A Marginal Reliability Impact Based Accreditation Framework for Capacity Markets

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Abstract— **This paper presents a Marginal Reliability Impact (MRI) based resource accreditation framework in the context of capacity market design. Under this framework, a resource is accredited based on its marginal impact on system reliability, thus aligning the resource's capacity market value with its reliability contribution. A salient feature of the MRI-based accreditation is that each unit of accredited capacity from different resources will have the same reliability contribution, implying "substitutability" among supply quantities of capacity, the desired feature of a homogeneous product. Moreover, with MRI-based capacity demand, substitutability between capacity supply and demand is also achieved. As a result, a capacity market with the MRI-based capacity product can better characterize the underlying resource adequacy problem and lead to more efficient market outcomes.**

Index Terms— **Capacity accreditation, capacity market, demand curve, Effective Load Carrying Capability (ELCC), Marginal Reliability Impact (MRI), MRI Capacity (MRIC), MRI hours, Resource Adequacy Assessment (RAA).**

I. Introduction

Adequacy is a key aspect of power system reliability. According to the North American Electric Reliability Corporation (NERC), adequacy is "the ability of the electricity system to supply the aggregate electrical demand and energy requirements of the end-use customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements" [1]. Currently, several Regional Transmission Organizations (RTOs) in the US, e.g., ISO New England, Mid-continent ISO (MISO), New York ISO (NYISO) and PJM, use capacity markets to address their regions' adequacy needs. Resource accreditation is an important part of the capacity market design as it dictates the capacity product and determines the quantity that a resource can offer into the market. Installed Capacity (ICAP) and its outage rate discounted Unforced Capacity (UCAP) were often used as the accredited capacity in regional capacity markets [2].

While ICAP and UCAP may be acceptable for accrediting thermal resources, extending these concepts to non-thermal resources such as intermittent and energy storage raises the fairness concern between different resource types. Therefore, in recent years many US regions have pursued capacity accreditation reforms [3]-[6]. ISO-NE is currently undergoing the transition from Qualified Capacity (QC) accreditation, an ICAP alike concept, to a Marginal Reliability Impact (MRI) based accreditation [3]; MISO has changed from UCAP to a Direct Loss of Load (DLOL) method for their capacity accreditation [4]; NYISO has implemented a marginal reliability improvement based accreditation to replace UCAP for non-thermal resources [5]; and PJM has shifted from the UCAP accreditation to an average Effective Load Carrying Capability (ELCC) accreditation and more recently, a marginal ELCC method [6]. Compared to ICAP and UCAP, these new accreditations are intended to more accurately reflect a resource's contribution to system adequacy. A shared feature of these methods is that a resource's accreditation value is affected not only by its own characteristics but by other resources as well, a result of system reliability *not* being an additively separable function of individual resources. Such interdependence indeed allows these new accreditation methods to reflect the diversity impact of the resource mix, e.g., adding resources of the same characteristics tends to reduce their marginal reliability benefit.

This paper introduces the MRI-based accreditation framework that has served as the foundation for ISO-NE's ongoing accreditation reform [7]-[8]. Starting with the desired substitutability of a homogeneous capacity product, we first derive a general accreditation framework based on resource MRIs. By choosing Expected Unserved Energy (EUE) as the adequacy metric and the perfect capacity MRI as the reference, a resource's MRI Capacity (MRIC) is then defined with an intuitive interpretation of the expected energy contribution in the hours affecting system EUE. These hours are critical for each resource's MRIC value and thus termed "MRI hours" in this paper. Next, numerical approaches for calculating MRIs of different resource types using a probabilistic Resource Adequacy Assessment (RAA) simulation tool such as GE-MARS [9] are described. Finally, MRIC demand curves are constructed based on our previous works [10]-[12].

Several properties of MRI-based accreditation including *additivity*, *homogeneity*, *common MRI hours*, *resource mix dependence*, *capacity benefit preservation*, and *reference MRI independence*, are discussed. Also, we compare the MRI-based accreditation to ICAP, UCAP, average and marginal ELCC approaches. The main contributions of this paper are *i)* introducing a rigorous MRI accreditation framework for capacity market design; *ii)* exploring interpretations and

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properties of the MRI accreditation; and *iii)* providing a comprehensive comparison of different accreditation methods.

The rest of the paper is organized as follows. Section II provides details of the MRI-based accreditation framework. Section III compares MRI-based accreditation with other accreditation methods. Section IV summarizes numerical testing results. Section V concludes the paper.

II. The MRI-based Accreditation Framework for Capacity Markets

The key idea of MRI-based accreditation is to align a resource's accredited capacity, which is the quantity the resource can offer into a capacity market, with its contribution to system adequacy. The MRI concept plays a central role in this alignment. The following Subsection II.A starts with the desired substitutability feature for a homogeneous capacity product and deduces the MRI and MRI Capacity (MRIC) concepts. Subsection II.B then derives the MRIC demand curves from our previously developed capacity demand curves [10]. Subsection II.C presents the calculation of MRI for different resource types. Subsection II.D explores the interpretations of MRI and MRIC. Subsection II.E examines the properties of the MRI-based accreditation. Lastly, Subsection II.F provides insights into the efficiency of market outcomes by aligning resources' accreditation values with their contributions to adequacy.

II.A MRI-based Capacity Accreditation

In capacity market design, a homogeneous capacity product is desired. Homogeneity implies *substitutability*, i.e., each unit of accredited capacity, regardless of source, provides the same benefit of system adequacy or reliability[1], or mathematically,

$$\frac{\partial M}{\partial \hat{C}_i} = -K, \quad \forall\, resource\ i. \tag{1}$$

where M is an adequacy risk metric, $\hat{C}_i$ is resource i's *accredited capacity* or *market capacity*, and K is a positive constant. The negative sign indicates reduced adequacy risk with the increase of capacity. Note that M is a multi-variate function of all resources' capacities since system adequacy is affected by all resources in the system, i.e., the *resource mix*. Eq. (1) indicates that different resources' accredited capacities should have the same marginal reliability contribution. Next, we derive the mathematical form of accredited capacity $\hat{C}_i$ that satisfies (1).

