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# GE MARS Technical Session

*January 20, 2026 Session*

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PLANNING SERVICES AND MARKET DEVELOPMENT

# Introduction

- This MARS technical session provides a closer look at how the MARS Resource Adequacy Assessment (RAA) model is set up to perform assessments and calculations to support existing processes for the Forward Capacity Market (FCM) and new processes for the Capacity Auction Reforms (CAR) project
- The examples and results used this presentation are for illustration purposes

# SYSTEM-WIDE INSTALLED CAPACITY REQUIREMENT (ICR) AND CAPACITY DEMAND MRI CURVE

# Understanding the Net Installed Capacity Requirement (Net ICR)

- Net ICR is the minimum MW quantity of capacity resources required to meet the Resource Adequacy criteria (based on a Loss of Load Expectation (LOLE) target)
- It is a key input for both ISO planning functions and capacity market design
- Under the CAR-SA framework, Net ICR:
  - Will be expressed in both physical and market terms
  - Will be determined individually for each season

# Net ICR Calculation Overview

- Net ICR is determined using the MARS RAA model
- An RAA base case for net ICR calculation represents the expected system conditions for both load and resources under a given study year
- Typically, the system's currently existing capacity (as-is condition) exceeds the reliability target (e.g., LOLE is less than 0.1), indicating a long position where system resources are able to serve load with better reliability than the required
- There are two practical and equivalent ways of finding the Net ICR that we will explain in detail:
  - Capacity scaling while keeping the load unchanged
  - Load scaling while keeping capacity unchanged (this is the approach ISO uses)

# Net ICR Determination through Capacity Scaling

- To determine the minimum required capacity:
  - Step 1: simulate the system LOLE for the as-is condition
  - Step 2: if system LOLE in step 1 is greater than the LOLE target, add proxy unit(s) until system LOLE becomes less than 0.1; otherwise, proceed to Step 3 directly
    - Current proxy unit is assumed 400 MW in size with an EFORd of 5.47%
  - Step 3: keep the load model unchanged as in the base case, and scale down the size of each modeled capacity resource by the same percentage until the LOLE reaches the target
  - This maximum allowable % decrease in capacity represents the surplus capacity margin (SCM)
- The Net ICR can be calculated as

$$Net\ ICR = Total\ Current\ Capacity\ \times (1 - SCM)$$

  - Total Current Capacity includes the proxy unit(s) capacity added in Step 2

# Net ICR Determination through Load Scaling

- To determine the minimum required capacity:
  - Step 1: simulate the system LOLE for the as-is condition
  - Step 2: if system LOLE in step 1 is greater than the LOLE target, add proxy unit(s) until system LOLE becomes less than 0.1; otherwise proceed to Step 3 directly
  - Step 3: keep the resource model unchanged as in the base case, and scale up the load uniformly until the LOLE reaches the target
  - This maximum allowable increase in peak load represents the Additional Load Carrying Capability (ALCC)
  - ALCC reflects the extra MW of peak load (50/50 peak) that the current capacity can support without violating the reliability criteria

- The Net ICR can be calculated using the Net ICR formula:

$$Net\ ICR = \frac{Total\ Current\ Capacity}{1 + \frac{ALCC}{Peak\ Load}}$$

  - Total Current Capacity includes the proxy unit(s) capacity added in Step 2

# Net ICR Formula and Interpretation

- The ALCC result allows us to derive the minimum reserve margin required to satisfy the LOLE criterion in percentage of peak load forecast

$$RM_{min} = \frac{Total\ Current\ Capacity}{Peak\ Load + ALCC} - 1$$

- Applying this to the forecast peak load yields

$$Net\ ICR = (1 + RM_{\ min}) \times Peak\ Load = \frac{Total\ Current\ Capacity}{1 + \frac{ALCC}{Peak\ Load}}$$

- Examples:
  - If the load can be scaled up by 100% before hitting the LOLE target:

$$Net\ ICR = \frac{Total\ Current\ Capacity}{1+100\%} = Total\ Current\ Capacity \times \frac{1}{2}$$

➔ current capacity can support 2x peak load

  - If the load can be scaled by 50%:

$$Net\ ICR = \frac{Total\ Current\ Capacity}{1+50\%} = Total\ Current\ Capacity \times \frac{2}{3}$$

➔ only two-thirds of current capacity is required

# Illustrative Numerical Example for Net ICR Calculation – Base System

- The example system has three resources

| Resource Type | Capacity (MW) | Energy Capacity (MWh) | Duration (h) |
|---|---|---|---|
| Thermal | 500 | NA | NA |
| IPR | 150 | NA | NA |
| Battery | 100 | 200 | 2 |

- There is no loss of load events in this base case

| Hour | Load (MWh) | Thermal (MWh) | IPR (MWh) | Battery SOC Init (MWh) | Battery Dispatch (MWh) | Battery SOC End (MWh) | Unserved Energy (MWh) |
|---|---|---|---|---|---|---|---|
| 1 | 600 | 500 | 150 | 200 | 0 | 200 | 0 |
| 2 | 650 | 500 | 130 | 200 | 20 | 180 | 0 |
| 3 | 512 | 500 | 140 | 180 | 20 | 160 | 0 |
| 4 | 600 | 500 | 150 | 160 | 40 | 120 | 0 |
| 5 | 400 | 500 | 145 | 120 | 80 | 40 | 0 |
| | | | | | | EUE | 0 |

# Illustrative Numerical Example for Net ICR Calculation – Load Scaling

- Scaling up the load by 25% while keeping the capacity unchanged results in two loss of load hours, which is assumed to be the reliability target

$$Net\ ICR = \frac{750}{1 + 25\%} = 600$$

| Hour | Load (MWh) | Thermal (MWh) | IPR (MWh) | Battery SOC Init (MWh) | Battery Dispatch (MWh) | Battery SOC End (MWh) | Unserved Energy (MWh) |
|---|---|---|---|---|---|---|---|
| 1 | 750 | 500 | 150 | 200 | 100 | 100 | 0 |
| 2 | 812.5 | 500 | 130 | 100 | 100 | 0 | 82.5 |
| 3 | 640 | 500 | 140 | 0 | 0 | 0 | 0 |
| 4 | 750 | 500 | 150 | 0 | 0 | 0 | 100 |
| 5 | 500 | 500 | 145 | 0 | -100 | 100 | 0 |
| | | | | | | EUE | 182.5 |

# Illustrative Numerical Example for Net ICR Calculation – Capacity Scaling

- Scaling down capacity by 20% [=25%/(1+25%)] while keeping the load unchanged also results in the **same two hours** having loss of load, but with different EUE

$$Net\ ICR = 750 \times (1 - 20\%) = 600$$

- The EUE from the load scaling is 25% (the same load scaling %) higher than capacity scaling

| Hour | Load (MWh) | Thermal (MWh) | IPR (MWh) | Battery SOC Init (MWh) | Battery Dispatch (MWh) | Battery SOC End (MWh) | Unserved Energy (MWh) |
|---|---|---|---|---|---|---|---|
| 1 | 600 | 400 | 120 | 160 | 80 | 80 | 0 |
| 2 | 650 | 400 | 104 | 80 | 80 | 0 | 66 |
| 3 | 512 | 400 | 112 | 0 | 0 | 0 | 0 |
| 4 | 600 | 400 | 120 | 0 | 0 | 0 | 80 |
| 5 | 400 | 400 | 116 | 0 | -80 | 80 | 0 |
| | | | | | | EUE | 146 |

