤

RF(r,ci) * RegMaxLimit(r,ci)

+ [CF(r,ci) – RF(r,ci)] * EcoMaxLimit(r,ci)

+ EmerMaxRelease(r,ci) * [EmerMaxLimit(r,ci) - EcoMaxLimit(r,ci)]

+ MaxLimitViolation(r,ci)

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).

Note: For LAC studies, RF(r,ci) is not a binary variable; rather, it is a fixed input parameter.

#### 4.2.1.40 Minimum Limit Constraints

Constraint Classification: Physical

Constraint Type: Penalized GE

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

EnergyDispatch(r,ci)

- RegResDispatch1(r,ci)

≥

RF(r,ci) * RegMinLimit(r,ci)

+ [CF(r,ci) – RF(r,ci)] * EcoMinLimit(r,ci)

- MinLimitViolation(r,ci)

If the commitment flag and the regulation flag are set to 1 for the resource during the commitment interval, 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 commitment interval, 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). 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 commitment interval of an ***Emergency Mode*** SCUC execution when there was a surplus detected for that commitment interval during the initial ***Normal Mode*** SCUC iteration.

EnergyDispatch(r,ci)

- RegResDispatch1(r,ci)

≥

RF(r,ci) * RegMinLimit(r,ci)

+ [CF(r,ci) – RF(r,ci)] * EcoMinLimit(r,ci)

- EmerMinRelease(r,ci) * [EcoMinLimit(r,ci) - EmerMinLimit(r,ci)]

- MinLimitViolation(r,ci)

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 portion of the 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).

Note: For LAC studies, RF(r,ci) is not a binary variable; rather, it is a fixed input parameter.

#### 4.2.1.41 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, ci)

< =

CF(r, ci)*[1-IF(r)]*[InputRampRate(r,ci)*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.

#### 4.2.1.42 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, ci)

< =

CF(r, ci)*[1-IF(r)]*[InputRampRate(r,ci)*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.

#### 4.2.1.43 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 commitment interval of a ***Normal Mode*** SCUC execution or during any commitment interval of an ***Emergency Mode*** SCUC execution when there was no shortage detected for that commitment interval during the initial ***Normal Mode*** SCUC iteration.

RampUpCap(r, ci)

< =

CF(r, ci)*EcoMaxLimit(r, ci)

+ RF(r, ci)*[RegMaxLimit(r, ci) - EcoMaxLimit(r, ci)]

– EnergyDispatch(r, ci)

– RampCapReg*[RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

– RampCapContRes*ContResDispatch(r, ci)

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

RampUpCap(r, ci)

< =

CF(r, ci)*EcoMaxLimit(r, ci)

+ RF(r, ci)*[RegMaxLimit(r, ci) – EcoMaxLimit(r, ci)]

+ EmerMaxRelease(r, ci) *[EmerMaxLimit(r, ci) – EcoMaxLimit(r, ci)]

+ [1 – CF(r, ci)]*MaxOffLineResponse(r, ci)

– EnergyDispatch(r, ci)

– RampCapReg*[RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

– RampCapContRes*ContResDispatch(r, ci)

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.

Note: For LAC studies, RF(r,ci) is not a binary variable; rather, it is a fixed input parameter.

#### 4.2.1.44 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 commitment interval of a ***Normal Mode*** SCUC execution or during any commitment interval of an ***Emergency Mode*** SCUC execution when there was no surplus detected for that commitment interval during the initial ***Normal Mode*** SCUC iteration.

RampDnCap(r, ci)

<=

EnergyDispatch(r, ci)

– RampCapReg*RegResDispatch1(r, ci)

– CF(r, ci)*EcoMinLimit(r, ci)

– RF(r, ci)*[RegMinLimit(r, ci) – EcoMinLimit(r, ci)]

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

RampDnCap(r, ci)

< =

EnergyDispatch(r, ci)

– RampCapReg*RegResDispatch1(r, ci)

– CF(r, ci)*EcoMinLimit(r, ci)

– RF(r, ci)*[RegMinLimit(r, ci) – EcoMinLimit(r, ci)]

+ EmerMinRelease(r, ci) *[EcoMinLimit(r, ci) – EmerMinLimit(r, ci)]

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.

Note: For LAC studies, RF(r,ci) is not a binary variable; rather, it is a fixed input parameter.

#### 4.2.1.45 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 commitment interval to the next based on ramp-up capability.

**IF {** ci > 1 and CF(r,ci-1)=1 **}**

EnergyDispatch(r,ci)

≤

EnergyDispatch(r,ci-1)

+ [1- SU(r,ci)] * 60 * LTSCUCRampUpRate(r,ci)

+ SU(r,ci) * 60 * LTSCUCSURampRate(r,ci)

**ELSE IF {** ci > 1 **}**

EnergyDispatch(r,ci)

≤

EcoMinLimit(r, ci) + 30 * LTSCUCSURampRate(r,ci)

**ELSE IF {** InitialOnStatus(r) = 0 **}**

EnergyDispatch(r,ci)

≤

EcoMinLimit(r, ci) + 30 * LTSCUCSURampRate(r,ci)

**END IF**

If a resource is started in a specific commitment interval, 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 commitment interval. In the first commitment interval of the SCUC period, the long-term SCUC ramp-up constraint only applies to resources that are started during the first commitment interval.

#### 4.2.1.46 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 commitment interval to the next based on ramp-down capability.

**IF {** ci > 1 **}**

EnergyDispatch(r,ci)

≥

EnergyDispatch(r,ci-1)

- CF(r,ci) * 60 * LTSCUCRampDownRate(r,ci)

- [1-CF(r,ci)] * 60 * LTSCUCSDRampRate(r,ci)

**END IF**

If a resource is not committed in a specific commitment interval, 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 commitment interval. This constraint does not apply to the first commitment interval of the SCUC period.

#### 4.2.1.47 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 a commitment interval based on ramp capability.

[ContResRampMult / ContResDeployTime]* ContResDispatch(r,ci)

≤

InputRampRate(r,ci)

+ ContResRampViolation(r,ci)

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.

#### 4.2.1.48 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 a commitment interval based on ramp capability.

[RegRampMult / RegResponseTime]* [RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

≤

InputRampRate(r,ci)

+ RegRampViolation(r,ci)

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.

#### 4.2.1.49 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 commitment interval to a maximum percentage of the market-wide Regulating Reserve requirement for that commitment interval.

[RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

≤

MaxRegResFactor * MWRegReq(ci)

+ MaxResourceRegViolation(r,ci)

#### 4.2.1.50 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 commitment interval to a maximum percentage of the market-wide contingency reserve requirement.

ContResDispatch(r,ci)

≤

MaxContResFactor * MWContResReq(ci)

+ MaxResourceContResViolation(r,ci)

#### 4.2.1.51 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 interval to a maximum percentage of the market-wide Contingency Reserve requirement.

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

#### 4.2.1.52 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,ci)

≥

CF(r,ci) * SSEnergyStatus(r, ci) * SSEnergyMW(r,ci)

- SSEnergyDeficit(r, ci)

Energy self-schedules are enforced only in commitment intervals 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.

#### 4.2.1.53 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,ci)

≥

CF(r,ci) * SSRegResStatus(r,ci) * SSRegResMW(r,ci)

- SSRegResDeficit(r,ci)

Regulating Reserve self-schedules are enforced only in commitment intervals 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.

#### 4.2.1.54 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,ci)

≥

CF(r,ci) * SSSpinResStatus(r,ci) * SSSpinResMW(r,ci) * SpinAvailability(r,ci)

+ CF(r,ci) * SSOnLineSupResStatus(r,ci) * SSOnLineSupResMW(r,ci)
* [SupAvailability(r,ci) - SpinAvailability(r,ci)]

- SSContResDeficit(r,ci)

Spinning Reserve self-schedules are enforced only in commitment intervals 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 commitment intervals 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.

#### 4.2.1.50 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,ci)

≥

$$\frac{[1 - CF(r,ci)] * SSOffLineSupResStatus(r,ci) * SSOffLineSupResMW(r,ci)}{OffLineSupAvailability(r,ci)}$$

$$- SSOffLineSupResDeficit(r,ci)$$

Off-Line Supplemental Reserve self-schedules are enforced only in commitment intervals 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 STR 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.

$$\sum_{ci=ci_{1st\ overlap}}^{ci-1} \{OnlineSTRResDispatch(r, ci1)\}$$

$$<= CF(r,ci) * \sum_{ci1=ci_{1st\ overlap}}^{ci-1} \{EcoMaxLimit(r,ci1) – EcoMinLimit(r,ci1)\}$$

$ci_{1st\ overlap}$ indicates the earliest commitment interval which is fully or partially within the STR response period of the beginning of the commitment interval ci.

### 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 commitment interval in order to be committed in that commitment interval.