Let C_i be a parameter representing resource i's own size, e.g., nameplate capacity, ICAP, UCAP, etc. Hereafter we will use *native capacity* or *physical capacity* for C_i as it represents resource i's own physical characteristics. The native capacities of different resources may not be substitutable, e.g., one MW nameplate capacity of a nuclear resource could have a very different impact than that of a solar resource on system reliability. To have an accreditation scheme that satisfies the substitutability property (1), resource i's native capacity C_i is adjusted by a factor $\alpha_i \geq 0$ to define its accredited capacity $\hat{C}_i$, i.e.,

$$\hat{C}_i \equiv C_i \cdot \alpha_i, \ \forall\, resource\ i. \tag{2}$$

Substituting (2) into (1), we have $\frac{\partial M}{\partial \hat{C}_i} = \frac{\partial M}{\partial C_i} \cdot \frac{1}{\alpha_i} = -K$, or

$$\alpha_i = -\frac{\partial M}{\partial C_i} \cdot \frac{1}{K}, \forall\, resource\ i. \tag{3}$$

Substituting the above adjustment factor α_i into (2), we obtain the following form of accredited capacity $\hat{C}_i$ that is substitutable in terms of marginal reliability contribution:

$$\hat{C}_i = C_i \cdot \left(-\frac{\partial M}{\partial C_i}\right) \cdot \frac{1}{K}, \ \forall\, resource\ i. \tag{4}$$

Eq. (4) shows that resource i's accredited capacity $\hat{C}_i$, in MW, is the resource's native capacity C_i, in MW, adjusted by its marginal reliability impact $\left(-\frac{\partial M}{\partial C_i}\right)$, and normalized by a constant K that has the same unit as the marginal reliability impact (in order to yield the accredited capacity in MW). Note that the higher a resource's marginal reliability impact, the higher its accreditation value. This way, a resource's accredited capacity $\hat{C}_i$ accounts for its Marginal Reliability Impact (MRI) and is thus termed MRI Capacity (MRIC) hereafter. With substitutability, MRIC can be treated as a homogeneous capacity product and priced uniformly, allowing a more transparent and competitive capacity market.

Below we discuss the choices of M and K in (4). In [13], NERC defines several system adequacy metrics including Loss of Load Expectation (LOLE), Loss of Load Probability (LOLP), and Expected Unserved Energy (EUE). Among them, the EUE metric encapsulates both frequency and magnitude of Loss of Load (LOL) events and yields intuitive interpretations for MRI and MRIC (shown in Subsection II.D). It is therefore selected for the reliability metric M. With EUE, expressed in *MWh/year*[2], resource i's MRI, in *hours/year*, is defined as

$$MRI_i \equiv -\frac{dEUE}{dC_i}\Big|_{base-case}, \ \forall\, resource\ i. \tag{5}$$

The total derivative[3] notation "*d*" indicates that a resource's MRI reflects the entirety of its marginal reliability impact, to distinguish from the partial derivative notation for the MRI components discussed in later Subsection II.C. The derivative is evaluated at a particular point on the EUE function, which is represented by the "*base case*" that summarizes all settings of load and resources needed to calculate EUE and its derivatives. The choice of base case is discussed at the end of this section.

The constant K in (4) has the same unit as MRI and serves as the common *reference MRI* for all resources. Following the use of perfect capacity in conventional Effective Load Carrying Capability (ELCC) calculation [14], we adopt perfect capacity's MRI as the constant K in (4), i.e.,

[1] The two terms "adequacy" and "reliability" are used interchangeably hereafter in this paper.

[2] This paper considers one-year period for resource planning and capacity market. The MRI accreditation framework can be applied to different timeframes such as seasons.

[3] The adequacy metric is assumed differentiable in this paper for the convenience of notation in deriving the MRI concept. In practice, the function may not be differentiable.

$$K = MRI_{perfect}. \quad (6)$$

Note that perfect capacity represents a hypothetical resource that is always available at its full capacity. The value of $MRI_{perfect}$ has an important interpretation which will be introduced in Subsection II.D.

With the above choices of EUE and $MRI_{perfect}$ in (4), the accredited capacity of resource i, or $MRIC_i$, is represented as

$$MRIC_i = C_i \cdot MRI_i / MRI_{perfect}, \ \forall \, resource \ i. \quad (7)$$

The ratio of MRIs in (7) represents the *relative MRI* (rMRI) of resource i with respect to perfect capacity, i.e.,

$$rMRI_i \equiv MRI_i / MRI_{perfect}, \ \forall \, resource \ i. \quad (8)$$

Note that rMRI is unitless and $MRI_{perfect}$ serves as a common reference for all resources' MRIs. Then resource i's accredited MRIC is expressed as

$$MRIC_i = C_i \cdot rMRI_i, \ \forall \, resource \ i. \quad (9)$$

In the above accreditation scheme, MRI plays a key role in determining a resource's accreditation value. As resource MRIs in (5) are defined at the base case, their values are determined by the base case settings of *load* and *resource mix*.[4] Probabilistic load for the planning period is typically modeled in the base case. For resource mix, ideally it should be the *ex post* optimal resource mix resulting from capacity market clearing. However, as resource accreditation values are *ex ante* calculated for a capacity market, the optimal resource mix would be unknown for the accreditation process. Therefore practically, the optimal resource mix from the last auction or the existing resource mix can be used for the base case, provided that the resource mix does not change significantly from one auction to the next, an assumption that largely holds. Finally, the base case is often set to the planning criteria such as "*1-day-in-10-year*s" of LOLE by scaling the load or the resource mix. The *at-criteria* base case relates the long-term market equilibrium to the planning criteria in constructing capacity demand curves [10], and its use for both resource accreditation and MRIC demand curves allows substitution between MRIC supply and demand quantities as described in the following subsection.

II.B MRIC Demand Curves

With MRI-based capacity accreditation, MRIC becomes the capacity market product, i.e., both the offered capacities and the capacity demands should be expressed in MRIC quantities. Below we derive the MRIC demand curves from our previously developed native capacity demand curves.

A capacity demand curve reflects the marginal benefits of capacity to system adequacy at different levels of the total acquired capacity. In our previous work [10] that has been implemented in ISO-NE's capacity market, the system capacity demand curve in terms of Qualified Capacity (QC), a native capacity, is defined as

$$D_{SYS}(C_{SYS}) \equiv VOLL \cdot \left(-\frac{dEUE}{dC_{SYS}}\right), \quad (10)$$

where Value of Lost Load (VOLL) is assumed constant and calculated from the long-term market equilibrium condition as described in [10]; and C_{SYS} represents the system demand in native capacity and is assumed to be met by the base case resource mix, i.e.,

$$C_{SYS} = \sum_i C_i, \quad (11)$$

and $\left(-\frac{dEUE}{dC_{SYS}}\right)$ is a directional derivative with the "*direction*" being determined by the vector of native capacities composing the base case resource mix.