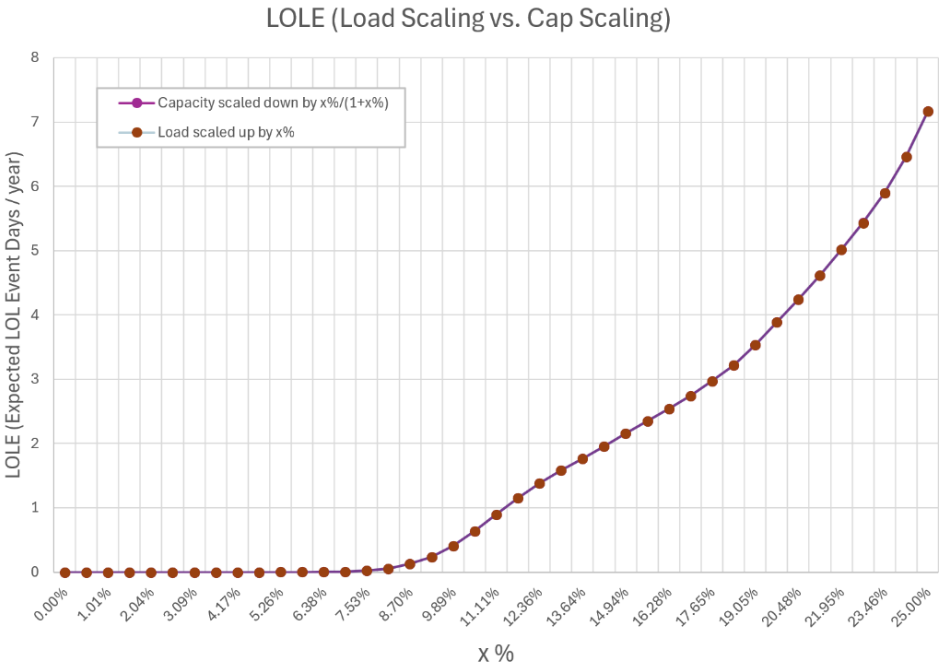
# LOLE and LOLH Equivalence Between Load Scaling and Capacity Scaling – Mathematical Explanation

- Scaling up load up by $x\%$ to reach the LOLE target is equivalent to scaling down resource capacity by a scaling factor of $\frac{x\%}{1+x\%}$ with load unchanged
- Both methods yield the same LOLE, and Loss of Load Hours (LOLH)
- This equivalence holds because a loss of load hour occurs whenever the load exceeds the available capacity. This condition remains whether load is increased, or capacity is reduced by corresponding scaling factors
  - If an hour results in a loss of load when the load is increased by $x\%,$ then
    $$Capacity - Load \times (1 + x\%) < 0$$
  - The same hour will also result in a loss of load when capacity is scaled down by a factor $\frac{x\%}{1+x\%}$ since
    $$Capacity \times \left(1 - \frac{x\%}{1+x\%}\right) - Load = \frac{Capacity - Load \times (1+x\%)}{1+x\%} < 0$$
  - Therefore, uniformly scaling either load or capacity across all hours produces the same pattern of loss of load events throughout the year
- Thus, the Net ICR will be equivalent whether using ALCC adjustment or capacity scaling

# LOLE and LOLH Equivalence Between Load Scaling and Capacity Scaling – Simulation Results

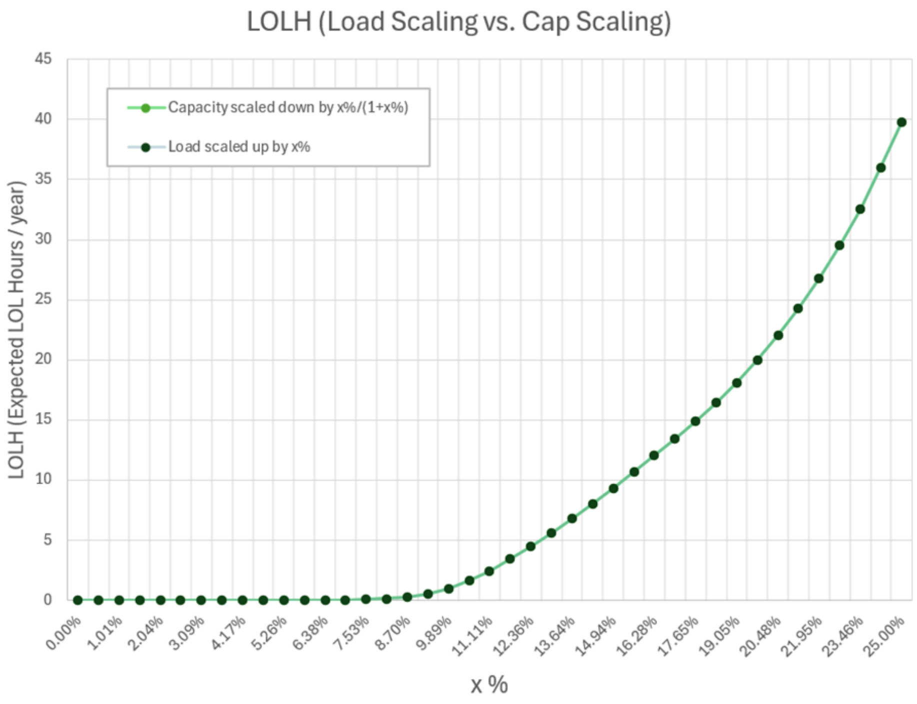
- A MARS test case with a small system that consists of thermal resources, profiled resources and energy storage resources is used to simulate the LOLE and LOLH using both load scaling and capacity scaling

- The graph shows scaling up the load by $x\%$ and scaling down capacity by $\frac{x\%}{1+x\%}$ result in identical LOLE values



# LOLE and LOLH Equivalence Between Load Scaling and Capacity Scaling – Simulation Results, cont.

- Similarly, the test case MARS simulation results show that
  - scaling up the load by $x\%$ and scaling down the capacity by $\frac{x\%}{1+x\%}$ also result in identical LOLH values



# EUE Impacts Between Load Scaling and Capacity Scaling – Mathematical Explanation

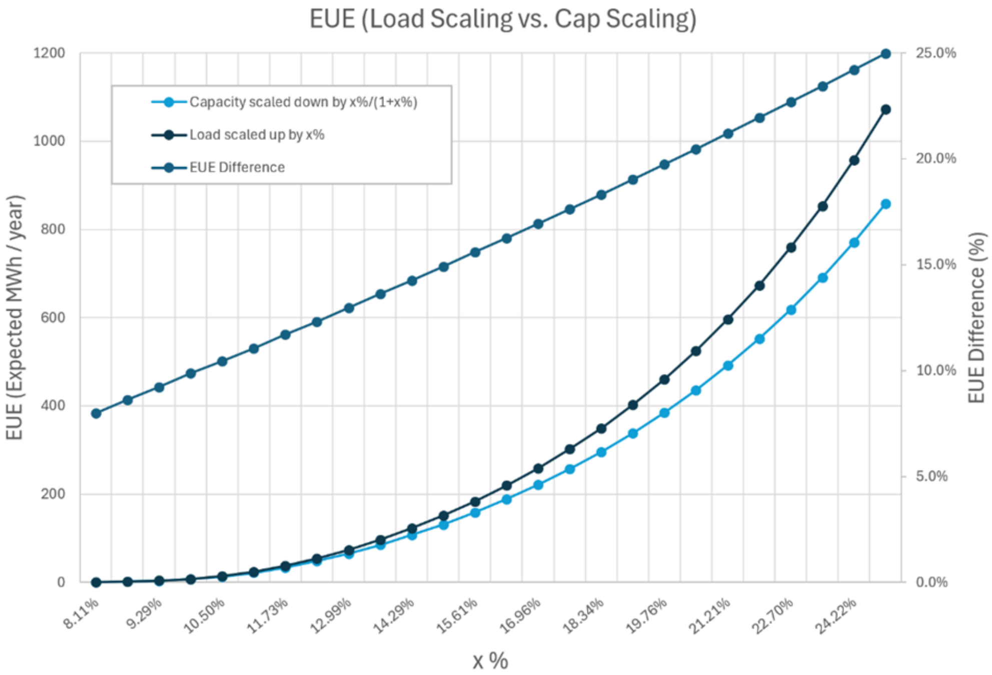
- The resulting capacity margin (both positive and negative) for each hour is $(1 + x\%)$ higher with load scaling

$$\frac{HCM_{load\ scaling}}{HCM_{cap\ scaling}} = \frac{Capacity - Load \times (1 + x\%)}{Capacity \times \left(1 - \frac{x\%}{1 + x\%}\right) - Load} = 1 + x\%$$

- This implies that with load scaling:
  - The EUE during the hours with negative capacity margin is $x\%$ higher with load scaling
  - The hourly dispatch of each resource is also $x\%$ higher with load scaling, if the dispatch rules are identical in the load scaling and capacity scaling approaches