CF(r,ci)

≤

CommitAvailability(r,ci)

If the commitment availability of a specific resource is 0 during a specific commitment interval, the commitment flag for that resource and commitment interval must also be 0. If the commitment availability for a specific resource is 1 during a specific commitment interval, the commitment flag for that resource and commitment interval 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 commitment interval.

RF(r,ci)

=

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 commitment interval in order to be dispatched for Contingency Reserve during that commitment interval.

ContResDispatch(r,ci)

≤

TargetDemRedLevel(r,ci) * SpinAvailability(r,ci)

+ TargetDemRedLevel(r,ci) * [SupAvailability(r,ci) - SpinAvailability(r,ci)]

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during a specific commitment interval, the contingency reserve dispatched on that resource during that commitment interval must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a specific resource is 1during a specific commitment interval, 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 prevent a Demand Response Resource - Type I from dispatching off-line Supplemental Reserve during any commitment interval.

OffLineSupResDispatch(r,ci)

=

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 interval to the targeted demand reduction level of the resource during that interval.

OfflineSTRResDispatch (r,ci)
≤
[1 - CF(r,ci)] * TargetDemRedLevel(r,di) * OfflineSTRAvailability(r,ci)

#### 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.

These constraints do not exist for LAC studies.

#### 4.2.2.7 Start-Up/Shut-Down Commitment Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

The following constraints apply to all commitment intervals subsequent to the first commitment interval 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 commitment interval to be equal to the Commitment Flag for the resource and commitment interval less the Commitment flag for the resource in the previous commitment interval.

SU(r,ci) – SD(r,ci)

=

CF(r,ci)

- CF(r,ci-1)

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

#### 4.2.2.8 Start-Up/Shut-Down Constraints

Constraint Classification: Physical

Constraint Type: Hard GE

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

SU(r, ci) + SD(r, ci) ≤ 1

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

These constraints do not exist for LAC studies.

#### 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 {** ci + InitialOnHours(r) < MinIntTime(r)**}**

CF(r,ci)

≥

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.

This constraint is not enforced for LAC studies.

#### 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 {** ci + InitialOffHours(r) < MinNonIntTime(r)**}**

CF(r,ci)

≤

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 commitment interval.

SU(r,ci)

≤

ci+MinCommitTime(r,ci)-1
Σ { CF(r,ci)} / MinCommitTime(r,ci)
ci'=ci

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 commitment interval.

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

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 commitment interval of the SCUC period and are used to ensure a resource is not committed in the first commitment interval of the SCUC period if the initial on commitment intervals 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 {** ci > MaxIntTime(r)**}**

$$\sum_{ci'=ci-MaxIntTime(r)}^{ci} \{ CF(r,ci') \} \leq MaxIntTime(r)$$

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

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

**END IF**

This constraint ensures that a resource will not be committed in a specific commitment interval if commitment in that commitment interval 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) ≥ ci – InitialOnHours **}**

ContResDispatch(r,ci)

≤

InitialOnStatus(r) * TargetDemRedLevel(r,ci)

**ELSE**

$$\sum_{ci'=ci}^{ci+\mathrm{MinNonIntTime}(r)-1} \mathrm{ContResDispatch}(r,ci')$$

≤

$$[1-\mathrm{CF}(r,ci-1)] * \sum_{ci'=ci}^{ci+\mathrm{MinNonIntTime}(r)-1} \{\mathrm{TargetDemRedLevel}(r,ci')\}$$

**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) ≥ ci – InitialOnHours **}**

OffLineSTRResDispatch (r,ci)
≤
InitialOnStatus(r) * TargetDemRedLevel(r,ci)

**ELSE**

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

**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 commitment interval where the first start-up flag indicates the first start-up of the SCUC period.

**IF {** ci > 1 **}**

FirstSU(r,ci)

≥

SU(r,ci)

ci-1
- Σ { SU(r,ci')}
ci'=1

**ELSE**

FirstSU(r,1)

≥

SU(r,1)

**END IF**

If the start-up flag for a resource in a specific commitment interval is set to 1 and the start-up flag is not set for the resource in any of the preceding commitment intervals of the SCUC period, then the first start-up flag will set to 1 for the resource during that commitment interval 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 commitment interval where the start-up time plus the start-up notification time would not be honored based on the anticipated posting time of the Reliability Assessment Commitment results.

**IF {** SUTime(r,ci) + SUNotTime(r,ci) > ci + PostingPeriod – 1 }

SU(r,ci)

≤

1

\- FirstSU(r,ci)

**END IF**

If the number of commitment intervals from the Reliability Assessment Commitment posting time to the beginning of commitment interval ci 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 commitment interval, 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.

Σ SU(r,ci)

ci∈ d

≤

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,ci)

=

CF(r,ci) * TargDemRedLevel(r,ci)

If the commitment flag is set to 0 for a resource during a specific commitment interval, then the energy dispatch for the resource must be zero. If the commitment flag is set to 1 for a resource during a specific commitment interval, 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,ci) = 0

RegResDispatch2(r,ci) = 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 a commitment interval 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 commitment interval to the targeted demand reduction level of the resource during that commitment interval.

ContResDispatch(r,ci)

≤

[1 - CF(r,ci)] * TargetDemRedLevel(r,ci)

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

#### 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, ci)

=

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, ci)

=

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 commitment interval to a maximum percentage of the market-wide contingency reserve requirement.

ContResDispatch(r,ci)

≤

MaxContResFactor * MWContResReq(ci)

+ MaxResourceContResViolation(r,ci)

#### 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 interval to a maximum percentage of the market-wide Short Term Reserve requirement.

OfflineSTRResDispatch(r,ci)
≤

MaxSTRResFactor * MWSTRReq(ci)
+ MaxResourceSTRResViolation(r,ci)

#### 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,ci)

≥

[1 - CF(r,ci)] * SSSpinResStatus(r,ci) * SSSpinResMW(r,ci) * SpinAvailability(r,ci)

+ [1 - CF(r,ci)] * SSSupResStatus(r,ci) * SSSupResMW(r,ci)
* [SupAvailability(r,ci) - SpinAvailability(r,ci)]

- SSContResDeficit(r,ci)

Spinning Reserve self-schedules are enforced only in commitment intervals 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 commitment intervals 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 commitment interval in order to be committed in that commitment interval.

CF(r,ci)

=

CommitAvailability(r,ci)

If the commitment availability of a specific resource is 0 during a specific commitment interval, the commitment flag for that resource and commitment interval must also be 0. If the commitment availability for a specific resource is 1 during a specific commitment interval, the commitment flag for that resource and commitment interval 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 commitment interval in order to be selected for regulation during that commitment interval.

RF(r,ci)

≤

RegAvailability(r,ci)

If the regulation availability of a specific resource is 0 during a specific commitment interval, the regulation flag for that resource and commitment interval must also be 0. If the regulation availability for a specific resource is 1 during a specific commitment interval, the regulation flag for that resource and commitment interval 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 commitment interval in order to be dispatched for Contingency Reserve during that commitment interval.

ContResDispatch(r,ci)

≤

[EmerMaxLimit(r,ci) - EmerMinLimit(r, ci)] * [SpinAvailability(r,ci)]

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

If the spinning reserve availability and the supplemental reserve availability of a specific resource are both 0 during a specific commitment interval, the contingency reserve dispatched on that resource during that commitment interval must also be 0. If either the spinning reserve availability or the supplemental reserve availability of a specific resource is 1 during a specific commitment interval, 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 a commitment interval 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 commitment intervals 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 commitment interval.

OffLineSupResDispatch(r,ci)

=

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 interval.

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

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

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

#### 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 constraint is used to quantify and limit the cleared on-line Short Term Reserve on each Resource based on ramp rate.

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

#### 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 commitment interval in order to be considered for regulation for that commitment interval.

RF(r,ci)

≤

CF(r,ci)

If the commitment flag is 0 for a specific resource and commitment interval, the regulation flag for that resource and commitment interval must also be zero. If the commitment flag is 1 for a specific resource and commitment interval, the regulation flag for that resource and commitment interval 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 commitment interval 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 commitment interval in order for the resource to be selected for regulation or the release of the emergency maximum operating range during that commitment interval.

RF(r,ci)

+ EmerMaxRelease(r,ci)

≤

CF(r,ci)

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

#### 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,ci,st)

≤

CF(r,ci) * EnergyStepWidth(r,ci,st)

If the commitment flag is set to 0 for a resource during a specific commitment interval, 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 commitment interval, 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,ci)

=

$\Sigma_{st}$ { EnergyStepDispatch(r,ci,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 a commitment interval 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, ci) + RegResDispatch2(r,ci)]

≤

0.5 * RF(r,ci) * [RegMaxLimit(r,ci) - RegMinLimit(r,ci)]

If the regulation flag is set to 1 for a resource during a specific commitment interval, 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 commitment interval. If the regulation flag is set to 0 for a resource during a specific commitment interval, no regulating reserve may be dispatched on the resource during that commitment interval.

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 commitment interval of a ***Normal Mode*** SCUC execution or during any commitment interval of an ***Emergency Mode*** SCUC execution when there was no shortage detected for that commitment interval during the initial ***Normal Mode*** SCUC iteration.