With MRIC being the market product, capacity demand needs to be measured in MRIC instead of native capacity C_{SYS}. Following the MRI-based resource accreditation, one can define the MRI for system capacity demand C_{SYS} as

$$MRI_{SYS} \equiv -\frac{dEUE}{dC_{SYS}}\Big|_{base-case}, \quad (12)$$

where the derivative is evaluated at the same base case as resource MRI definition (5). Then the corresponding rMRI and system demand MRIC, respectively, can be expressed as

$$rMRI_{SYS} = MRI_{SYS} / MRI_{perfect}, \quad (13)$$

and

$$MRIC_{SYS} = C_{SYS} \cdot rMRI_{SYS}. \quad (14)$$

With (12)-(14), it can be shown in a similar way as in Subsection II.A that one MW system MRIC demand has the same reliability benefit as one MW perfect capacity. Thus, the *substitutability between MRI-based capacity supply and demand* quantities is achieved. Eq. (14) also indicates that the native capacity demand C_{SYS} can be converted to the system MRIC demand by an adjustment factor $rMRI_{SYS}$. Next, we calculate $rMRI_{SYS}$ from resource rMRIs.

Since C_{SYS} is assumed to be composed of the base case resource mix, varying C_{SYS} implies proportional variations to the resources considered in the mix, i.e.,

$$\frac{dC_{SYS}}{C_{SYS}} = \frac{dC_i}{C_i}, \ \forall \, resource \ i. \quad (15)$$

Therefore, the directional derivative in (12) can be expressed as

$$\frac{dEUE}{dC_{SYS}} = \sum_i \left(\frac{dEUE}{dC_i} \cdot \frac{dC_i}{dC_{SYS}}\right) = \sum_i \left(\frac{dEUE}{dC_i} \cdot \frac{C_i}{C_{SYS}}\right), \quad (16)$$

where the derivatives are taken at the same base case, allowing the substitution of (5) and (12) into (16) to yield

$$MRI_{SYS} = \sum_i \left(MRI_i \cdot \frac{C_i}{C_{SYS}}\right). \quad (17)$$

By dividing both sides of (17) with the same reference of $MRI_{perfect}$ and substituting C_{SYS} with (11), we have

[4] A "resource mix" refers to a set of distinct resources with their shares of the total native capacity in the mix, e.g., a resource mix of N resources can be represented by the vector $[\frac{C_1}{\sum_i C_i}, \cdots, \frac{C_N}{\sum_i C_i}]$ of their native capacity shares.

$$rMRI_{SYS} = \frac{\sum_i (C_i \cdot rMRI_i)}{\sum_i C_i}. \quad (18)$$

Namely, the rMRI of system capacity demand, $rMRI_{SYS}$, can be calculated as the native capacity *weighted average rMRI* of the base case resource mix. This result is consistent with the consideration of one MW system capacity demand as one MW base case resource mix in capacity demand curve construction.

The system MRIC demand curve $\widehat{D}_{SYS}(\cdot)$ represents the marginal reliability benefit of system MRIC capacity, i.e.,

$$\widehat{D}_{SYS}(MRIC_{SYS}) \equiv VOLL \cdot \left(-\frac{dEUE}{dMRIC_{SYS}}\right). \quad (19)$$

With the linear relationship (14) between C_{SYS} and $MRIC_{SYS}$, the above MRIC demand curve (19) can be derived from the native capacity demand curve (10):

$$\widehat{D}_{SYS}(MRIC_{SYS}) = VOLL \cdot \frac{1}{rMRI_{SYS}} \cdot \left(-\frac{dEUE}{dC_{SYS}}\right)$$

$$= \frac{1}{rMRI_{SYS}} D_{SYS}(C_{SYS})$$

$$= \frac{1}{rMRI_{SYS}} D_{SYS}\left(\frac{MRIC_{SYS}}{rMRI_{SYS}}\right). \quad (20)$$

The above (20) reveals that the system *MRIC* demand curve can be obtained by scaling the coordinates of the system native capacity demand curve (10) using the system rMRI. Similarly, a zonal MRIC demand curve can be transformed from the corresponding zonal demand curve in native capacity using the zonal rMRI (i.e., the native capacity weighted average rMRI of resources modeled in the zone of the base case). In summary, the MRIC demand curves can be conveniently transformed from our previously developed capacity demand curves using the corresponding system or zonal rMRIs.

II.C Resource MRI Calculations

Depending on resource characteristics, the calculation of resource MRI may take different forms. In this section, the MRI is calculated for *thermal*, *energy-limited*, *intermittent* and *group* resources based on the general MRI definition (5). For each resource type, we describe what parameters are modeled and how to calculate its MRI.

Calculating MRI for Thermal Resources

A thermal resource is typically modeled in RAA as a Markov process with input parameters of size, state transition rates and mean time in state [24]-[25]. For example, a thermal resource may be represented by a two-state Markov model in the hourly RAA simulations, whereas the resource will be modeled either at "available" state (with full capacity) or "unavailable" state (on outage with zero capacity) for each simulated hour.

The MRI of thermal resource *i* is calculated by measuring the system EUE change with respect to a small perturbation to the modeled resource size, denoted by C_i^{max} as it typically reflects the maximum output of the resource, while keeping all other parameters constant. Note that MRI in (5) is defined on native capacity C_i, which may not necessarily be the modeled capacity C_i^{max}. Consider that C_i and C_i^{max} change proportionally, i.e., $\frac{dC_i}{C_i} = \frac{dC_i^{max}}{C_i^{max}}$, which is a reasonable assumption as both parameters represent physical size of the resource. Then the MRI of thermal resource *i* can be calculated as

$$MRI_i = -\frac{dEUE}{dC_i} = -\frac{dEUE}{dC_i^{max}} \cdot \frac{C_i^{max}}{C_i}, \ \forall \ thermal\ i. \quad (21)$$

Calculating MRI for Energy Limited Resources

An energy limited resource (ELR), e.g., battery, hydro, individual fuel-constrained thermal and pumped storage, has limited energy for supporting its capacity. Consequently, the ELR's MRI is affected by both its capacity and energy limits.