# EUE Impacts Between Load Scaling and Capacity Scaling – Simulation Results

- The test case MARS simulation results show that
  - The EUE with scaling up the load by $x\%$ is $x\%$ higher than scaling down the capacity by $\frac{x\%}{1+x\%}$



# Illustrative Numerical Example for Accreditation- Load Scaling

- Load scaling base case

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 750 | 500 | 150 | 200 | 100 | 100 | 0 |
| 2 | 812.5 | 500 | 130 | 100 | 100 | 0 | 82.5 |
| 3 | 640 | 500 | 140 | 0 | 0 | 0 | 0 |
| 4 | 750 | 500 | 150 | 0 | 0 | 0 | 100 |
| 5 | 500 | 500 | 145 | 0 | -100 | 100 | 0 |
| | | | | | | EUE | 182.5 |

- IPR Perturbation by 0.5 MW of nameplate

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 750 | 500 | 150.5 | 200.0 | 99.5 | 100.5 | 0.0 |
| 2 | 812.5 | 500 | 130.4 | 100.5 | 100.0 | 0.5 | 82.1 |
| 3 | 640 | 500 | 140.5 | 0.5 | -0.5 | 1.0 | 0.0 |
| 4 | 750 | 500 | 150.5 | 1.0 | 1.0 | 0.0 | 98.5 |
| 5 | 500 | 500 | 145.5 | 0.0 | -100.0 | 100.0 | 0.0 |
| | | | | | | EUE | 180.6 |
| | | | | | | MRI | -3.8 |
| | | | | | | rMRI | 95% |

- Thermal (Perfect Capacity) Perturbation by 0.5 MW

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 750 | 500.5 | 150 | 200 | 99.5 | 100.5 | 0 |
| 2 | 812.5 | 500.5 | 130 | 100.5 | 100 | 0.5 | 82 |
| 3 | 640 | 500.5 | 140 | 0.5 | -0.5 | 1 | 0 |
| 4 | 750 | 500.5 | 150 | 1 | 1 | 0 | 98.5 |
| 5 | 500 | 500.5 | 145 | 0 | -100 | 100 | 0 |
| | | | | | | EUE | 180.5 |
| | | | | | | MRI | -4 |

- Energy Storage Perturbation by 0.5 MW

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 750 | 500 | 150 | 201 | 100 | 101 | 0 |
| 2 | 812.5 | 500 | 130 | 101 | 100.5 | 0.5 | 82 |
| 3 | 640 | 500 | 140 | 0.5 | 0 | 0.5 | 0 |
| 4 | 750 | 500 | 150 | 0.5 | 0.5 | 0 | 99.5 |
| 5 | 500 | 500 | 145 | 0 | -100.5 | 100.5 | 0 |
| | | | | | | EUE | 181.5 |
| | | | | | | MRI | -2 |
| | | | | | | rMRI | 50% |

# Illustrative Numerical Example for Accreditation- Capacity Scaling

- Capacity scaling base case

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 600 | 400 | 120 | 160 | 80 | 80 | 0 |
| 2 | 650 | 400 | 104 | 80 | 80 | 0 | 66 |
| 3 | 512 | 400 | 112 | 0 | 0 | 0 | 0 |
| 4 | 600 | 400 | 120 | 0 | 0 | 0 | 80 |
| 5 | 400 | 400 | 116 | 0 | -80 | 80 | 0 |
| | | | | | | EUE | 146 |

- Thermal (Perfect Capacity) Perturbation by 0.5 MW

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 600 | 400.5 | 120 | 160 | 79.5 | 80.5 | 0 |
| 2 | 650 | 400.5 | 104 | 80.5 | 80 | 0.5 | 65.5 |
| 3 | 512 | 400.5 | 112 | 0.5 | -0.5 | 1 | 0 |
| 4 | 600 | 400.5 | 120 | 1 | 1 | 0 | 78.5 |
| 5 | 400 | 400.5 | 116 | 0 | -80 | 80 | 0 |
| | | | | | | EUE | 144 |
| | | | | | | MRI | -4 |

- IPR Perturbation by 0.5 MW of nameplate

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 600 | 400 | 120.5 | 160.0 | 79.5 | 80.5 | 0.0 |
| 2 | 650 | 400 | 104.4 | 80.5 | 80.0 | 0.5 | 65.6 |
| 3 | 512 | 400 | 112.5 | 0.5 | -0.5 | 1.0 | 0.0 |
| 4 | 600 | 400 | 120.5 | 1.0 | 1.0 | 0.0 | 78.5 |
| 5 | 400 | 400 | 116.5 | 0.0 | -80.0 | 80.0 | 0.0 |
| | | | | | | EUE | 144.1 |
| | | | | | | MRI | -3.8 |
| | | | | | | rMRI | 95% |

- Energy Storage Perturbation by 0.5 MW

| Hr | Load | Thermal | IPR | Battery SOC Init | Battery Dispatch | Battery SOC End | Unserved Energy |
|---|---|---|---|---|---|---|---|
| 1 | 600 | 400 | 120 | 161 | 80 | 81 | 0 |
| 2 | 650 | 400 | 104 | 81 | 80.5 | 0.5 | 65.5 |
| 3 | 512 | 400 | 112 | 0.5 | 0 | 0.5 | 0 |
| 4 | 600 | 400 | 120 | 0.5 | 0.5 | 0 | 79.5 |
| 5 | 400 | 400 | 116 | 0 | -80.5 | 80.5 | 0 |
| | | | | | | EUE | 145 |
| | | | | | | MRI | -2 |
| | | | | | | rMRI | 50% |

# Illustrative Numerical Example – Accreditation Comparison Between Load Scaling and Capacity Scaling

- The EUE change from incremental capacity of each resource is the same under both load scaling and capacity scaling
- Thus, resource accreditation is identical under both load scaling and capacity scaling

| Load Scaling | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Base | Thermal/Perfect Capacity Perturbation | | IPR Perturbation | | Storage Perturbation | |
| Hour | EUE | EUE | **ΔEUE** | EUE | **ΔEUE** | EUE | **ΔEUE** |
| 1 | 0 | 0 | **0** | 0 | **0** | 0 | **0** |
| 2 | 82.5 | 82 | **-0.5** | 82.1 | **-0.4** | 82 | **-0.5** |
| 3 | 0 | 0 | **0** | 0.0 | **0.0** | 0 | **0** |
| 4 | 100 | 98.5 | **-1.5** | 98.5 | **-1.5** | 99.5 | **-0.5** |
| 5 | 0 | 0 | **0** | 0 | **0** | 0 | **0** |
| Total | | | **-2** | | **-1.9** | | **-1** |
| MRI | | | **-4** | | **-3.8** | | **-2** |
| rMRI | | | **1** | | **0.95** | | **0.50** |

| Capacity Scaling | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Base | Thermal/Perfect Capacity Perturbation | | IPR Perturbation | | Storage Perturbation | |
| 1 | 0 | 0 | **0** | 0 | **0** | 0 | **0** |
| 2 | 66 | 65.5 | **-0.5** | 65.6 | **-0.4** | 65.5 | **-0.5** |
| 3 | 0 | 0 | **0** | 0.0 | **0.0** | 0 | **0** |
| 4 | 80 | 78.5 | **-1.5** | 78.5 | **-1.5** | 79.5 | **-0.5** |
| 5 | 0 | 0 | **0** | 0 | **0** | 0 | **0** |
| Total | | | **-2** | | **-1.9** | | **-1** |
| MRI | | | **-4** | | **-3.8** | | **-2** |
| rMRI | | | **1** | | **0.95** | | **0.50** |

# Accreditation Equivalence Between Load Scaling and Capacity Scaling – Mathematical Explanation

- A resource accreditation (rMRI) compares the EUE change from adding an incremental capacity to that resource with adding an incremental perfect capacity to the system

$$rMRI = \frac{\Delta EUE_R}{\Delta EUE_{PC}} = \frac{EUE_{Base+\Delta R} - EUE_{Base}}{EUE_{Base+\Delta PC} - EUE_{Base}}$$

  – $EUE_{Base}$ is the total base system EUE, $EUE_{Base+\Delta R}$ and $EUE_{Base+\Delta PC}$ are the resulting system EUE from adding an incremental capacity to a resource and an incremental perfect capacity to the system respectively