EnergyDispatch(r,ci)

+ [RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

+ ContResDispatch(r,ci)

≤

RF(r,ci) * RegMaxLimit(r,ci)

+ [CF(r,ci) – RF(r,ci)] * EcoMaxLimit(r,ci)

+ MaxLimitViolation(r,ci)

If the commitment flag and the regulation flag are set to 1 for the resource during the commitment interval, 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 commitment interval, 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 commitment interval, then the energy, regulating reserve and contingency reserve dispatch must all sum to zero for the resource during the commitment interval. 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 commitment interval of an emergency mode SCUC execution when there was a shortage detected for that commitment interval during the initial normal mode SCUC iteration.

EnergyDispatch(r,ci)

+ [RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

+ ContResDispatch(r,ci)

≤

RF(r,ci) * RegMaxLimit(r,ci)

+ [CF(r,ci) – RF(r,ci)] * EcoMaxLimit(r,ci)

+ EmerMaxRelease(r,ci) * [EmerMaxLimit(r,ci) - EcoMaxLimit(r,ci)]

+ MaxLimitViolation(r,ci)

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 commitment interval of a ***Normal Mode*** SCUC execution or during any commitment interval of an ***Emergency Mode*** SCUC execution when there was no surplus detected for that commitment interval during the initial ***Normal Mode*** SCUC iteration.

EnergyDispatch(r,ci)

- RegResDispatch1(r,ci)

≥

RF(r,ci) * RegMinLimit(r,ci)

- MinLimitViolation(r,ci)

If the regulation flag is set to 1 for the resource during the commitment interval, the energy dispatch less the portion regulating reserve dispatch based on total offer must be greater than or equal to the regulation minimum limit. If the regulation flag is set to 0 for the resource during the commitment interval, the energy dispatch must be greater than or equal to 0.

#### 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, ci)

<=

CF(r, ci)*[InputRampRate(r,ci)*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, ci)

<=

CF(r, ci)*[InputRampRate(r,ci)*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 commitment interval of a ***Normal Mode*** SCUC execution or during any commitment interval of an ***Emergency Mode*** SCUC execution when there was no shortage detected for that commitment interval during the initial ***Normal Mode*** SCUC iteration.

RampUpCap(r, ci)

<=

CF(r, ci)*EcoMaxLimit(r, ci)

+ RF(r, ci)*[RegMaxLimit(r, ci) – EcoMaxLimit(r, ci)]

– EnergyDispatch(r, ci)

– RampCapReg*[RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

– RampCapContRes*ContResDispatch(r, ci)

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

RampUpCap(r, ci)

<=

CF(r, ci)*EcoMaxLimit(r, ci)

+ RF(r, ci)*[RegMaxLimit(r, ci) – EcoMaxLimit(r, ci)]

+ EmerMaxRelease(r, ci) *[EmerMaxLimit(r, ci) – EcoMaxLimit(r, ci)]

– EnergyDispatch(r, ci)

– RampCapReg*[RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

– RampCapContRes*ContResDispatch(r, ci)

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 commitment interval of a SCUC execution.

RampDnCap(r, ci)

< =

EnergyDispatch(r, ci)

– RampCapReg*RegResDispatch1(r, ci)

– RF(r, ci)*RegMinLimit(r, ci)

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 commitment interval to the next based on ramp-up capability.

**IF {** ci > 1 **}**

EnergyDispatch(r,ci)

≤

EnergyDispatch(r,ci-1)

60 * LTSCUCRampUpRate(r,ci)

**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 commitment interval to the next based on ramp-down capability.

**IF {** ci > 1 **}**

EnergyDispatch(r,ci)
≥

EnergyDispatch(r,ci-1)

- 60 * LTSCUCRampDownRate(r,ci)

**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 a commitment interval based on ramp capability.

[ContResRampMult / ContResDeployTime]* ContResDispatch(r,ci)

≤

InputRampRate(r,ci)

+ ContResRampViolation(r,ci)

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 a commitment interval based on ramp capability.

[RegRampMult / RegResponseTime]* [RegResDispatch1(r, ci) + RegResDispatch2(r,ci)]

≤

InputRampRate(r,ci)

+ RegRampViolation(r,ci)

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 commitment interval to a maximum percentage of the market-wide Regulating Reserve requirement for that commitment interval.

RegResDispatch1(r, ci) + RegResDispatch2(r,ci)

≤

MaxRegResFactor * MWRegReq(ci)

+ MaxResourceRegViolation(r,ci)

#### 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 commitment interval to a maximum percentage of the market-wide contingency reserve requirement.

ContResDispatch(r,ci)

≤

MaxContResFactor * MWContResReq(ci)

+ MaxResourceContResViolation(r,ci)

#### 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 interval to a maximum percentage of the market-wide Short Term Reserve requirement.

onlineSTRResDispatch(r,ci)
≤
MaxSTRResFactor * MWSTRReq(ci)
+ MaxResourceSTRResViolation(r,ci)

#### 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,ci)

≥

CF(r,ci) * SSEnergyStatus(r, ci) * SSEnergyMW(r,ci)

- SSEnergyDeficit(r, ci)

Energy self-schedules are enforced only in commitment intervals 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 dispatched on a resource based on total offer 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,ci)

≥

CF(r,ci) * SSRegResStatus(r,ci) * SSRegResMW(r,ci)

- SSRegResDeficit(r,ci)

Regulating Reserve self-schedules are enforced only in commitment intervals 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,ci)

≥

CF(r,ci) * SSSpinResStatus(r,ci) * SSSpinResMW(r,ci) * SpinAvailability(r,ci)

+ CF(r,ci) * SSOnLineSupResStatus(r,ci) * SSOnLineSupResMW(r,ci)
* [SupAvailability(r,ci) - SpinAvailability(r,ci)]

- SSContResDeficit(r,ci)

Spinning Reserve self-schedules are enforced only in commitment intervals 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 commitment intervals 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 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 STR 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.

$$\sum_{ci=ci_{1st\ overlap}}^{ci-1} \{OnlineSTRResDispatch(r, ci1)\}$$

$$<= CF(r,ci) * \sum_{ci1=ci_{1st\ overlap}}^{ci-1} \{EcoMaxLimit(r,ci1) – EcoMinLimit(r,ci1)\}$$

$ci_{1st\ overlap}$ indicates the earliest commitment interval which is fully or partially within the STR response period of the beginning of commitment interval ci.

### 4.2.4 Reliability Constraints

#### 4.2.4.1 Global Power Balance Constraints

Constraint Classification: Reliability

Constraint Type: Penalized Equality

The global power balance constraints ensure that all energy generated with the MISO Balancing Authority plus all fixed imports into the MISO Balancing Authority during a specific commitment interval is equal to the medium term load forecast for that commitment interval plus all fixed exports for that commitment interval plus projected MISO actual losses for that commitment interval.

$$\sum_{r} \{ EnergyDispatch(r,ci)\}$$

$$+ \sum_{tr} \{ FixedImportMW(tr,ci) \}$$

$$+ GlobalEnergyShortage(ci)$$

$$=$$

$$LF(ci) * [1 + LossRate]$$

$$+ \sum_{tr} \{ FixedExportMW(tr,ci) \}$$

$$+ GlobalEnergySurplus(ci)$$

During each commitment interval, the global power balance constraint requires all energy generated in the MISO Balancing Authority by physical resources plus energy imported into the MISO Balancing Authority be equal to energy demanded within the MISO Balancing Authority plus energy exported out of the MISO Balancing Authority plus MISO Balancing Authority losses.

The global power balance constraint does not consider external generation serving external load and external losses since external generation must balance external load and external losses independently of the MISO Balancing Authority. However, external generation serving external load is modeled in the transmission constraints via the loop flow injection/withdrawal model.

#### 4.2.4.2 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 a commitment interval be greater than or equal to the market-wide Operating Reserve requirement for that commitment interval.

MWRegReq(ci)

$+ \sum_{z} \{ ZminSpinReq(z,ci) \}$

$+ \sum_{z} \{ ZMinSuppReq(z,ci) \}$

≥

MWORReq(ci)

- MWOpResShortage(ci)

#### 4.2.4.3 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, the zonal minimum spinning reserve requirements in a commitment interval be greater than or equal to the market-wide Regulating plus Spinning Reserve requirement for that commitment interval.