Suppose that an energy-limited resource *i* is modeled with its native capacity of C_i MW (e.g., maximum dispatching power) and an energy limit of E_i MWh. The marginal reliability impacts of the resource's capacity and energy limits, respectively, can be defined as:

$$MRI_{i,C} \equiv -\frac{\partial EUE}{\partial C_i} \ and \ MRI_{i,E} \equiv -\frac{\partial EUE}{\partial E_i}. \quad (22)$$

The above $MRI_{i,C}$ and $MRI_{i,E}$, respectively, can be viewed as capacity and energy components of the ELR's MRI. To reflect the total marginal reliability impact of both capacity and energy limits, storage resource *i*'s capacity and energy limit are perturbed proportionally, i.e., $\frac{dE_i}{E_i} = \frac{dC_i}{C_i}$, in calculating the resource's MRI, i.e.,

$$MRI_i \equiv -\frac{dEUE}{dC_i} = -\frac{\partial EUE}{\partial C_i} - \frac{\partial EUE}{\partial E_i} \cdot \frac{dE_i}{dC_i}$$

$$= -\frac{\partial EUE}{\partial C_i} - \frac{\partial EUE}{\partial E_i} \cdot \frac{E_i}{C_i}, \quad (23)$$

where "*d*" represents the total derivative and "∂" represents the partial derivative. Note that for a resource *i* with unconstrained energy, $\frac{\partial EUE}{\partial E_i} = 0$ and MRI_i will only reflects the marginal impact of capacity.

Substituting (22) into (23), we have

$$MRI_i \cdot C_i = MRI_{i,C} \cdot C_i + MRI_{i,E} \cdot E_i. \quad (24)$$

As will be discussed in later Section II.D, the term "$MRI_i \cdot C_i$" can be interpreted as resource *i*'s total contribution to adequacy. Then the above (24) indicates that a storage resource's contribution is made of its capacity and energy contributions.

The above MRI calculation formula (23) applies to individual ELRs. For resources with shared energy constraint, e.g., natural gas units subject to a regional gas supply limit, it is better handled through a capacity market constraint than in individual resources' MRI calculation[5].

Calculating MRI for Intermittent Resources

An intermittent resource such as wind and solar has varying

[5] Design details of a capacity market constraint for shared natural gas supply limitation will be discussed in a separate paper.

outputs over time and is often modeled as an hourly profile. Consequently, the hourly outputs of the intermittent resource determine its reliability contribution.

Supposed that an intermittent resource *i* has an hourly output profile $\{C_{i,t}\}_{t=1,\dots,T}$, where $C_{i,t}$ is its MW output in hour *t* of the planning horizon of *T* hours. Define the marginal reliability impact of the resource's output in hour *t* as

$$MRI_{i,t} \equiv -\frac{\partial EUE}{\partial C_{i,t}},\ \forall\, t = 1,\cdots,T. \quad (25)$$

The IPR's MRI reflects the marginal impact of a small perturbation to the resource's size C_i. Consider that varying the resource's size leads to proportional variations to the resource's outputs in all hours, i.e., $\frac{dC_{i,t}}{C_{i,t}} = \frac{dC_i}{C_i}, \forall\, t$. Then we have

$$MRI_i \equiv -\frac{dEUE}{dC_i} = \sum_{t=1}^{T}\left(-\frac{\partial EUE}{\partial C_{i,t}} \cdot \frac{C_{i,t}}{C_i}\right). \quad (26)$$

Namely, the intermittent resource *i*'s MRI can be calculated by evaluating the system EUE change over proportional changes to the hourly outputs of the IPR.

Substituting (25) into (26), we have

$$MRI_i \cdot C_i = \sum_{t=1}^{T}\left(MRI_{i,t} \cdot C_{i,t}\right) \quad (27)$$

With the MRI and MRIC interpretations to be discussed in later Section II.D, the above (27) indicates that an IPR's reliability contribution is the sum of its contributions in individual hours.

Calculating MRI for a Resource Group

There are situations that may require calculating the MRI for a group of resources, e.g., the system demand MRI in Subsection II.B, or a class MRI for a technology type. Below we define the group MRI and derive its relationship with individual member resources' MRIs.

Consider a group of resources with each member resource *i*'s native capacity being C_i and its marginal reliability impact being MRI_i. Denote the group's native capacity as $C_g = \sum_i C_i$ to represent the native capacity size of the group. Following the MRI definition (5), the group's marginal reliability impact MRI_g can be defined as

$$MRI_g \equiv -\frac{dEUE}{dC_g}. \quad (28)$$

The above resource group's MRI reflects the marginal impact of the group size C_g. To preserve the group's resource mix represented by the vector of individual member resources' shares of native capacities, varying C_g would lead to proportional variations to member resources' native capacities, i.e., $\frac{dC_i}{C_i} = \frac{dC_g}{C_g}, \forall\, i \in g$. Then we have

$$MRI_g \equiv -\frac{dEUE}{dC_g} = \sum_{i\in g}\left(-\frac{dEUE}{dC_i} \cdot \frac{C_i}{C_g}\right). \quad (29)$$

Namely, the group's MRI can be calculated by evaluating the EUE change over proportional changes to the individual resources in the group.

With individual resource MRIs defined in (5), the above (29) can be represented as

$$MRI_g \cdot C_g = \sum_i (MRI_i \cdot C_i). \quad (30)$$

With the MRI and MRIC interpretations to be discussed in later Section II.D, the above (30) indicates that the group's reliability contribution is the sum of contributions from individual resources in the group.

II.D MRI and MRIC Interpretations

In this section, we discuss the interpretations of a resource's MRI and MRIC. In probabilistic RAA simulations, each simulated scenario of the planning period is composed of a sampled hourly load profile based on a probabilistic load model and each resource's sampled hourly availability based on its probabilistic resource model. The Unserved Energy (UE) for each scenario is the total energy shortage across the hours with Loss of Load (LOL), and EUE is the probability-weighted expected UE across all scenarios. Therefore, a resource's MRI, defined as its marginal impact on EUE, reflects how a small change to the resource's size would affect its hourly contributions and consequently system UE across all scenarios.