- Because system total EUE is the sum of the unserved energy from all loss of load hours, rMRI can be calculated based on hourly capacity margin since the unserved energy for any given loss of load hour (*i*) is equal to the negative capacity margin for that hour, $HCM^i$ , thus

$$rMRI = \frac{EUE_{Base+\Delta R} - EUE_{Base}}{EUE_{Base+\Delta PC} - EUE_{Base}} = \frac{\sum(HCM^i_{Base+\Delta R} - HCM^i_{Base})}{\sum(HCM^i_{Base+\Delta PC} - HCM^i_{Base})}$$

# Accreditation Equivalence Between Load Scaling and Capacity Scaling – Mathematical Explanation, cont.

- The reduction of unserved energy for any given loss of load hour (*i*) from perturbing (adding) a small amount of Perfect Capacity, $\Delta P$, is identical under both load scaling and capacity scaling
  - Under the load scaling
    $= [Capacity + \Delta p - Load \times (1 + x\%)] - [Capacity - Load \times (1 + x\%)] = \Delta p$
  - Under the capacity scaling
    $= [Capacity \times \left(1 - \frac{x\%}{1+x\%}\right) - Load] + \Delta p - [Capacity \times \left(1 - \frac{x\%}{1+x\%}\right) - Load] = \Delta p$
- Thus, system total EUE reduction (from all hours) by Perfect Capacity Perturbation is also identical for both load scaling and capacity scaling
  - This also holds true for any resource perturbation due to the linear relationship of capacity margins between load scaling and capacity scaling
  - Comparison in the illustrative numerical examples in previous slide demonstrates these properties
- Thus, the resource accreditation will be equivalent whether using ALCC adjustment or capacity scaling

# Accreditation Equivalence Between Load Scaling and Capacity Scaling - Simulation Results

- MARS test case simulation results show that the rMRI values are similar under load scaling and capacity scaling

| | | Equivalent Scaling Case #1 | | Equivalent Scaling Case #2 | | Equivalent Scaling Case #3 | |
|---|---|---|---|---|---|---|---|
| | | Cap Scaling | Load Scaling | Cap Scaling | Load Scaling | Cap Scaling | Load Scaling |
| | Scaling % | 92.5% | 108.108% | 91.5% | 109.290% | 90.5% | 110.497% |
| Baseline (no perturbation) | LOLD | 0.12368 | 0.12368 | 0.23335 | 0.23335 | 0.35573 | 0.35573 |
| | EUE | 2.992 | 3.235 | 6.943 | 7.586 | 13.659 | 15.088 |
| Perfect Unit Perturbation | EUE | 1.866 | 2.108 | 4.769 | 5.413 | 10.174 | 11.604 |
| | ΔEUE | 1.126 | 1.127 | 2.174 | 2.173 | 3.485 | 3.484 |
| Thermal (TH) Unit Perturbation | EUE | 1.901 | 2.144 | 4.828 | 5.472 | 10.258 | 11.689 |
| | ΔEUE | 1.091 | 1.091 | 2.115 | 2.114 | 3.401 | 3.399 |
| | rMRI | 0.968 | 0.968 | 0.973 | 0.973 | 0.976 | 0.976 |
| Storage (ES) Unit Perturbation | EUE | 2.873 | 3.116 | 6.719 | 7.362 | 13.313 | 14.743 |
| | ΔEUE | 0.119 | 0.119 | 0.224 | 0.224 | 0.346 | 0.345 |
| | rMRI | 0.106 | 0.106 | 0.103 | 0.103 | 0.099 | 0.099 |
| Profile (IPR) Unit Perturbation | EUE | 2.974 | 3.216 | 6.901 | 7.544 | 13.584 | 15.014 |
| | ΔEUE | 0.018 | 0.019 | 0.042 | 0.042 | 0.075 | 0.074 |
| | rMRI | 0.016 | 0.017 | 0.019 | 0.019 | 0.022 | 0.021 |

# Why ISO Uses Load Scaling Rather Than Capacity Scaling

- Simplicity in implementation
  - Capacity scaling involves adjustments to each individual resource
  - Adjustments may include multiple parameters for some resource types (e.g. energy storage resources include charging/discharging capacity, energy capacity )
- Representing each resource using their actual size in the model allows for expandability of potential modeling enhancements and is much more straightforward in data reporting

# Net ICR Calculation Process using MARS

- MARS runs are performed iteratively with different load scaling factors corresponding to various trial Net ICR values
- For each trial Net ICR value, *C*, the load scaling factor $x$ is calculated by solving the Net ICR equation:

$$x = \frac{Total\ Current\ Capacity}{C} - 1$$

- LOLE is calculated for each trial. The scaling factor that yields LOLE closest to the target determines the Net ICR

Illustrative example: Net ICR candidate values, scaling factors, and resulting LOLE

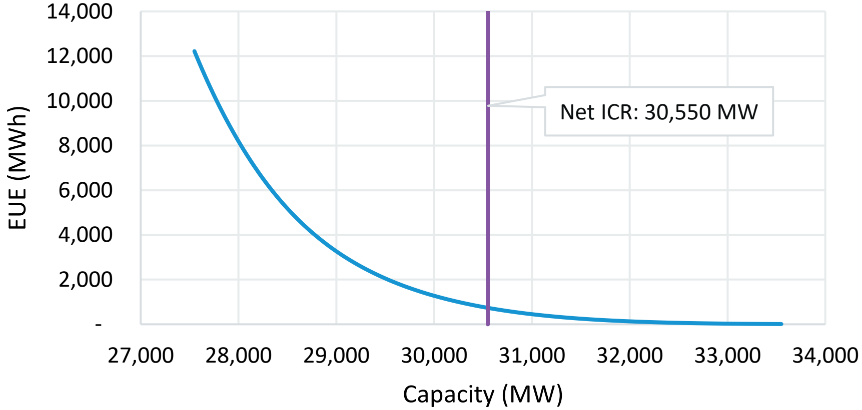
| Trial Net ICR [MW] | Load Scaling Factor | LOLE [days/year] |
|---|---|---|
| 30,580 | 1.0713 | 0.0974 |
| 30,575 | 1.0715 | 0.0978 |
| 30,570 | 1.0716 | 0.0982 |
| 30,565 | 1.0718 | 0.0986 |
| 30,560 | 1.0720 | 0.0990 |
| 30,555 | 1.0722 | 0.0995 |
| 30,550 | 1.0723 | 0.0998 |
| 30,545 | 1.0725 | 0.1003 |
| 30,540 | 1.0727 | 0.1007 |

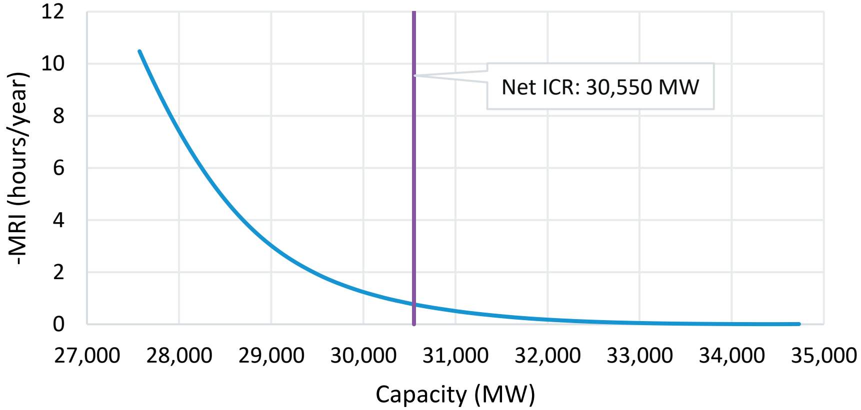
# System Capacity Demand MRI Curve - Concept and Process

- The system capacity demand MRI curve quantifies the reliability value (impact on EUE) of incremental change to system capacity at various capacity levels
- This MRI curve serves as the foundation for the capacity demand curve in auctions
- MRI is defined as $MRI_{(x)} = \frac{EUE(x+\Delta x)-EUE(x)}{\Delta x}$, $x$ is any given the system capacity level
- Development steps:
  - Define the capacity range (e.g., 2,000 MW below to 4,000 MW above Net ICR)
  - For each capacity point (e.g., in 10 MW increments), calculate the load scaling factor based on the Net ICR formula
  - Run MARS for each point to obtain EUE result
  - Smooth the EUE curve
  - Derive the MRI curve as the derivative of the smoothed EUE curve