MWRegReq(ci)

$+ \sum_{z} \{ ZMinSpinReq(z,ci) \}$

≥

MWRegSpinReq(ci)

- MWRegSpinResShortage(ci)

#### 4.2.4.4 Market-Wide Regulating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: Penalized GE

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

$$\sum_{z} \{ ZminRegReq(z,ci) \}$$

$$\geq$$

$$MWRegReq(ci)$$

$$- MWRegResShortage(ci)$$

#### 4.2.4.5 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 interval.

$$\sum_{z} \{ ZminSTRReq(z,ci) \}$$

$$\geq$$

$$MWSTRReq(ci) - MWSTRShortage(ci)$$

#### 4.2.4.6 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 commitment interval.

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

#### 4.2.4.7 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,ci)}
z
≥ MWRampDnReq(ci)*MWRampDnReqScaleFactor(ci)
- MWHourlyRampDnViolation(ci)

#### 4.2.4.8 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 a commitment interval be greater than or equal to the minimum reserve zone Regulating Reserve requirement for that reserve zone.

$$\sum_{\substack{r \in z \\ r \neq SER}} \{ RegResDispatch1(r,ci) \}$$

$$\geq$$

$$ZMinRegReq(z,ci)$$

These constraints require that sum of the Regulating Reserve dispatched on all resources within a specific reserve zone during the commitment interval 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.

#### 4.2.4.9 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 a commitment interval be greater than or equal to the minimum reserve zone Regulating plus Spinning Reserve requirement for that reserve zone.

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

$$+$$

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

≥

ZMinRegReq(z,ci)

+

ZMinSpinReq(z,ci)

These constraints require that sum of the Regulating Reserve and Contingency Reserves dispatched on all resources within a specific reserve zone during the commitment interval 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.

#### 4.2.4.10 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 a commitment interval 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 commitment interval.

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

+

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

≥

ZMinRegReq(z,ci)

+

ZMinSpinReq(z,ci)

+

ZMinSuppReq(z,ci)

These constraints require that sum of the Regulating Reserve and Contingency Reserves dispatched on all resources within a specific reserve zone during the commitment interval 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.

#### 4.2.4.11 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 interval be greater than or equal to the sum of the minimum Reserve Zone Short Term Reserve requirement for that Reserve Zone and that interval.

Σ { OnlineSTRResDispatch(r,ci) + OfflineSTRResDispatch(r,ci)}
r∈z
≥
ZMinSTRReq(z,ci)

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.

#### 4.2.4.12 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 interval be greater than or equal to the minimum Reserve Zone Up Ramp Capability requirement for that Reserve Zone.

$$\sum_{r \in z} \{ RampUpCap\ (r,ci) \}$$

$$\geq$$

$$ZMinRCUpReq(z,ci)$$

These constraints require that sum of Up Ramp Capability dispatched on all resources within a specific Reserve Zone during the 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.

#### 4.2.4.13 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 a Commitment Interval be greater than or equal to the minimum Reserve Zone Down Ramp Capability requirement for that Reserve Zone.

$$\sum_{r \in z} \{ RampDnCap\ (r,ci) \}$$

≥
ZMinRCDownReq(z,ci)

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 is deliverable as needed.

#### 4.2.4.14 Generation-Based Operating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: 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.

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

$$+ \sum_{r \notin DRR1} \{ ContResDispatch(r,ci) \}$$

$$+ \sum_{r \notin DRR1} \{ OffLineSupResDispatch(r,ci) \}$$

$$\geq$$

$$MWORReq(ci) * GenORReqFactor$$

$$- GenOpResShortage(ci)$$

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.

#### 4.2.4.15 Generation-Based Regulating plus Spinning Reserve Constraints

Constraint Classification: Reliability

Constraint Type: 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.

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

$$+ \sum_{r \notin DRR1} \{ ContResDispatch(r,ci) * SpinAvailability(r,ci) \}$$

$$\geq$$

$$MWRegSpinReq(ci) * GenRegSpinReqFactor$$

$$- GenRegSpinResShortage(ci)$$

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%.

#### 4.2.4.16 Generation-Based Regulating Reserve Constraints

Constraint Classification: Reliability

Constraint Type: 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.

$$\sum_{r} \{ RegResDispatch1(r,ci) + RegResDispatch2(r,ci) \}$$

$$\geq$$

$$MWRegReq(ci) * GenRegReqFactor$$

$$- GenRegResShortage(ci)$$

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.

#### 4.2.4.17 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.

$$\sum_{r} \{[EnergyDispatch(r,ci)][\partial Flow(k,ci)/\partial P(r,ci)]\}$$

$$+ \sum_{tr} \{ FixedImportMW(tr,ci) * \partial Flow(k,ci)/\partial P(tr,ci)\}$$

$$+ \sum_{i} \{ LoopFlowInjectionMW(i,ci) * \partial Flow(k,ci)/\partial P(i,ci)\}$$

$$- \sum_{tr} \{ FixedExportMW(tr,ci) * \partial Flow(k,ci)/\partial P(tr,ci)\}$$

$$- \sum_{i} \{ LoopFlowWithdrawalMW(i,ci) * \partial Flow(k,ci)/\partial P(i,ci)\}$$

$$\leq$$

$$FGLimit(k,ci)$$

$$+ TransLimitViolation(k,ci)$$

These constraints are not used in LAC studies. For LAC studies, all constraints are Transmission Contingency Analysis Constraints, as described in Section 4.2.4.19.

#### 4.2.4.18 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.

Σ {[EnergyDispatch(r,ci)][InyC(k,r,ci)]}
r

+ Σ { FixedImportMW(tr,ci) * InyC(k, tr, ci)}
tr

i

- Σ { FixedExportMW(tr,ci) * InyC(k, tr, ci)}
tr

i

≤

FGLimit(k,ci)

+ Σ SubRegLimitStepViolation(st,k,ci)
st

This constraint is not used in LAC studies. For LAC studies, all constraints are Transmission Contingency Analysis Constraints, as described in Section 4.2.4.19.

#### 4.2.4.19 Transmission Contingency Analysis Constraints

Constraint Classification: Reliability

Constraint Type: Penalized LE

For FRAC and IRAC studies, transmission contingency analysis constraints represent the set of transmission constraints identified by the optional hourly transmission contingency analysis process (described in detail in Section 5) as potential problems and are enforced in the second

SCUC execution (post contingency analysis SCUC execution). For LAC studies, transmission contingency analysis constraints are determined by real-time online contingency analysis tools.

$$\sum_{r} \{[EnergyDispatch(r,ci) - EnergyDispatch(r,ci)|_{\text{First SCUC Execution}}] * [\partial Flow(k,ci)/\partial P(r,ci)]\}$$

$$+ \sum_{tr} \{ FixedImportMW(tr,ci) * \partial Flow(k,ci)/\partial P(tr,ci)\}$$

$$+ \sum_{i} \{ LoopFlowInjectionMW(i,ci) * \partial Flow(k,ci)/\partial P(i,ci)\}$$

$$- \sum_{tr} \{ FixedExportMW(tr,ci) * \partial Flow(k,ci)/\partial P(tr,ci)\}$$

$$- \sum_{i} \{ LoopFlowWithdrawalMW(i,ci) * \partial Flow(k,ci)/\partial P(i,ci)\}$$

+ ACFlow(k,ci) (or, ACFlow(k), for LAC Studies; see note below)

$$\leq$$

FGLimit(k,ci)

+ TransLimitViolation(k,ci)

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

Note: For LAC studies, ACFlow(k,ci) is replaced by ACFlow(k); that is, it is the ACTUAL flow for constraint k given the current on-line, real-time state estimation.

#### 4.2.4.20 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.

$$\text{Flow\_SystemEnergySCUC}(k,ci) + \sum_{z} \text{ZMinRegReq}(z,ci) * \text{ZonalRegDepSens}(k,z,ci) \leq \text{FGLimit}(k,ci) + \text{TransLimitViolationRegUp}(k,ci)$$

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 4.2.4.19, 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.

#### 4.2.4.21 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,ci)

$$- \sum_{z} ZMinRegReq(z,ci) * ZonalRegDepSens(k,z,ci)$$

≤

FGLimit(k,ci)

+ TransLimitViolationRegDown(k,ci)

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 4.2.4.18, 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.

#### 4.2.4.22 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,ci) ≥PmaxThreshold}

**IF {** (1/SpinImpact) * PMaxEvent(z,ci) ≤MWRegSpinReq(ci)-MWRegReq(ci)**}**

Flow_SystemEnergySCUC(k,ci)

-

PMaxEvent(z,ci)* ZonalTripSens(k,z,ci)

+

RegImpact * { Σ ZMinRegReq(z1,ci) * ZonalRegDepSens(k,z1,ci)
z1

+

{(1/SpinImpact) * PMaxEvent(z,ci)} ÷ [MWRegSpinReq(ci)-MWRegReq(ci)]}

* { Σ ZMinSpinReq(z1,ci) * ZonalSpinDepSens(k,z1,ci)}* SpinImpact
z1

≤

FGLimit_CREvent(k,ci)

+ TransLimitViolationCREvent(k,z,ci)

**ELSE**

Flow_SystemEnergySCUC(k,ci)

-

PMaxEvent(z,ci)* ZonalTripSens(k,z,ci)

+

RegImpact * { Σ ZMinRegReq(z1,ci) * ZonalRegDepSens(k,z1,ci)
z1

+

SpinImpact * { Σ ZMinSpinReq(z1,ci) * ZonalSpinDepSens(k,z1,ci) z1

+

{ PMaxEvent(z,ci) - SpinImpact * [MWRegSpinReq(ci)-MWRegReq(ci)]

÷ {[MWOpResReq(ci)-MWRegSpinReq(ci)]

* { SuppImpact * Σ ZminSuppReq(z1,ci) * ZonalSuppDepSens(k,z1,ci)}
z1

≤

FGLimit_CREvent(k,ci)

+ TransLimitViolationCREvent(k,z,ci)

**END IF**

**ELSE**

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

**END IF**

**WHERE**

PMaxEvent(z,ci) is the size of the largest resource in zone z during commitment interval ci;

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,ci), or the zonal trip sensitivity, is a capacity-weighted average of the sensitivities of the resources available for commitment in the zone during commitment interval ci;

ZonalSpinDepSens(k,z,ci), 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 commitment interval ci;

ZonalSuppDepSens(k,z), or the zonal supplemental deployment sensitivity, 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 during commitment interval ci;

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,ci) 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.