Consider first the meaning of perfect capacity MRI. Since perfect capacity is always fully available, a small increase of Δ MW to its size results in Δ MW increase of available capacity to every hour of a scenario. In the absence of Energy-Limited Resources (ELRs) that could link the available capacities of different hours, the UE of a scenario would reduce by Δ MW for each of the LOL hours under that scenario, and thus $MRI_{perfect}$ would represent the expected number of LOL hours over all scenarios. With the presence of ELRs, however, extra perfect capacity in a non-LOL hour may also reduce the UE, e.g., the extra available capacity from a non-LOL hour can save ELR outputs in the hour for reducing UE in subsequent LOL hours, and thus such a non-LOL hour would also contribute to the perfect capacity's MRI. As a result, in general $\boldsymbol{MRI_{perfect}}$ represents **the expected number of hours that affect system adequacy**, including LOL hours when the system is inadequate and certain non-LOL hours[6] when the system adequacy is on the margin. All these hours will be termed "*MRI hours*" hereafter since they are the hours relevant to evaluating MRIs of all resources. Note that MRI hours are scenario dependent.

Next, consider the meaning of MRI for a resource *i*. According to the MRI definition, a small Δ MW size increase of resource *i* would lead to $(MRI_i \cdot \Delta)$ MWh reduction in EUE. Namely, the resource's available energy during the MRI hours would increase by $(MRI_i \cdot \Delta)$ MWh. Since resource *i* is not perfect, its capacity increase of Δ MW will only transfer to energy increase during its available hours. As a result, $\boldsymbol{MRI_i}$, in *hours/year*, **represents the expected number of MRI hours when resource *i*'s capacity is fully available**. Note that if the resource is available for a portion of its capacity during an MRI

[6] To identify the MRI hours with system adequacy on the margin (i.e., system capacity margin is zero), one may examine each non-LOL hour for each of the simulated scenario (typically in thousands) by assessing the EUE impact of adding a small perfect capacity to that hour, which is computationally intense. As a result, it is a challenge to identify all MRI hours for each simulated scenario in the presence of energy-limited resources.

hour, then the equivalent portion of the hour will be considered fully available for the resource and counted toward its MRI. Also, as a special case, the perfect capacity is fully available in all MRI hours, and thus $\boldsymbol{MRI_{perfect}}$ **reflects the expected number of MRI hours**.

According to the MRI calculations introduced in Subsection II.C, an increase to a resource's size means proportional increases to its capacity and if modeled, its energy limit, resulting in a proportional increase to the resource's hourly available capacity in RAA simulations. Since resource *i*'s MRI represents its expected number of fully available hours during the MRI hours, and the resource provides the full capacity of C_i during an available hour, then $(\boldsymbol{C_i \cdot MRI_i})$, in *MWh/year*, **represents resource *i*'s expected energy output during the MRI hours**. Consequently, MRIC of the resource, i.e., $(C_i \cdot MRI_i)/MRI_{perfect}$, can be interpreted as resource *i*'s **expected available capacity during an MRI hour**.

The above interpretations link all resources' accreditation values to their energy outputs during the common set of MRI hours. As one unit of energy has the same EUE reduction effect during those MRI hours, the substitutability of MRIC as derived in Subsection II.A is also implied from the interpretations.

II.E Properties of MRI-based Accreditation

Besides the substitutability in Subsection II.A, the MRI-based framework has several additional properties including additivity, homogeneity, common MRI hours, resource mix dependency, demand benefits preservation, and reference MRI independence. These properties are discussed as follows.

Additivity and homogeneity. *Additivity* means the accreditation value of a group of resources is equal to the sum of individual accreditation values of resources in the group, and *homogeneity* means the accreditation value of *n* identical resources is *n* times the accreditation value of an individual one. Based on the group MRI definition in (28), eq. (30) representing additivity holds for the MRI-based accreditation. Moreover, applying additivity to *n* identical group resources would lead to homogeneity, and thus homogeneity also holds for the MRI-based accreditation.

Common MRI hours. Based on the interpretation of $MRI_{perfect}$ in Subsection II.D, the MRI hours are the ones that affect system adequacy, i.e., adding small available energy to any of these hours would yield EUE reduction. The MRI hours are determined by the resource and load modeled in the RAA base case, and infinitely small perturbations in Subsection II.C for calculating each resource's MRI will not change the MRI hours of the base case. Namely, the MRI accreditation employs a common set of MRI hours for evaluating all resource MRIs. The use of common MRI hours for all resources poses a sharp contrast to an average accreditation scheme, which will be compared in later Section III.

Resource mix dependency. MRI is defined as a derivative of EUE. As system EUE is affected by resource mix, so is the MRI and thus the MRIC of any resource. Namely, a resource's MRI accreditation value depends on not only its own physical characteristics but the resource mix as well. Such resource mix dependency allows the accreditation value to capture the diversity benefits of resource mix, e.g., adding capacities with similar characteristic tends to reduce their marginal reliability benefit and consequently accreditation values.

Capacity benefits preservation. As discussed in Subsection II.B, capacity demand curves are administratively constructed to reflect the marginal reliability benefits of capacity under a resource mix assumption. The reliability benefits of a given size and mix of physical resources, represented by the area under a demand curve, should not depend on how resources are accredited. Such demand benefit preservation is maintained between the capacity demand curve in native capacity and the corresponding MRIC demand curve, since the latter is constructed by scaling the two coordinates of the former with reciprocal factors based on (20).

Reference MRI independence. The MRI accreditation formula (8) uses perfect capacity MRI as the reference to define each resource's rMRI. From the derivation of the general accreditation formula (5), however, the reference $Const.$ can be an arbitrary constant while still satisfying substitutability. With a different reference (e.g., a non-perfect resource MRI), each resource's rMRI and thus MRIC will be scaled by a factor β of the two references, i.e., $\beta = MRI_{other-ref}/MRI_{perfect}$. Consequently, each resource's offer curve will have its MRIC quantity axis scaled by $1/\beta$ and the offer price scaled by β, preserving each resource's total capacity cost under the two different references. And the demand curves will have its total MRIC quantity axis scaled by $1/\beta$ and the marginal benefit scaled by β. With the demand curves and each supply curve scaled by the same factor, the auction clearing will yield the same set of optimal physical resources and the same capacity payment for each resource, although the cleared resource quantities will be scaled by $1/\beta$ and the clearing prices will be scaled by β. In sum, the optimal resource mix and resource payments are independent of the choice of reference MRI. The reference-independent property of MRI-based accreditation indicates the importance of relative accreditation values instead of absolute ones for resources.

II.F Market Efficiency Under MRI-based Accreditation

This section provides insight into how MRI-based accreditation, as compared to native capacity, could better align a capacity market with system adequacy and thus allow more efficient market outcomes.