# System Capacity Demand MRI Curve Example

- Below graphs demonstrate how system EUE and MRI values would change as a result of the system capacity level changes
  - The system EUE decreases as system capacity level increases
  - The marginal reliability value of additional capacity diminishes as the system capacity increases
    - The rate of EUE reduction from incremental system capacity decreases as system capacity increases



# Questions

# ZONAL REQUIREMENTS AND ZONAL CAPACITY DEMAND MRI CURVE

# Purpose of Capacity Zones

- Transmission limitations within the system may prevent capacity in certain areas from being delivered to where it is needed
- Capacity zones are established to:
  - Assess the reliability and market impacts of these transmission limitations, and
  - Provide market signals to incentivize/compensate resources to locate where they most effectively relieve constraints
- Two types of transmission-related capacity zones:
  - Import-constrained zones: Local resources and/or import capability may be insufficient to meet local reliability needs
  - Export-constrained zones: Local capacity may exceed what can be exported to the rest of the system effectively due to transmission limits
- CAR-SA addition: A gas capacity zone will be introduced to reflect winter gas-supply limitations - i.e., limited gas availability causes reliability contributions from additional gas capacity to decrease as total gas capacity increases

# Capacity Zone Requirements

- A zonal capacity requirement specifies how much of the total minimum amount of system capacity, which is required to meet the reliability criterion (Net ICR), is targeted to be located in the import-constrained zone or located in the export-constrained zone without causing the transmission constraint to bind
- Import-constrained zone:
  - Requirement = **Local Resource Adequacy (LRA)**
  - Minimum amount of capacity targeted to be located in the zone, given transmission limitation on importing capacity from the rest of the system into the zone
- Export-constrained zone:
  - Requirement = **Maximum Capacity Limit (MCL)**
  - Maximum amount of capacity targeted to be located in the zone, given transmission limitation on exporting capacity from the zone to the rest of the system
- Gas capacity zone:
  - Requirement = **Gas Maximum Capacity Limit (GMCL)**
  - Maximum amount of capacity targeted to be coming from the gas fleet given winter gas-supply limitations

# Capacity Zone Requirement Calculation Overview

- Zonal requirement calculations use a two-area setup in the MARS RAA model:
  - Constrained zone contains its native resources inside the zone
  - Rest of system contains all other resources in the system
  - An interface with limits represents the physical constraint

- Process:

1. Starting with Step 3 in the Net ICR calculation, relax the constraint and determine the total capacity needed to meet the LOLE target
   - Typically done by removing firm capacity from the rest of system until system LOLE reaches the target, e.g. 0.1

2. Enforce the constraint and observe LOLE change
   - Typically, LOLE increases due to the transmission constraint

3. Shift firm capacity between the two areas (add to one, remove the same amount from the other) until LOLE returns to the target with a small tolerance (0.005 of LOLE)

4. Zonal requirement
   = Existing constrained-zone capacity
   **minus** firm capacity removed (adjusted for outages), or
   **plus** firm capacity added (adjusted for outages)

# Illustrative Example: Import-Constrained Zone

- **Example system**
  - Capacity: 30,000 MW total
    - 5,000 MW in constrained zone (10% weighted EFORd)
    - 25,000 MW in rest of system (10% weighted EFORd)
  - Load: 25,000 MW total
    - 10,000 MW in constrained zone
    - 15,000 MW in rest of system
  - Import limit: 4,000 MW

- **Steps**

1. Constraint relaxed:
   - System needs 27,000 MW to meet LOLE target → remove firm capacity from rest of system (e.g. 3,000 MW of system capacity with 10% EFORd ≈ 2,700 MW of firm capacity)

2. Constraint enforced:
   - LOLE increases because constrained-zone load is high relative to local capacity and import limit

3. Shift capacity:
   - Moving 2,000 MW of firm capacity from rest of system to the constrained zone restores LOLE to target

4. Constrained-zone Requirement:
   = 5,000 MW + 2,222 MW (2,000 MW firm adjusted for 10% EFORd)
   = **7,222** MW

# Illustrative Example: Export-Constrained Zone

- **Example system**
  - Capacity: 30,000 MW total
    - 10,000 MW in constrained zone (10% weighted EFORd)
    - 20,000 MW in rest of system (10% weighted EFORd)
  - Load: 25,000 MW total
    - 5,000 MW in constrained zone
    - 20,000 MW in rest of system
  - Export limit: 3,000 MW

- **Steps**

1. Constraint relaxed:
   - System needs 27,000 MW to meet LOLE target → remove firm capacity from rest of system (e.g. 3,000 MW of system capacity with 10% EFORd ≈ 2,700 MW of firm capacity)

2. Constraint enforced:
   - LOLE increases because excess constrained-zone capacity cannot be fully exported

3. Shift capacity:
   - Moving 1,000 MW of firm capacity from constrained zone to rest of system restores LOLE

4. Constrained-zone Requirement:
   = 10,000 MW – 1,111 MW (1,000 MW firm adjusted for 10% EFORd)
   = **8,889** MW

**Note:** In practice, export-constrained zone calculation is performed by treating the rest of system as an import-constrained zone and computing its minimum requirement. The export-zone requirement is then calculated as system Net ICR minus rest-of-system minimum requirement

# Illustrative Example: Gas-Constrained Zone

- Process mirrors the export-constrained calculation, except the gas-constrained area contains **capacity only**, with **no load**

- **Example system**
  - Capacity:
    - 10,000 MW gas capacity in constrained zone (10% weighted EFORd)
    - 20,000 MW in rest of system (10% weighted EFORd)
  - Load:
    - 25,000 MW in rest of system
    - 0 MW in constrained zone
  - Gas-export limit: 5,000 MW

- **Steps**

1. Relax constraint → 27,000 MW needed → remove firm capacity from rest of system (e.g. 3,000 MW of system capacity with 10% EFORd ≈ 2,700 MW of firm capacity)

2. Enforce constraint → LOLE increases because gas supply (export capability) limits usable gas capacity

3. Move 4,000 MW of firm capacity from constrained area to rest of system → LOLE returns to target

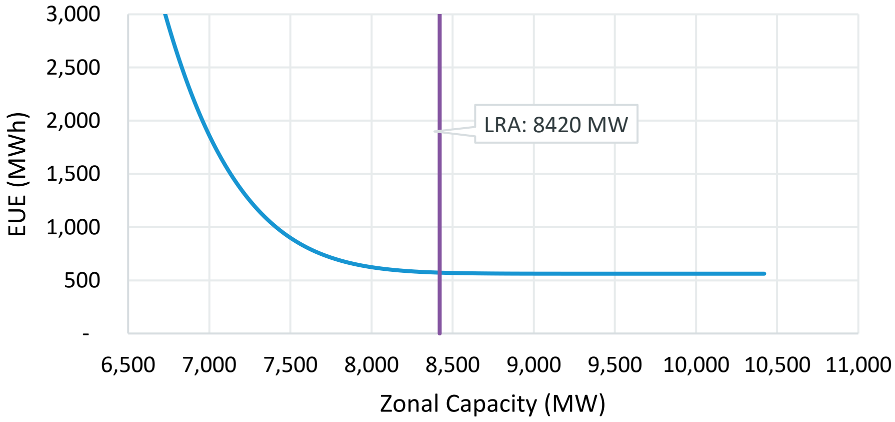
4. Gas-zone requirement
   = 10,000 MW – 4,444 MW (4,000 MW firm adjusted for 10% EFORd)
   = **5,556** MW