#### 4.2.4.23 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,ci)
=
Flow_SystemEnergySCUC(k,ci)
-
ZonalSTRNeed (e,ci)* ZonalTripSens(k,e,ci)
+
$\sum_{z}$ STRResponse(z,e,ci) * ZonalSTRDepSens(k,z,ci)
≤
STRTransLimit (k,ci)
+ TransLimitViolationSTREvent(k,z,ci)

**WHERE**

ZonalSTRNeed (e,ci), the possible deployment MW for STR if event e happens at interval ci . 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,ci), 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,ci), STR response provided by resources for constraint *k* in zone *z* at interval ci . STR Response is less than sum of all cleared STR in zone z excluding cleared STR on the event contingency generation.

ZonalSTRDepSens(k,z,ci), Zonal STR response sensitivity from zone z to constraint k at interval ci , 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,ci), STR transmission constraint maximum flow allowed after STR response for constraint k at interval ci .

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.

#### 4.2.4.24 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.

$$
\begin{aligned}
& FG\_SystemEnergySCED(k,ci) \\
& + \sum_{z} ZMinRCUpReq(z,ci) * ZonalRCUpDepSens(k,z,ci) \\
& \leq \\
& FGLimit(k,ci) \\
& + TransLimitViolationRCUp(k,ci)
\end{aligned}
$$

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 as a result 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.

#### 4.2.4.25 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.

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

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

$$\leq$$

$$FGLimit(k,ci)$$

$$+ TransLimitViolationRCDown(k,ci)$$

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.**3, 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.

#### 4.2.4.26 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 STR deployment and zonal events. The post-event power balance will be enforced for each STR event.

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

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

#### 4.2.4.27 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 ci has to be less than the dynamically calculated zonal requirement.

STRResponse(z,e,ci)
<=

## 4.3 ZminSTR(z,ci)SCUC Emergency Logic

During the ***Normal Mode*** execution of SCUC, a shortage flag, designated as **ShortFlag(ci)**, will be set to 1 in any commitment interval where any of the following occur:

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

- For LAC studies, **ShortFlag(ci)** will be set to 1 if a shortage Emergency condition has been declared in Real-Time.

During the ***Normal Mode*** execution of SCUC, a surplus flag, designated as **SurplusFlag(ci)**, will be set to 1 in any commitment interval where any of the following occur:

- Global energy surplus or GlobalEnergySurplus(ci) > 0
- For LAC studies, **SurplusFlag(ci)** will be set to 1 if a surplus Emergency condition has been declared in Real-Time.

When the ***Normal Mode*** execution of SCUC completes, if a shortage or surplus is detected for any commitment interval, that is if the shortage flag or surplus flag is set to 1 in any commitment interval, 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 commitment interval may be considered for commitment in that commitment interval if a shortage was detected in at least one commitment interval of the commitment period.
- 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 in at least one hour of the commitment periods.

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 in at least one hour of the commitment periods.

Off-Line Supplemental Reserve may be dispatched on an uncommitted resource in a commitment interval where the Off-Line Supplemental Reserve Dispatch Status of that was resource is set to ***Emergency*** if a shortage was detected in at least one commitment interval of the commitment period.

- The emergency maximum operating range may be released on any resource in any commitment interval where a shortage was detected.
- The emergency minimum operating range may be released on any resource in any commitment interval where 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,ci) > 0 for a specific resource in a specific commitment interval indicating that the emergency maximum operating range was utilized by SCUC for that resource and commitment interval, then the emergency maximum flag, designated as **EmerMaxFlag(r,ci)**, is set to 1 for that resource and commitment interval.

### 4.3.2 Emergency Minimum Flag

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

### 4.3.3 Emergency Condition Flag

An emergency condition flag, designated as **EmerCond(ci)**, is established by SCUC for each commitment interval and is set as follows:

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

## 4.4 SCUC Output

The following output is generated by the SCUC algorithm.

- Commitment flags for each resources or **CF(r,ci)**

- For FRAC and IRAC studies, hourly regulation flags for each resource or **RF(r,ci)**
- Emergency maximum flags for each resource or **EmerMaxFlag(r,ci)**
- Emergency minimum flags for each resource or **EmerMinFlag(r,ci)**
- Emergency condition flag for each commitment interval or EmerCond(ci)

# 5. Transmission Contingency Analysis

When a reliability assessment commitment is executed, there is an option to perform two SCUC executions separated by transmission contingency analysis. If this option is selected for a specific Reliability Assessment Commitment case, the first SCUC execution considers only the watchlist transmission constraints. At the end of the first SCUC execution, the SCUC commitment flags and energy dispatch 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 SCUC solution and identify potential transmission contingencies (both contingency and basecase) that could be an issue based on the commitment and energy dispatch results of the first SCUC execution. Based on the results of the transmission contingency analysis, additional transmission constraints are formulated and passed back to SCUC for a second iteration (See 4.2.4.12. 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 SCUC iteration to make adjustments as necessary to enforce these constraints. Because the total number of transmission constraints that can be supported by a MIP-based SCUC algorithm is limited, the Reliability Assessment Commitment software must selectively replace some of the watchlist constraints with transmission contingency analysis constraints prior to the second SCUC execution. In general, the Reliability Assessment Commitment software will only replace a watchlist constraint with a transmission contingency analysis constraint if the watchlist constraint flow in the initial SCUC execution was well below the constraint limit and the transmission contingency analysis constraint flow based on the results of the subsequent SCUC execution was at or above the constraint limit.

For LAC studies, no second SCUC execution. Transmission Contingency Analysis Constraints are received from online Real-Time contingency analysis tools, and are considered in the LAC SCUC execution.

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.

# 6. Current Tuning Parameter Settings

Listed below are the current tuning parameter settings for the RAC SCUC algorithm:

- ContResRampMult = 1.0
- ContResDeployTime = 10 Minutes
- MaxContResFactor = 0.2
- MaxRegResFactor = 0.2
- RegRampMult = 1.0
- RegResponseTime = 5 Minutes
- STRResponseTime = 30 Minutes
- MaxSTRResFactor = 1.0

# 7. Glossary of Variables, Arrays and Parameters

## 7.1 Array Indices

- **d:** Index of days in SCUC period
- **ci:** Index of commitment interval in SCUC period. For FRAC and IRAC studies, each commitment interval has a commitment interval duration of one hour. For LAC studies, each commitment interval can have either fifteen minute or thirty minute duration.
- **i:** Index of buses or electrical nodes
- **k:** Index of transmission branches, constraints or flowgates
- **r:** Index of resources
- **st:** Index of offer curve steps
- **tr:** Index of energy transactions (including fixed imports and fixed exports - excluding resources)
- **z:** Index of reserve zones

## 7.2 MISO Input Data

- **FGLimit(k,ci):** A floating point array. The limit of flowgate constraint k in commitment interval ci. Expressed in MW.
- **FGLimit_CREvent(k,ci):** A floating point array. The limit of flowgate constraint k in commitment interval ci used for Reserve Procurement Contingency Reserve Event Constraints. Expressed in MW.
- **InyC(k,r,ci)**: A floating point array. Injection Coefficient for resource r over Sub-Regional Power Balance Constraint k during commitment interval ci. Expressed in MW.
- **LoopFlowInjectionMW(i,ci):** A floating point array. The loop flow MWs injected at external bus i during commitment interval ci to model the impact of external generation serving external load. Expressed in MW. Established by MISO staff ahead of time.
- **LoopFlowWithdrawalMW(i,ci):** A floating point array. The loop flow MWs withdrawn at external bus i during commitment interval ci to model the impact of external generation serving external load. Expressed in MW. Established by MISO staff ahead of time.
- **∂Loss(ci)/∂P(i,ci):** A floating point array. The marginal loss sensitivity factor for injections at bus i during commitment interval ci calculated with respect to the load distributed reference bus. Established by MISO staff ahead of time.