Prior to the recent capacity accreditation reforms, most of the RTOs equipped with a capacity market procure an *adequate* amount of native capacity, i.e., capacity requirement, that meets the region's adequacy target. This is represented by the supply-demand constraint in capacity market, e.g.,

$$\sum_i C_i \geq C_{SYS}, \tag{31}$$

where C_i is the native capacity of resource i, and C_{SYS} is the native capacity requirement which represents the size of a given resource mix that, together with a given load, would meet the adequacy criteria such as 0.1 days/year LOLE. The calculation of C_{SYS} requires load and resource mix assumptions, which are captured in the *base case*. Note that capacity demand curve is an extension of the capacity requirement by allowing different C_{SYS} levels that correspond to different system adequacy levels.

Constraint (31) does not distinguish different resources' native capacities in meeting the capacity demand. Rather, it treats system adequacy as a single-variable linear function of the total capacity $\sum_i C_i$. However, system adequacy is a multivariate nonlinear function of individual resources (represented by the resource mix vector and its size). Thus, the linear capacity requirement constraint (31) can be viewed as an approximation to the actual adequacy need. This is illustrated in Fig. 1 with a stylized system of two resources. In the figure, the actual adequacy level curve represents all the pairs (C_1, C_2) that yield the same adequacy level as the at-criteria base case. The curve is in general nonlinear[7] and tends to be flatter (steeper) as C_1 (C_2) increases since it would require more capacity from an abundant resource to replace the other resource to maintain the same system adequacy level. The native capacity market implied level curve represents the pairs (C_1, C_2) that yield the same total capacity requirement C_{SYS} in the market constraint (31). The curve is linear with the slope of -1, indicating the capacity market's approximation of system adequacy need with the total capacity requirement. The two curves model the same adequacy level as the base case, which corresponds to their intersection point. The difference between the two curves reflects the approximation error of capacity requirement to the actual adequacy need.

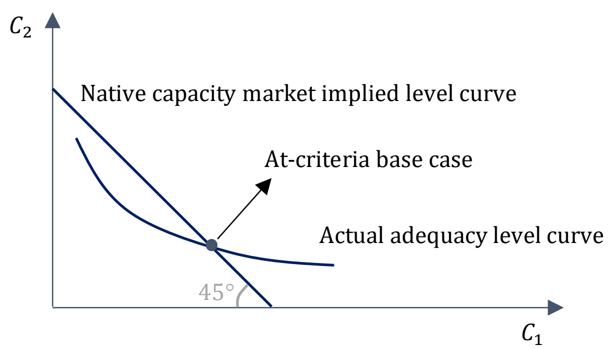

Fig. 1. Level curves of adequacy function and its approximation

With the MRI-based capacity product, both capacity supply and demand are denominated in MRIC. Thus, the native capacity requirement constraint (31) is replaced by

$$\sum_i MRIC_i \geq MRIC_{SYS}. \tag{32}$$

where $MRIC_i$ and $MRIC_{SYS}$, respectively, are individual resource MRICs and the system MRIC requirement. To compare the above MRIC requirement (32) with the native capacity requirement (31), the MRICs are substituted by (9) and (14) to yield

$$\sum_i (rMRI_i \cdot C_i) \geq rMRI_{SYS} \cdot C_{SYS}. \tag{33}$$

Constraint (33) attaches rMRIs as weights to individual resources in meeting the capacity requirement. Namely, the same amount of native capacity from different resources are not treated as substitutable. The implied adequacy level curve for the above two-resource example is depicted in Fig.2. In the figure, the actual adequacy level curve remains unchanged from Fig.1 as it reflects the physical characteristics of the system. The MRIC market implied curve represents the pairs (C_1, C_2) that yield the same total MRIC requirement $MRIC_{SYS}$ in the market constraint (32). The curve is linear and intersects with the actual adequacy level curve at the point corresponding to the base case when rMRIs and $rMRI_{SYS}$ are calculated from the same base case. The slope of the curve is determined by the vector $[rMRI_1, rMRI_2]$, which represents the gradient of the actual adequacy level curve at the base case point when EUE is used as the adequacy measure[8]. Thus, the adequacy level curve implied by the MRIC requirement constraint (33) can be viewed as a linear approximation of the nonlinear adequacy level curve. By incorporating the gradient information of adequacy function at the base case, the MRI-induced linear approximation is more accurate than the one under native capacity *near the base case point*. Assume that the *optimal solution* under the actual nonlinear adequacy function is not far from the base case point, which likely holds in practice since the base case is often constructed from the set of existing or recently cleared resources and a drastic change from the set is typically costly and thus will not be optimal. Then, a more accurate approximation near the base case would likely lead to a market solution closer to the optimal one.

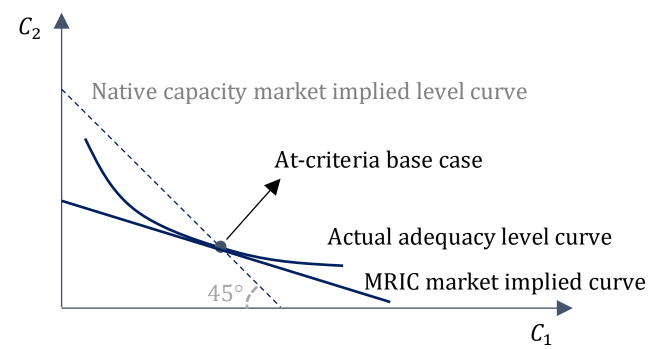

Fig. 2. Level curves of adequacy function and its MRIC approximation

The above analysis shows that the MRIC requirement (32) or (33) provides a more accurate linear approximation to the nonlinear adequacy function than the native capacity requirement (31). This is reflected in more accurate representations of individual resources' reliability contributions (i.e., accredited capacities) and a more accurate model of the reliability benefit (i.e., −EUE×VOLL), thus allowing more efficient capacity market outcomes.

III. Comparison with Other Accreditation Methods

In this section, existing accreditation methods of ICAP/UCAP (Subsection III.A), Average ELCC (Subsection III.B) and Marginal ELCC (Subsection III.C) are introduced

[7] The actual adequacy level curve can be linear when both resources are perfectly 1:1 substitutable, e.g., both are perfect capacity.

[8] Note that the use of EUE to characterize system adequacy will not contradict the adequacy criteria defined on a different adequacy measure, e.g., the 1-in-10 LOLE criteria can be used to construct the base case, while EUE can be used to derive the level curves and their gradients.

and compared with the MRI accreditation method.