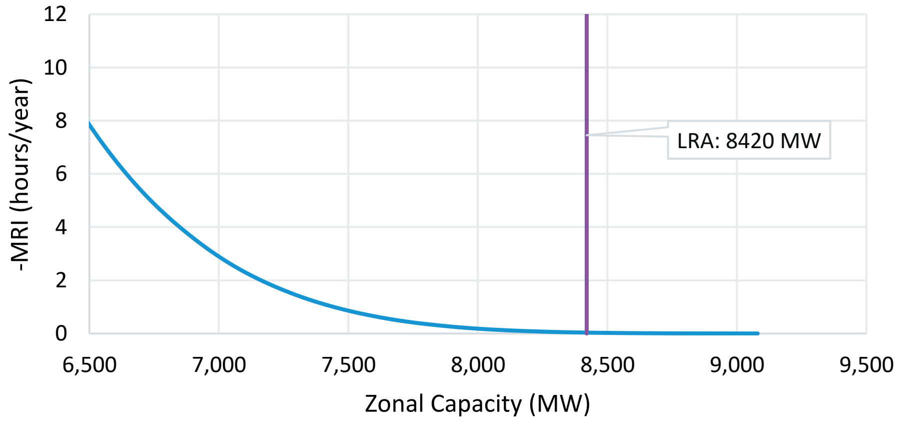
# Zonal Capacity MRI Curve Development

- When zonal capacity deviates from the requirement (above the MCL or below the LRA), its reliability contribution diminishes because the constraint increasingly limits deliverability
- The zonal capacity MRI curve quantifies the negative reliability value (EUE increase) of incremental changes in zonal capacity across a range, analogous to the system-wide capacity MRI curve
- Purpose: forms the basis for zonal demand curves used in auctions
- Development Steps
  - Define the zonal capacity range (e.g., 2,000 MW above the MCL or below the LRA)
  - Starting from the requirement case, adjust zonal capacity in 9 MW firm increments (accounting for EFORd) and run MARS to obtain EUE for each point
  - Iterate: use the EUE result from the previous step as the base case and continue shifting capacity up or down in 9 MW increments until the entire range is covered
  - Smooth the resulting EUE curve
  - Take the derivative of the smoothed EUE curve to obtain the MRI curve. The sign of MRI is positive when EUE decreases

# Illustrative Example: Import-Constrained Zone MRI Curve

- Below graphs demonstrate how system EUE and MRI values would change as a total fixed amount of system capacity (equal to Net ICR) is distributed in between the import-constrained zone and the rest of the system
  - The system EUE starts to increase when the capacity in the import-constrained zone is reduced to certain level where the import capability is not adequate to effectively deliver the capacity from the rest of the system into the zone
- The marginal reliability value of zonal capacity exponentially increases when zonal capacity falls below the LRA
  - Zonal capacity becomes more and more effective in reducing the system EUE when it is lower

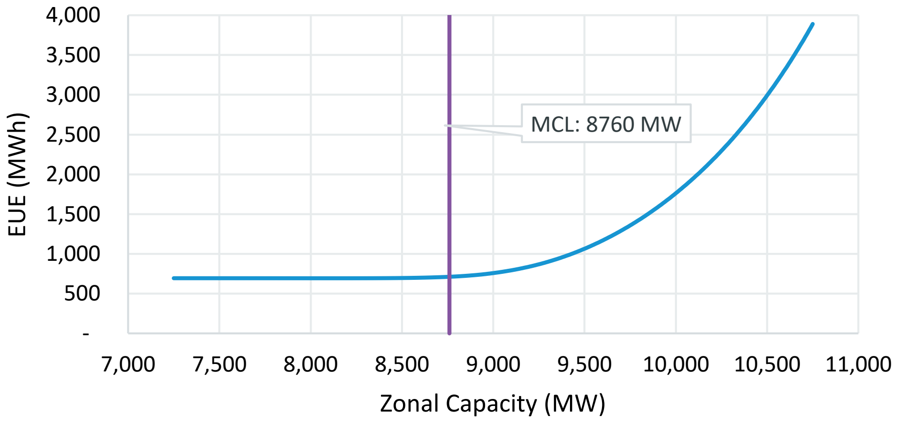


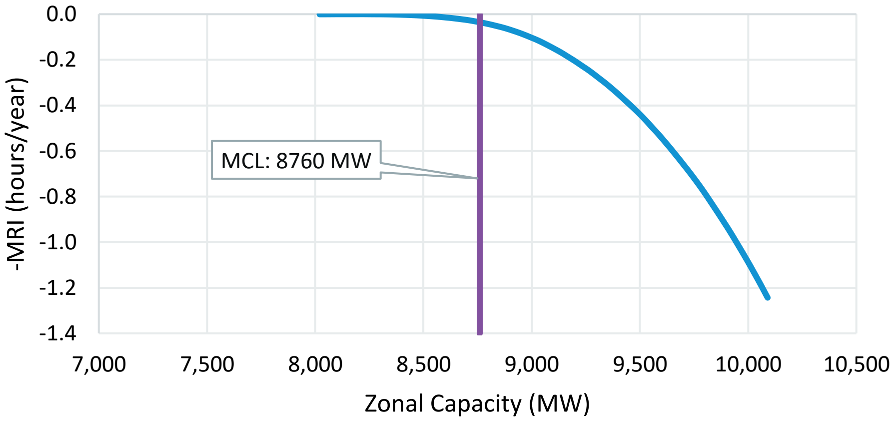



# Illustrative Example: Export-Constrained Zone MRI Curve

- Below graphs demonstrate how system EUE and MRI values would change as a total fixed amount of system capacity (equal to Net ICR) is distributed in between the export-constrained zone and the rest of the system
  - The system EUE starts to increase when the capacity in the export-constrained zone is increased to certain level where the export capability is not adequate to effectively deliver the capacity from the zone to the rest of the system

- The marginal reliability value of zonal capacity exponentially decreases when zonal capacity reaches beyond the MCL
  - Zonal capacity becomes less and less effective in reducing the system EUE when it is higher



# Questions

# RMRI CALCULATION

# rMRI Concept

- Relative Marginal Reliability Impact (rMRI) is used to determine a resource's Maximum Accredited Capacity (MRIC) eligible for procurement in the capacity auction

$$MRIC_{(r)} = rMRI \times Maximum\ Capability$$

- rMRI measures a resource's marginal reliability contribution relative to perfect capacity

$$\text{r}MRI_{(r)} = \frac{MRI(r)}{MRI(perfect\ capacity)}$$

- Similar to system capacity demand MRI, the MRI value for a resource (*r*) represents the change in system EUE from a small incremental change in its capacity *c*:

$$MRI_{(r)} = \frac{EUE(c+\Delta c)-EUE(base)}{\Delta c}$$

# rMRI Calculation Overview

- Calculating rMRI requires computing the MRI of a resource and the MRI of perfect capacity
- MRI values are obtained using the RAA model, which quantifies the EUE impact of incremental capacity addition
- Process:
  - Start with the Net ICR RAA case, where
    - Load is scaled to meet the LOLE target
    - Resulting EUE value is the base EUE
  - Perturb target resource's capacity
    - Increase resource's capacity by a small amount $\Delta c$ and rerun the simulation
    - Obtain the new EUE, $EUE(c + \Delta c)$
  - Calculate resource MRI using the MRI formula

$$MRI_{(r)} = \frac{EUE(c + \Delta c) - EUE(base)}{\Delta c}$$

# rMRI Calculation Overview, cont.

- Process (cont.)
  - Calculate perfect capacity MRI
    - Add a small amount of perfect capacity to the Net ICR RAA case (without resource perturbation in previous steps), rerun the simulation, and compute the MRI using the same formula, $MRI(perfect\ capacity)$
  - Compute rMRI
    - rMRI is the ratio of the resource's MRI to the MRI of perfect capacity

$$\mathrm{r}MRI_{(r)} = \frac{MRI(r)}{MRI(perfect\ capacity)}$$

# rMRI Calculation for Resources using Thermal Model

- Thermal resources are characterized by
  - Seasonal Maximum Capability (MCap): maximum output when not on outages
  - Seasonal EFORd: forced outage likelihood
  - Annual maintenance weeks
- rMRI calculation:
  - Increase MCap by a small increment and compare the resulting EUE change with the base system

# Sensitivity of Accreditation to Unit Size and Outage Rate

- Under the MRI approach, the size and outage rate of a thermal resource could have significant impacts on their accreditation value
- Using a MARS test model, resource perturbations were applied to calculate rMRI value of each thermal resources, as shown in the following table

| Metric | | rMRI | | | MRIc | | |
|---|---|---|---|---|---|---|---|
| Outage Rate | | 2% | 5% | 8% | 2% | 5% | 8% |
| Capacity (MW) | 30 | 99.8% | 98.4% | 90.9% | 29.9 | 29.5 | 27.3 |
| | 60 | 95.5% | 93.0% | 88.2% | 57.3 | 55.8 | 52.9 |
| | 120 | 83.4% | 72.8% | 69.8% | 100.0 | 87.4 | 83.8 |
| | 240 | 65.5% | 24.5% | 7.3% | 157.2 | 58.9 | 17.6 |