- **LF(ci):** A floating point array. The load forecast in use for the study period. For FRAC and IRAC studies, it is the sum of the medium term load forecasts for all Local Balancing Authorities with in the MISO Balancing Authority, and is established by MISO staff ahead of time based on forecast data from the Local Balancing Authorities. For LAC studies, it is the short term load forecast for all Local Balancing Authorities in the MISO Balancing Authority, and is established by MISO staff ahead of time.
- **MWContResReq(ci):** A floating point array. The Market-Wide Contingency Reserve requirement for commitment interval ci. Expressed in MW.
- **MWRampDnReq(ci)**: A floating point array. The Market-Wide Ramp-Down requirement for commitment interval ci. Expressed in MW/hr.
- **MWRampDnReqScaleFactor(ci):** A floating point array. The factor by which the Market-Wide Ramp-Down Requirement is scaled in commitment interval ci, modified as necessary to ensure an adequate commitment.
- **MWRampUpReq(ci)**: A floating point array. The Market-Wide Ramp-Up requirement for commitment interval ci. Expressed in MW/hr.
- **MWRampUpReqScaleFactor(ci):** A floating point array. The factor by which the Market-Wide Ramp-Up Requirement is scaled in commitment interval ci, modified as necessary to ensure an adequate commitment.
- **MWRegReq(ci):** A floating point array. The Market-Wide Regulating Reserve requirement for commitment interval ci. Expressed in MW.
- **Posting Period:** A floating point variable. The length of the period between the time the Reliability Assessment Commitment results are posted and the Reliability Assessment Commitment SCUC period beings.
- **MWSTRReq(ci):** A floating point array. The Market-Wide Short Term Reserve requirement for commitment interval ci. Expressed in MW.
-

## 7.3 Market Participant Input Data

- **EnergyOfferPrice(r,ci):** A floating point array. The energy offer price for resource r for commitment interval ci. Expressed in $ per MWh. Applies only to Demand Resource Resources - Type I.
- **EnergyOfferCurve(r,ci,MW):** A floating point array. The energy offer curve, piece-wise linear or stepped, submitted for resource r for commitment interval ci. Expressed in $ per MWh.
- **FixedExportMW(tr,ci):** A floating point array. The MW for fixed export transaction tr for commitment interval ci. Expressed in MW.
- **FixedImportMW(tr,ci):** floating point array. The MW for fixed import transaction tr for commitment interval ci. 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,ci):** A floating point array. The hourly curtailment offer price for resource r for commitment interval ci. Expressed in $ per hour. Applies only to Demand Resource Resources - Type I.
- **IF(r):** A Boolean array. The Intermittent Resource Status for resource r during commitment interval ci.
- **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,ci):** A floating point array. The maximum off-line response limit of resource r during commitment interval ci. 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,ci):** A floating point array. The no-load offer price for resource r for commitment interval ci. Expressed in $ per hour. Applies to Generation Resources and Demand Resource Resources - Type II.
- **OffLineSupResOfferPrice(r,ci):** A floating point array. The off-line supplemental reserve offer price for resource r for commitment interval ci. Expressed in $ per MWh.
- **RegCapOfferPrice(r,h):** A floating point array. The regulating reserve capacity offer price for resource r for commitment interval ci. 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 MWh.

- **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,ci):** A floating point array. The energy self-schedule for resource r during commitment interval ci. Expressed in MW.
- **SSRegResMW(r,ci):** A floating point array. The regulating reserve self-schedule for resource r during commitment interval ci. Expressed in MW.
- **SSSpinResMW(r,ci):** A floating point array. The spinning reserve self-schedule for resource r during commitment interval ci. Expressed in MW.
- **SSSupResMW(r,ci):** A floating point array. The supplemental reserve self-schedule for resource r during commitment interval ci. Expressed in MW. Applies only to Demand Response Resources - Type I and External Asynchronous Resources.
- **SSOffLineSupResMW(r,ci):** A floating point array. The off-line supplemental reserve self-schedule for resource r during commitment interval ci. Expressed in MW. Applies only to generation resource and Demand Response Resources - Type II.
- **SSOnLineSupResMW(r,ci):** A floating point array. The on-line supplemental reserve self-schedule for resource r during commitment interval ci. Expressed in MW. Applies only to generation resource and Demand Response Resources - Type II.
- **SUCNotTime(r,ci):** A floating point array. The cold start-up notification time used to evaluate a start-up for resource r in commitment interval ci. 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,ci):** A floating point array. The cold start-up time used to evaluate a start-up for resource r in commitment interval ci. Expressed in hours.
- **SUHNotTime(r,ci):** A floating point array. The hot start-up notification time used to evaluate a start-up for resource r in commitment interval ci. 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,ci):** A floating point array. The hot start-up time used to evaluate a start-up for resource r in commitment interval ci. Expressed in hours.
- **SUINotTime(r,ci):** A floating point array. The intermediate start-up notification time used to evaluate a start-up for resource r in commitment interval ci. 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,ci):** A floating point array. The intermediate start-up time used to evaluate a start-up for resource r in commitment interval ci. Expressed in hours.
- **SUNotTime(r,ci):** A floating point array. The single start-up notification time used to evaluate a start-up for resource r in commitment interval ci. Expressed in hours. Applies only to Demand Response Resources - Type I.

- **SUTime(r,ci):** A floating point array. The single start-up time used to evaluate a start-up for resource r in commitment interval ci. Expressed in hours. Applies only to Demand Response Resources - Type I , and is associated with the time needed to interrupt load.
- **TargetDemRedLevel(r,ci):** A floating point array. The targeted demand reduction level for resource r during commitment interval ci. Expressed in MW. Applies only to Demand Resource Resources - Type I.
- **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 interval ci within the STR response time h
- **OffLineSTROfferPrice (r,ci):** Offline STR offer Price for resource r at interval ci
- **MaximumChargeTime (r):** The maximum amount of time an Electric Storage Resource could be in a Charge state. Expressed in hours.
- **MinimumChargeTime (r):** The minimum amount of time an Electric Storage Resource needs to be in a Charge state. Expressed in hours.
- **MaximumDisChargeTime (r):** The maximum amount of time an Electric Storage Resource could be in a DisCharge state. Expressed in hours.
- **MinimumDisChargeTime (r):** The minimum amount of time an Electric Storage Resource need to be in a DisCharge state. Expressed in hours.
- **InitialEnergyStorage (r):** A floating point array. The initial amount of energy level for resource r prior to the SCUC period. Expressed in MWh. Applies only to Electric Storage Resource
-

## 7.4 Pre-SCUC Processing Variables

- **CertainMustRunStartup(r, ci):** A Boolean array. A flag that indicates whether a start-up issued for the resource in commitment interval ci is a start-up associated with a Must-Run commitment interval. Set to 1 if an issued start-up for resource r in commitment interval ci will be a Must-Run commitment, with no associated start-up costs to the system.
- **CommitAvailability(r,ci):** A Boolean array. The commitment availability of resource r during commitment interval ci. Set to 1 if resource r is available for commitment during commitment interval ci. Set to 0 if resource r is not available for commitment during commitment interval ci.
- **ContResOfferPrice(r,ci):** A floating point array. The contingency reserve offer price used in the SCUC algorithm to dispatch contingency reserve on committed resource r during commitment interval ci. Expressed in $ per MW.
- **EcoMaxLimit(r,ci):** A floating point array. The economic maximum limit for resource r during commitment interval ci. Expressed in MW.
- **EcoMinLimit(r,ci):** A floating point array. The economic minimum limit for resource r during commitment interval ci. Expressed in MW.

- **EmerMaxLimit(r,ci):** A floating point array. The emergency maximum limit for resource r during commitment interval ci. Expressed in MW.
- **EmerMinLimit(r,ci):** A floating point array. The emergency minimum limit for resource r during commitment interval ci. Expressed in MW.
- **EmerStatus(r,ci):** A Boolean array. The emergency status of resource r during commitment interval ci. Set to 1 if resource r has a commitment status of ***Emergency*** during commitment interval ci, otherwise set to 0.
- **EnergyStepPrice(r,ci,st):** A floating point array. The energy offer curve step price for resource r and offer curve step st during commitment interval ci. Expressed in $ per MWh.
- **EnergyStepWidth(r,ci,st):** A floating point array. The energy offer curve step width for resource r and offer curve step st during commitment interval ci. Expressed in MW.
- ***∂*Flow(k,ci)/*∂*P(i,ci):** A floating point array. The shift factor for transmission constraint k and bus i during commitment interval ci, 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,ci)/*∂*P(r,ci):** A floating point array. The shift factor for transmission constraint k and resource r during commitment interval ci, 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,ci)/*∂*P(tr,ci):** A floating point array. The shift factor for transmission constraint k and energy transaction r during commitment interval ci, 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(ci):** 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 commitment interval ci 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.
- **InputRampRate(r,ci):** A floating point array. The ramp rate used for resource r during commitment interval ci (hourly if available, else default). Expressed in MW per Minute.
- **LTSCUCRampDownRate(r,ci):** A floating point array. A ramp rate used in the SCUC long-term ramp-down constraints. Expressed in MW per Minute.
- **LTSCUCRampUpRate(r,ci):** A floating point array. A ramp rate used in the SCUC long-term ramp-up constraints. Expressed in MW per Minute.
- **LTSCUCSDRampRate(r,ci):** A floating point array. A ramp rate used in the SCUC long-term ramp-down constraints. Expressed in MW per Minute.
- **LTSCUCSURampRate(r,ci):** A floating point array. A ramp rate used in the SCUC long-term ramp-up constraints. Expressed in MW per Minute.
- **MinCommitTime(r,ci):** A floating point array. The minimum amount of time resource r must be committed if started in commitment interval ci. Expressed in hours.