III.A ICAP/UCAP

Prior to the recent wave of capacity accreditation reform, many ISO/RTOs define a resource's accreditation based on its ICAP or UCAP. For example, ISO-NE and IESO use the ICAP concept for their capacity market quantity while PJM and NYISO use the UCAP concept. The main difference between ICAP and UCAP of a resource is: The ICAP of a resource does not capture the resource's unavailability information, while the UCAP of a resource often includes an Equivalent Forced Outage Rate demand (EFORd) discount from the ICAP.

Both ICAP and UCAP of a resource are determined only by the resource's own characteristics. As a result, ICAP or UCAP does not provide an accurate characterization of a resource's reliability contribution and is generally not substitutable between different types of resources, since system reliability metrics such as LOLE and EUE are inseparable functions of individual resources and a resource's reliability contribution is affected by other resources.

In comparison, the accredited MRIC of a resource is determined by not only the resource's own characteristics, but load and other resources as well. Such dependence of a resource's accreditation value on the resource mix allows diversity benefits to be reflected.

III.B Average ELCC

The average Effective Load Carrying Capability (AELCC) method or conventionally called ELCC method [9], accredits a resource by the equivalent amount of perfect capacity that could replace the resource for the same level of system reliability. It has been used for calculating a resource's capacity factor (i.e., percentage of the equivalent perfect capacity amount to the resource's native capacity). LOLE is typically adopted as the reliability metric in ELCC calculations. The AELCC method can also be applied to a class of resources by replacing the entire class with an equivalent amount of perfect capacity.

The AELCC method is illustrated in Fig. 3 for a resource (or class) i with a native capacity of C_i MW. The difference in system adequacy levels with and without the resource is represented by ΔLOLE. In the figure, a perfect capacity of $C_{perfect}$ MW is assumed to replace C_i MW of the resource to have the same system adequacy impact. Note that the LOLE curves are shown as decreasing functions of capacity as additional capacity would improve system adequacy (i.e., reducing LOLE). Also, the steepness of the curves reduces with the increase of capacity, reflecting the generally decreasing marginal reliability benefit of additional capacity. The AELCC method would accredit resource i at $C_{perfect}$ MW, i.e.,

$$AELCC_i \equiv C_{perfect}, \tag{34}$$

and the Capacity Factor (CF) for the resource is $C_{perfect}/C_i$. For the convenience of comparing AELCC to the marginal ELCC in the following Subsection III.C, let $\Delta C_{perfect} = C_{perfect} - 0$ and $\Delta C_i = C_i - 0$. Then the capacity factor of resource i can be represented as

$$CF_i \equiv \frac{C_{perfect}}{C_i} = \frac{\Delta C_{perfect}}{\Delta C_i} = \frac{\Delta C_{perfect}/\Delta LOLE}{\Delta C_i/\Delta LOLE} \tag{35}$$

The above formula indicates that to yield the same reliability impact of $\Delta LOLE$ would require ΔC_i MW resource i or $\Delta C_{i,perfect}$ MW perfect capacity. Two RAA cases are involved in the AELCC evaluation of resource i: the case with resource i (represented by point A in Fig. 3); and the case with the perfect capacity replacement (point B). The former establishes the LOLE impact of resource i (i.e., $\Delta LOLE$) and the latter finds the perfect capacity replacement (i.e., $\Delta C_{i,perfect}$) that yields the same LOLE impact using a searching method such as the bisection method. Note that the equivalence between ΔC_i and $\Delta C_{i,perfect}$ is conditioned on the remaining resource mix, i.e., for a different mix of other resources, $\Delta LOLE$ and the amount of perfect capacity $\Delta C_{i,perfect}$ to yield the different LOLE impact can be different.

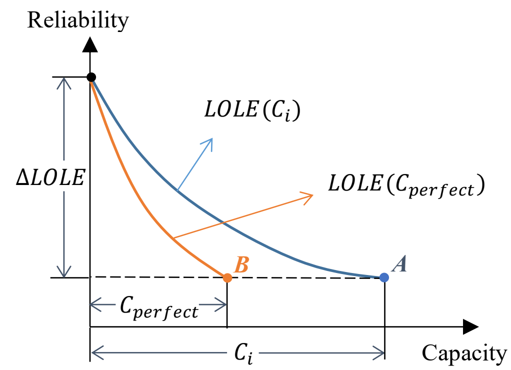

Fig.3. Illustration of AELCC method.

For each resource or class, the above AELCC method finds a perfect capacity replacement that has the same LOLE impact. As the system LOLE is affected by the resource mix, the AELCC value of a resource or class is dependent on the resource mix. Such property is shared by the MRI-based accreditation. However, the resource mix is different for the two RAA cases involved in resource i's AELCC evaluation and those involved in other resources' accreditation, resulting in different LOL event patterns in the AELCC calculation of different resources. Therefore, unlike the MRI-based accreditation characterized by common MRI hours, the AELCC accreditation for different resources is not based on a common set of hours. Also, with nonlinear LOLE functions of capacity, additivity and homogeneity do not hold with the AELCC accreditation method, i.e., the AELCC value of a group of resources isn't the sum of individual AELCC values of the resources in the group, and the AELCC value of n identical resources isn't n times the value of an individual resource.

III.C Marginal ELCC

Marginal ELCC (MELCC) is the marginal version of the ELCC method. The calculation of MELCC follows a similar process as AELCC calculation, except that small (marginal)

[9] The word "average" is added to the ELCC term to distinguish the method from the marginal ELCC method introduced in Subsection III.C.

perturbations to a resource (or class) replace the removal or addition of the entire resource. Namely, it calculates the equivalent amount of perfect capacity that would yield the same LOLE impact of a small change to a resource's capacity.