- These results show the compounding effect of unit size and outage rate
  - The rMRI value for the smallest unit (30 MW) is linearly decreasing as its outage rate increases
  - The rMRI value for the largest unit (240 MW) is exponentially decreasing as its outage rate increases
    - The major driver of this behavior is that when a larger unit is out of service, the system is more likely to experience a loss of load event, and if the unit is out of service more often, the risk of events will also increase, both of which would result in a decrease of its rMRI
- In this example, the size of the largest unit is close to 20% of the system's peak load, much greater than the relative size of any resource in the actual system

# rMRI Calculation for Resources using Profile Model

- Input for profile-based resources include:
  - Normalized hourly profiles (values represent expected output as a fraction of a common base, which typically is the annual maximum)
  - Maximum Capability (MCap)
- MARS applies MCap to the profiles to determine hourly output
- MRI calculation:
  - Increase MCap by a small increment, which proportionally increases output across all hours, then compare the resulting EUE change with the base case EUE

# rMRI Calculation for Daily Energy Limited Resources

- Daily energy-limited resources use
  - Maximum Capability (MCap)
  - Maximum daily usable energy
  - Seasonal EFORd
  - Annual maintenance weeks
- Energy is dispatched only after all non-energy-limited resources are fully utilized
- Hourly output varies between zero and MCap depending on the energy need and remaining daily energy
- rMRI calculation:
  - Increase MCap by $\Delta c$
  - Increase daily usable energy by the factor (MCap + $\Delta c$)/MCap
- Run the simulation and compare the EUE change to the base case EUE

# rMRI Calculation for Energy Storage Resources

- Energy storage resources are represented by
  - Max Discharging Rate (MCap)
  - Max Charging Rate (may be lower than discharge rate)
  - Round-Trip Efficiency
  - Total energy storage capacity
  - Seasonal EFORd
  - Annual maintenance weeks
- Energy is dispatched similarly to other daily energy-limited resources, but replenished through charging using the energy from the grid
- rMRI calculation:
  - Increase discharging MCap by $\Delta c$,
  - Increase charging rate and total storage capacity proportionally by (MCap + $\Delta c$)/MCap
- Run the simulation and measure EUE reduction relative to the base case EUE

# rMRI Calculation for Resources with Shared Energy Storage Capacity

- When daily energy-limited and energy storage resources (e.g. PSH) share a common storage capability, they are modeled as an aggregate resource to better capture EFORd interactions

- Aggregate representation includes
    - Charging Rate = sum of individual MCap values
    - Discharging Rate = sum of individual discharging rates
    - Round-Trip Efficiency = weighted average
    - Total energy storage capacity = shared storage
    - Daily usable energy = shared daily limit
    - Annual maintenance = weighted average
    - EFORd = represented using equivalent multi-state partial outage rates
  - rMRI calculation:
    - Compute rMRI for the aggregate resource using the standard process

- Determine individual resource rMRI values using the proposed accreditation allocation method

# Questions

# MRI HOURS ESTIMATION

# MRI Hours Overview

- Under the MRI accreditation framework, resources are accredited based on their expected performance in the RAA model during MRI hours
- MRI Hours are defined as the hours where additional available capacity would mitigate or prevent load shed
- An MRI hour can be characterized in three types based on how additional capacity added to this hour prevents or mitigates load shed
  - Type 1: Hours with actual load shed (EUE occurs) – added capacity directly reduces EUE
  - Type 2: Hours prior to a load shed event where energy-limited resources are dispatched to prevent load shed – added capacity displaces the need to dispatch energy limited resources, saving limited energy capacity to reduce EUE in a future hour
  - Type 3: Hours prior to a load shed event where storage resources are charging-constrained – added capacity increases the amount energy storage resources can charge, which is used to reduce EUE in a future hour
- Identifying and publishing the MRI hours provides valuable insights into:
  - How resource adequacy risk is distributed across different months and hours within the season
  - The characteristics of the modeled resource mix and system constraints reflected in the RAA model

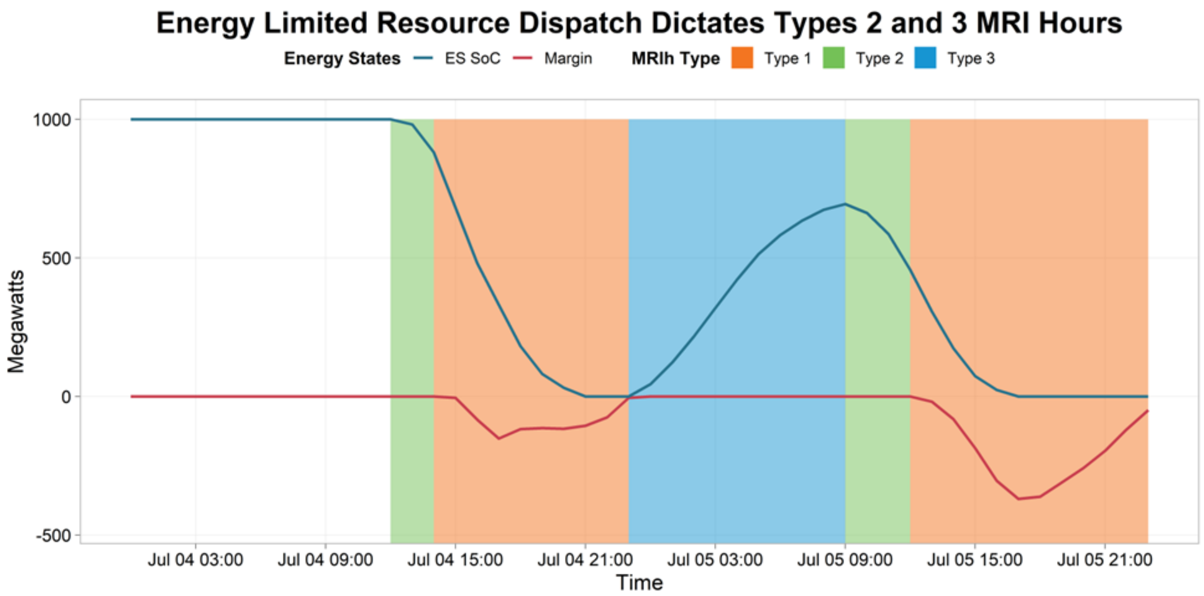
# Event-Based MRI Hours

- MRI hours are event-based
  - During the chronological simulation, MRI hours are generally a series of blocks of consecutive hours, each associated with a specific loss-of-load event(s)
- For each simulated loss-of-load event
  - All hours with unserved energy are MRI hours (Type 1)
  - Hours prior to the event may also be MRI hours if additional capacity in those hours could:
    - Delay the discharge of energy-limited or energy storage resources that run out of energy prior to the end of the EUE hours, allowing that energy to be used during the EUE hours (Type 2), or
    - Enable additional charging of storage resources that run out of energy prior to the end of the EUE hours, increasing the energy available to mitigate EUE during the event (Type 3)

# MRI Hours Block Illustration

- For illustration, this plot shows two consecutive load shed periods in orange: these are Type 1 MRI Hours

- Prior to the Type 1 intervals
  - Type 2 (Green): Energy Storage is dispatched to meet load eventually depleting storage during the load shed intervals
  - Type 3 (Blue): Energy Storage is dispatched to charge before discharging to meet load



# MRI Hours Determination

- One of the approaches that can be used to evaluate the MRI hours is by analyzing intermediate hourly data from the RAA model, on an event-by-event basis, moving backward in time

- Process:
  - Configure the RAA model to output all relevant hourly data for all replications
  - Start with the latest loss-of-load event and identify the continuous MRI hour block associated with that event using the logic below
  - For the hour immediately preceding the first EUE hour:
    - It is an MRI hour if **either** of the following conditions holds:
      - Any energy-limited or storage resource is discharging, and its energy is fully depleted by the last EUE hour (Type 2);
      - Any storage resource is charging, but the charging amount is less than the minimum of (charging rate, charging headroom) due to a surplus energy constraint, and its energy is fully depleted by the last EUE hour (Type 3)
  - If the hour qualifies as an MRI hour, move to the previous hour and apply the same logic