- **MinDecommitTime(r,ci):** A floating point array. The minimum amount of time resource r must be decommitted if shut-down in commitment interval ci. Expressed in hours.
- **MinEcoEnergyCosts(r,ci):** The total energy cost required to operate resource r at the economic minimum limit during commitment interval ci. Expressed in $.
- **MinEmerEnergyCosts(r,ci):** The total energy cost required to operate resource r at the emergency minimum limit during commitment interval ci. Expressed in $.
- **MinRegEnergyCosts(r,ci):** The total energy cost required to operate resource r at the regulation minimum limit during commitment interval ci. Expressed in $.
- **MustRunStatus(r,ci):** A Boolean array. The must run status of resource r during commitment interval ci. Set to 1 if resource r has commitment status of ***Must Run*** during commitment interval ci, otherwise set to 0.
- **MWORReq(ci):** A floating point array. The Market-Wide Operating Reserve requirement for commitment interval ci. Expressed in MW.
- **MWRegSpinReq(ci):** A floating point array. The Market-Wide Regulating plus Spinning Reserve requirement for commitment interval ci. Expressed in MW.
- **NextMustRunPeriod(r, ci):** A floating point array. This value indicates for a given resource r and commitment interval ci, the next commitment interval (greater than ci) for which the resource is considered a Must-Run resource.
- **OffLineSupAvailability(r,ci):** A Boolean array. The off-line supplemental reserve availability of resource r during commitment interval ci. Set to 1 if resource r is available to provide off-line supplemental reserve during commitment interval ci. Set to 0 if resource r is not available to provide off-line supplemental reserve during commitment interval ci.
- **PF(i,ci):** A floating point array. The marginal loss penalty factor for energy injections at bus i during commitment interval ci. If it 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, ci):** A Boolean array. A flag that indicates whether a start-up issued for the resource in commitment interval ci 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 commitment interval ci may be a Must-Run commitment, with no associated start-up costs to the system**.**
- **RegAvailability(r,ci):** A Boolean array. The regulating reserve availability of resource r during commitment interval ci. Set to 1 if resource r is available to provide regulating reserve during commitment interval ci. Set to 0 if resource r is not available to provide regulating reserve during commitment interval ci.
- **RegMaxLimit(r,ci):** A floating point array. The regulation maximum limit for resource r during commitment interval ci. Expressed in MW.
- **RegMinLimit(r,ci):** A floating point array. The regulation minimum limit for resource r during commitment interval ci. Expressed in MW.
- **RZORReq(z,ci):** A floating point array. The Reserve Zone Operating Reserve requirement for reserve zone z during commitment interval ci. Expressed in MW.
- **RZRegSpinReq(z,ci):** A floating point array. The Reserve Zone Regulating plus Spinning Reserve requirement for reserve zone z during commitment interval ci. Expressed in MW.

- **SpinAvailability(r,ci):** A Boolean array. The spinning reserve availability of resource r during commitment interval ci. Set to 1 if resource r is available to provide spinning reserve during commitment interval ci. Set to 0 if resource r is not available to provide spinning reserve during commitment interval ci.
- **SSEnergyStatus(r,ci):** A Boolean array. The energy self-schedule status of resource r during commitment interval ci. Set to 1 if energy is being self-scheduled on resource r during commitment interval ci. Set to 0 if energy is not being self-scheduled on resource r during commitment interval ci.
- **SSOnLineSupResStatus(r,ci):** A Boolean array. The one-line supplemental reserve self-schedule status of resource r during commitment interval ci. Set to 1 if on-line supplemental reserve is being self-scheduled on resource r during commitment interval ci. Set to 0 if on-line supplemental reserve is not being self-scheduled on resource r during commitment interval ci.
- **SSRegResStatus(r,ci):** A Boolean array. The regulating reserve self-schedule status of resource r during commitment interval ci. Set to 1 if regulating reserve is being self-scheduled on resource r during commitment interval ci. Set to 0 if regulating reserve is not being self-scheduled on resource r during commitment interval ci.
- **SSSpinResStatus(r,ci):** A Boolean array. The spinning reserve self-schedule status of resource r during commitment interval ci. Set to 1 if spinning reserve is being self-scheduled on resource r during commitment interval ci. Set to 0 if spinning reserve is not being self-scheduled on resource r during commitment interval ci.
- **SSSupResStatus(r,ci):** A Boolean array. The supplemental reserve self-schedule status of resource r during commitment interval ci. Set to 1 if supplemental reserve is being self-scheduled on resource r during commitment interval ci. Set to 0 if supplemental reserve is not being self-scheduled on resource r during commitment interval ci.
- **SupAvailability(r,ci):** A Boolean array. The supplemental reserve availability of resource r during commitment interval ci. Set to 1 if resource r is available to provide supplemental reserve during commitment interval ci. Set to 0 if resource r is not available to provide supplemental reserve during commitment interval ci.
- **OnlineSTRAvailability(r,ci):** 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 interval ci .
- **OfflineSTRAvailability(r,ci):** 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 interval ci .

## 7.5 SCUC Parameters

- **BaseRampDnReq:** The minimum ramp-down requirement for any commitment interval 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 commitment interval 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 and External Asynchronous Resources based on applicable reliability standards.
- **GenOpResShortagePenPrice:** The generation-based operating reserve constraint penalty price. Expressed in $ per MW.
- **PmaxEvent(z,ci):** The size of the largest resource in zone z during commitment interval ci.
- **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.
- **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.
- **LossRate:** The loss rate, expressed as a percent of the fixed demand bids, used calculate actual losses within the SCUC algorithm.

- **MaxConResFactor:** 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.
- **OpResShortagePenPrice:** The operating reserve constraint penalty price. Expressed in $ per MW.
- **PriceScaleFactor:** The price scaling factor is used to scale-down the energy offer curve, regulating reserve offer, spinning reserve offer and supplemental reserve offer of all resources during FRAC and IRAC studies, so that commitment decisions are based on the cost to operate a resource at the minimum limit. For LAC studies, the scaling factor is one. All production costs bear equal weight in LAC studies.
- **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.
- **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,ci):** The zonal regulation deployment sensitivity for transmission constraint k and reserve zone z during commitment interval ci 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,ci) is described further in Section 4.2.4.20.
- **ZonalSpinDepSens(k,z,ci):** The zonal spin deployment sensitivity for transmission constraint k and reserve zone z during commitment interval ci is a ramp-rate weighted average of the sensitivities of the regulation or spin qualified resources in the zone.
- **ZonalSuppDepSens(k,z,ci):** The zonal supplemental deployment sensitivity for transmission constraint k and reserve zone z during commitment interval ci 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.
- **ZonalSTRDepSens(k,z,ci):** The zonal Short Term Reserve deployment sensitivity for transmission constraint k and Reserve Zone z during commitment interval ci 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,ci):** The zonal trip sensitivity for transmission constraint k and reserve zone z during commitment interval ci 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.

## 7.6 SCUC Primal Variables and Output Data

- **CF(r,ci):** A Boolean array. The commitment flag for resource r during commitment interval ci. Set to 1 if resource r is committed during commitment interval ci, otherwise 0.
- **ContResDispatch(r,ci):** A floating point array. The contingency reserve dispatched by SCUC on resource r during commitment interval ci. Expressed in MW.
- **ContResRampViolation(r,ci):** A floating point array. The contingency reserve ramp constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **EmerCond(ci):** An integer array. Represents the emergency condition for commitment interval ci as determined by the SCUC.
- **EmerMaxFlag(r,ci):** An integer array. Set to 1 for resource r in commitment interval ci if the emergency maximum operating range has been released on resource r during commitment interval ci, otherwise set to 0.
- **EmerMaxRelease(r,ci):** A floating point array. The percentage of the emergency maximum operating range released by SCUC on resource r during commitment interval ci. Applies in ***Emergency Mode*** only. Expressed in per unit.
- **EmerMinFlag(r,ci):** An integer array. Set to 1 for resource r in commitment interval ci if the emergency minimum operating range has been released on resource r during commitment interval ci, otherwise set to 0.
- **EmerMinRelease(r,ci):** A floating point array. The percentage of the emergency minimum operating range released by SCUC on resource r during commitment interval ci. Applies in ***Emergency Mode*** only. Expressed in per unit.
- **EnergyDispatch(r,ci):** A floating point array. The energy dispatched by SCUC on resource r during commitment interval ci. Expressed in MW or MWh.
- **EnergyStepDispatch(r,ci,st):** A floating point array. The energy dispatched by SCUC on offer curve step st for resource r during commitment interval ci. Expressed in MW or MWh.
- **FirstSU(r,ci):** A Boolean array. The first start-up flag for resource r during commitment interval ci. Set to 1 if resource r has a first start-up during commitment interval ci, otherwise 0.
- **Flow_SystemEnergySCUC(k,ci):** A floating point array. The transmission flow on transmission constraint k during commitment interval ci from entire set of system energy clearings across all market activities, both injections and withdrawals. Flow_**SystemEnergySCUC(k,ci)** 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,ci)** is given in Section 4.2.4.1.
- **GenOpResShortage(ci):** A floating point array. The generation-based operating reserve constraint deficit violation variable during commitment interval ci. Expressed in MW.
- **GenRegShortage(ci):** A floating point array. The generation-based regulating reserve constraint deficit violation variable during commitment interval ci. Expressed in MW.

- **GenRegSpinShortage(ci):** A floating point array. The generation-based regulating plus spinning reserve constraint deficit violation variable during commitment interval ci. Expressed in MW.
- **GlobalEnergyShortage(ci):** A floating point array. The global power balance constraint deficit violation variable during commitment interval ci. Expressed in MW.
- **GlobalEnergySurplus(ci):** A floating point array. The global power balance constraint surplus violation variable during commitment interval ci. Expressed in MW.
- **LTRampDownViolation(r,ci):** A floating point array. The long-term ramp-down constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **LTRampUpViolation(r,ci):** A floating point array. The long-term ramp-up constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **MaxLimitViolation(r,ci):** A floating point array. The maximum limit constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **MaxResourceContResViolation(r,ci):** A floating point array. The maximum resource contingency reserve constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **MaxResourceRegViolation(r,ci):** A floating point array. The maximum resource regulating reserve constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **MinLimitViolation(r,ci):** A floating point array. The minimum limit constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **MRSU(r,ci):** A floating point array. The Must-Run start-up flag for resource r during commitment interval ci. Set to 1 if resource r has a Must-Run start-up during commitment interval ci, otherwise 0.
- **MWHourlyRampDnViolation(ci):** A floating point array. The market-wide ramp-down constraint violation variable for commitment interval ci. Expressed in MW/hr.
- **MWHourlyRampUpViolation(ci):** A floating point array. The market-wide ramp-up constraint violation variable for commitment interval ci. Expressed in MW/hr.
- **MWOpResShortage(ci):** A floating point array. The market-wide operating reserve constraint violation variable for commitment interval ci. Expressed in MW.
- **MWRegShortage(ci):** A floating point array. The market-wide regulating reserve constraint violation variable for commitment interval ci. Expressed in MW.
- **MWRegSpinShortage(ci):** A floating point array. The market-wide regulating plus spinning reserve constraint violation variable for commitment interval ci. Expressed in MW.
- **OffLineSupResDispatch(r,ci):** A floating point array. The off-line supplemental reserve dispatched by SCUC on resource r during commitment interval ci. Expressed in MW.
- **RampDnCap(r,ci):** A floating point array. The ramp-down capacity of resource r for commitment interval ci. Expressed in MW/hr.
- **RampUpCap(r,ci):** A floating point array. The ramp-up capacity of resource r for commitment interval ci. Expressed in MW/hr.

- **RegResDispatch1(r,ci):** A floating point array. The regulating reserve dispatched by SCUC on resource r during commitment interval ci. 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,ci):** 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,ci):** A Boolean array. The regulation flag for resource r during commitment interval ci. Set to 1 if resource r is selected to regulate during commitment interval ci, otherwise 0.
- **RZOpResShortage(z,ci):** A floating point array. The reserve zone operating reserve constraint violation variable for reserve zone z during commitment interval ci. Expressed in MW.
- **RZRegShortage(z,ci):** A floating point array. The reserve zone regulating reserve constraint violation variable for reserve zone z during commitment interval ci. Expressed in MW.
- **RZRegSpinShortage(z,ci):** A floating point array. The reserve zone regulating plus spinning reserve constraint violation variable for reserve zone z during commitment interval ci. Expressed in MW.
- **SSContResDeficit(r,ci):** A floating point array. The self-scheduled contingency reserve constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **SSEnergyDeficit(r,ci):** A floating point array. The self-scheduled energy constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **SSRegDeficit(r,ci):** A floating point array. The self-scheduled regulating reserve constraint violation variable for resource r during commitment interval ci. Expressed in MW.
- **SD(r,ci):** A Boolean array. The shut-down flag for resource r during commitment interval ci. Set to 1 if resource r has is shut down during commitment interval ci, otherwise 0. Note: For DRR Type I Resources, this variable indicates the return of load.
- **SU(r,ci):** A Boolean array. The start-up flag for resource r during commitment interval ci. Set to 1 if resource r has a start-up during commitment interval ci, otherwise 0. Note: For DRR Type I Resources, this variable indicates the interruption of load.
- **SubRegLimitStepViolation(st,k,ci):** A floating point array. The Sub-Regional Power Balance constraint violation variable for constraint k during commitment interval ci. Expressed in MW.
- **SUC(r,ci):** A Boolean array. The cold start-up flag for resource r during commitment interval ci. Set to 1 if resource r has a cold start-up during commitment interval ci, otherwise 0.
- **SUH(r,ci):** A Boolean array. The hot start-up flag for resource r during commitment interval ci. Set to 1 if resource r has a hot start-up during commitment interval ci, otherwise 0.
- **SUI(r,ci):** A Boolean array. The intermediate start-up flag for resource r during commitment interval ci. Set to 1 if resource r has an intermediate start-up during commitment interval ci, otherwise 0.
- **TransLimitViolation(k,ci):** A floating point array. The transmission constraint violation variable for constraint k during commitment interval ci. Expressed in MW.

- **TransLimitViolationCREvent(k,z,ci):** 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 commitment interval ci. Expressed in MW.
- **TransLimitViolationRegDown(k,ci):** A floating point array. The reserve procurement transmission constraint regulation down violation variable for constraint k during commitment interval ci. Expressed in MW.
- **TransLimitViolationRegUp(k,ci):** A floating point array. The reserve procurement transmission constraint regulation up violation variable for constraint k during commitment interval ci. Expressed in MW.
- **ZMinRegReq(z,ci):** A floating point array. The solved minimum zonal regulating reserve requirement for zone z during commitment interval ci, 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,ci):** A floating point array. The solved minimum zonal spinning reserve requirement for zone z during commitment interval ci, 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,ci):** A floating point array. The solved minimum zonal supplemental reserve requirement for zone z during commitment interval ci, 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.
- **ZMinRCUpReq(z,ci):** A floating point array. The solved minimum zonal Up Ramp Capability reserve requirement for zone z during commitment interval ci, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed
- **ZMinRCDownReq(z,ci):** A floating point array. The solved minimum zonal Down Ramp Capability reserve requirement for zone z during commitment interval ci, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed
- **ZMinSTRReq(z,ci):** A floating point array. The solved minimum zonal short term reserve requirement for zone z during commitment interval ci, expressed in MW. Together, the inclusion of the minimum zonal reserve requirements ensures the deliverability of procured reserves intra-zonally, as needed
- **MaxResourceSTRViol(r,ci):** Maximum single resource STR clearing constraint for resource at location r and interval ci
- **OfflineSTRResDispatch(r,ci):** Cleared offline STR MW value for resource r at hour h
- **OnlineSTRResDispatch(r,ci):** STRonlineMW(r,h): Cleared online STR MW value for resource r at interval ci
- **STRResDispatch (r,ci)** : Cleared STR MW value for resource r at interval ci
- **STRTransLimit(k,ci) :** STR transmission constraint maximum flow allowed after STR response for constraint k at interval ci

- **STRResponse(z,e,ci)** : STR response provided by resources for constraint k in zone z at interval ci.

## 7.7 Transmission Contingency Analysis Output Data

- **ACFlow(k,ci):** A floating point array. The flow calculated for transmission contingency analysis constraint k during commitment interval ci by the transmission contingency analysis algorithm.
- **∂Flow(k,ci)/∂P(i,ci):** A floating point array. The shift factor for transmission contingency analysis constraint k and bus i during commitment interval ci, 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,ci)/∂P(i,ci):** A floating point array. The shift factor for transmission contingency analysis constraint k and bus i during commitment interval ci, 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,ci)/∂P(r,ci):** A floating point array. The shift factor for transmission contingency analysis constraint k and resource r during commitment interval ci, 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,ci)/∂P(tr,ci):** A floating point array. The shift factor for transmission contingency analysis constraint k and energy transaction r during commitment interval ci, 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.