- Stop when an hour does not qualify. Then proceed to the next (earlier) loss-of-load event and repeat

# MRI Hours Determination Example

- The following slide contains a numerical example to walk through the MRI Hour determination for Type 2 and Type 3 MRI Hours.
- **ES02:** 100MW, 2-hour battery with a 100% RTE
- **ES01:** 50MW, 1-hour battery with a 100% RTE

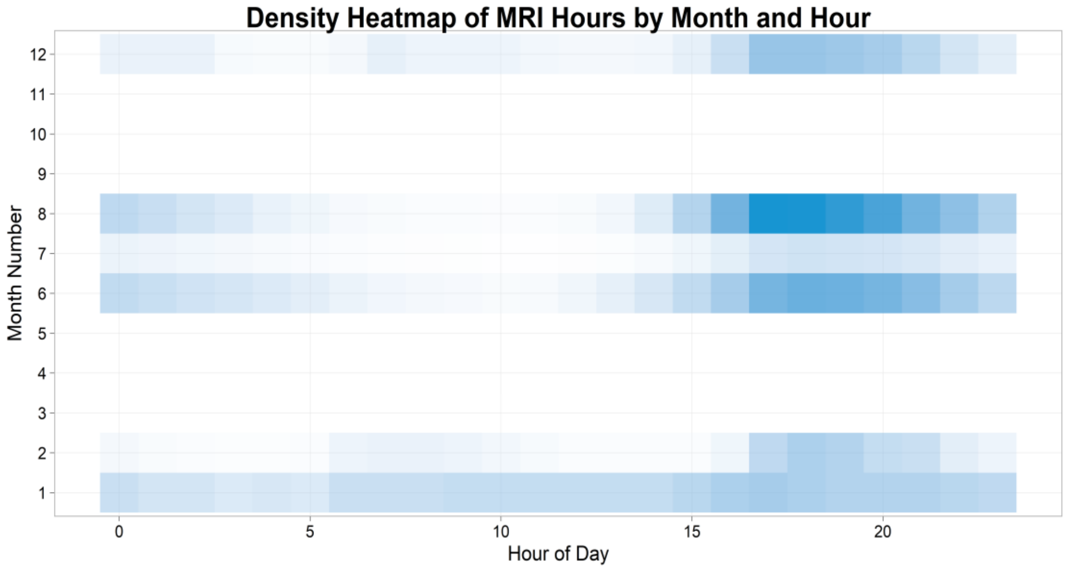
| Hour | Load | Other Capacity | ES02 Dispatch | ES01 Dispatch | Unserved Energy | MRI Hour? |
|---|---|---|---|---|---|---|
| 1 | 1,000 MW | 1,000 MW | 0 MW | 0 MW | 0 MW | No |
| 2 | 1,000 MW | 900 MW | 100 MW | 0MW | 0 MW | Type 2 |
| 3 | 1,100 MW | 950 MW | 100 MW | 50 MW | 0 MW | Type 2 |
| 4 | 1,000 MW | 1,100 MW | -50 MW | -50 MW | 0 MW | Type 3 |
| 5 | 1,200 MW | 1,050 MW | 50 MW | 50 MW | 50 MW | Type 1 |
| 6 | 1,100MW | 1,100 MW | 0 MW | 0 MW | 0 MW | No |
| 7 | 900 MW | 1,100 MW | -50 MW | -50 MW | 0 MW | No |

**Working backwards:**

- **Hours 7 and 6** do not have any loss of load nor are energy limited resources dispatched prior to a loss of load hour, therefore they are not MRI hours
- **Hour 5** is a load shed hour; therefore, it is a **Type 1** (load shed) MRI hour
- **Hour 4:** Because ES02 is depleted at the hour 5 load shed event and is not charging at its full capacity hour, thus is a **Type 3** MRI Hour
- **Hour 3 & 2:** ES02 is dispatched to meet demand and is fully depleted in **Hour 5**, therefore these hours are **Type 2** MRI hours
- **Hour 1:** The event stops here, ES02 and ES01 have full state of charge and load is met by other capacity meaning there is no EUE

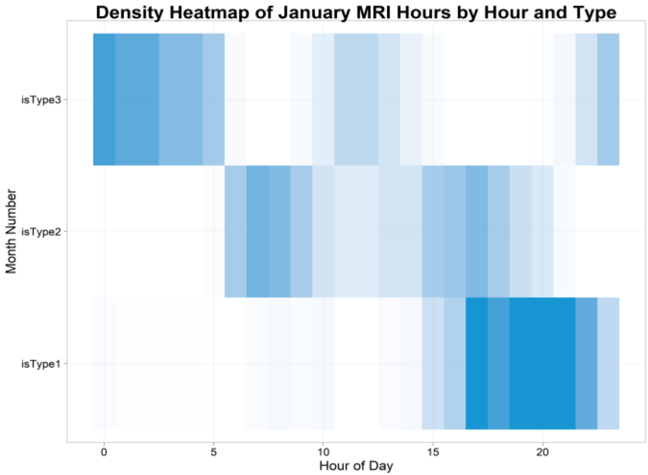
# Illustration of MRI Hours Heatmap

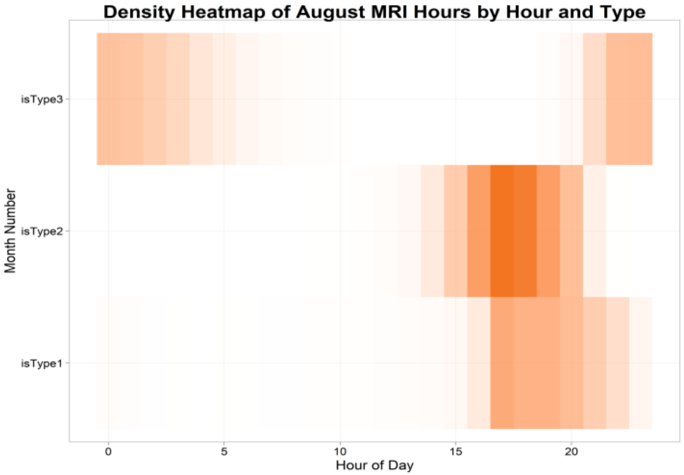
- The heatmap below shows how the MRI hours distributed among the months and hours based on a MARS test case
- MRI Hours are not spread evenly among months or hours
  - The highest frequency of MRI hours occurs in the afternoons (this is intuitively when a load shed event occurs) but includes intervals at night (this is when ES resources usually charge)
  - Winter hours occur only in January, February, and December
    - *January shows more uniform distribution of MRI Hours – this is indicative of capacity constraints causing MRI Hours instead of peak loads*
  - Summer hours in June, July and August



# Illustration of MRI Hours Heatmap by Type

- MRI hours observed in this test case show that the timing of different types of MRI hours follows an ordered sequence:
  - Type 3 (Charging Hours) occur the earliest, the late evening instances are seen when events cross the midnight boundary
  - Type 2 (Dispatch Hours) occur mid-day when demand is high and energy limited resources have ample storage to meet demand
  - Type 1 (Load Shed Hours) occur latest in the day when demand peaks and/or energy limited storage has been depleted



# Questions

# FUN FACTS ABOUT MARS RUNS

# Some Statistics of MARS Runs to Support Impact Analysis

- How long does it take to run a single MARS case?
  - ~4 hours for 5,000 replications
- How many trial MARS cases are run to obtain the Net ICR values?
  - MARS guru or being lucky: 30 for each season
  - MARS competent: 60 for each season
  - Newbie or being unlucky : unknown
- How many MARS cases are run to generate the capacity MRI curves?
  - System-wide capacity MRI curve: ~600 for each season
  - Gas capacity MRI curve: ~300
- How many MARS cases are run to calculate individual rMRI value?
  - Total: 900 for each season
- How many MARS cases are run in a batch in parallel?
  - 200-300 (but some could fail due to repeated rescheduling, thus needing extra round of runs)
- Process efforts:
  - It takes weeks to develop and review data assumptions for a base case
  - It takes days-weeks to set up and verify a MARS base case
  - It takes days-week to post-process MARS outputs (rMRI calculations, capacity MRI curves calculations, MRI hours calculation, other statistics)