The MELCC calculation is illustrated in Fig. 4, where the reliability impact $\partial LOLE$ of a small change ∂C_i to resource *i* is evaluated, and then the perfect capacity amount $\partial C_{perfect}$ that would yield the same reliability impact is identified. Note that with the marginal changes, the LOLE functions are plotted as straight lines in the figure. Following (35), the capacity factor for the small change ∂C_i to resource *i*, or the Marginal Capacity Factor (MCF), can be represented as

$$MCF_i \equiv \frac{\partial C_{perfect}}{\partial C_i} = \frac{\partial C_{perfect}/\partial LOLE}{\partial C_i/\partial LOLE} \tag{36}$$

where "∂" indicates marginal changes to be distinguished from the "Δ" changes of the entire resource in AELCC. The above formula indicates that to yield the same reliability impact of $\partial LOLE$ would require ∂C_i MW resource *i* or $\partial C_{i,perfect}$ MW perfect capacity. The MELCC method then accredits resource *i* as

$$MELCC_i \equiv C_i \cdot MCF_i = C_i \cdot \frac{\partial C_{perfect}/\partial LOLE}{\partial C_i/\partial LOLE} \tag{37}$$

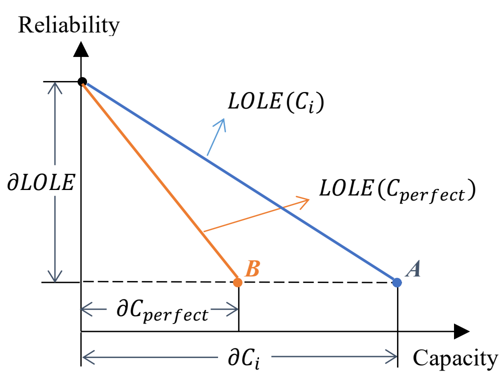

Fig.4. Illustration of MELCC method.

The MELCC accreditation (37) resembles the MRI-based accreditation (7) except for its use of LOLE metric and its calculation of capacity change corresponding to the reliability change. As a result, the MELCC accreditation shares the resource-mix dependency property with the MRI-based accreditation. The additivity and homogeneity properties also hold due to the marginal nature of the MELCC concept. However, with LOLE a resource's MELCC does not have the interpretation of energy contribution. Also, $MELCC_i$ calculates the amount of change to resource *i*'s capacity (RAA input) corresponding to a small change to LOLE (a RAA output), which requires multiple RAA runs instead of a single RAA run of calculating MRI as the amount of change to EUE (RAA output) corresponding to a small change to the resource capacity (RAA input). Furthermore, LOLE is less sensitive to capacity changes as compared to EUE or could even be discontinuous, and thus the practical MELCC calculation of LOLE derivatives may require sizable perturbations to incur traceable LOLE changes, undermining the marginal nature of the method.

IV. Numerical Testing

In this section, we test the accreditation methods on a 25-unit system with GE-MARS [9] and examine their properties discussed in the previous sections. A planning period of 8760 hours (i.e., one year) is considered for a system with 12 thermal units of different sizes and outage rates (each unit modeled as a 2-state Markov Chain with the "1" state representing full capacity and "0" representing zero capacity), 11 Intermittent Power Resources (IPRs) (each modeled as probabilistic hourly output profiles with outage rates), and 2 Energy Storage (ES) units (each modeled with charging / discharging capacity and energy limit). The ICAPs, outage rates (for non- ES units) and energy limits (for ES units) are listed in Table 1. Ten probabilistic hourly load profiles are modeled based on a historical year's load shape in New England. For simplicity, no transmission limit or unit maintenance is considered. A perfect capacity of 21576.3 MW is added to the system to yield the *base case* at 0.1 days/year LOLE criterion.

Following the MRIC calculation described in Section II.B, and the average and marginal ELCC calculations described in Section III, the resulting accredited capacities under these accreditation methods are summarized in Table 1. For MRIC calculation, the perturbation size of 1 MW is applied. For AELCC calculation, brute-force evaluations of candidate values for each unit are applied to identify the one that yields the closest LOLE impact. Note that for each resource, the AELCC calculation requires multiple evaluations of candidate values and thus is computationally more expensive as compared to the MRIC calculation that evaluates only once for the perturbed native capacity. Moreover, to reduce the computational needs of MELCC calculation, we apply a similar perturbation process to the MRIC calculation by examining the LOLE impact of "small" capacity changes. It should be noted that the MELCC calculation suffers from the non-continuous nature of LOLE function and thus may be undefined.

From Table 1, the AELCC, MELCC and MRIC accreditation values are no higher than the ICAP of a non-perfect unit since all these accreditation methods convert the unit's installed capacity to perfect capacity. Note that for perfect capacity, all three methods yield the same value as ICAP as expected. Also, MELCC and MRIC, both being marginal methods, yield different accreditation values due to their adoption of different reliability metrics, i.e., LOLE and EUE, respectively, and the inherent difficulty of calculating MELCC from the noncontinuous LOLE function. AELCC and MELCC, both using the same LOLE metric, generally yield different accreditation values due to the nonlinearity of the LOLE function.

Observe that MRIC of a thermal unit *i* is no more than its outage rate discounted UCAP value of $ICAP_i \cdot (1 - FOR_i)$, e.g., TH1 unit's MRIC of 148.39 MW is less than its UCAP of 150×(1-0.0097) = 148.55 MW. The reason is: UCAP reflects the unit's expected availability across all hours, while MRIC reflects its expected availability during the MRI hours. As an hour is more likely to be an MRI hour when the unit is at outage than when the unit is available (with all else being the same), the unit is more likely to be unavailable during the MRI hours.

Also, observe that the 8-hour storage ES2 has higher capacity factors (i.e., accreditation value divided by ICAP) than the 2-hour ES1, since the longer-duration storage tends to be less likely energy-constrained during a multi-hour adequacy event.

Table 1: Average ELCC, Marginal ELCC, and MRIC.

Unit	Native $ICAP_i$	FOR_i or E_i	AELCC	MELCC	MRIC
TH1	150	0.0097	148	148.5	148.4
TH2	100	0.2061	79	76.8	77.9
TH3	1000	0.008	986	969.7	979.6
TH4	750	0.1041	631	560.6	605.6
TH5	5	0.0723	4.6	4.6	4.6
TH6	10	0.0723	9.8	9.2	9.3
TH7	150	0.0964	134	133.3	133.8
TH8	600	0.0381	567	551.5	561.0
TH9	900	0.016	879	836.4	866.5
TH10	50	0.001	49.5	50	49.9
TH11	200	0.001	199	200	199.7
TH12	300	0.006	298	293.9	297.7
IPR1	900	0	145	132.9	138.9
IPR2	600	0	145	117.3	133.7
IPR3	1400	0	153	92.8	228.4
IPR4	60	0	35	34.8	35.3
IPR5	275	0	185	191.7	181.8
IPR6	15	0	7.8	8.0	8.0
IPR7	700	0	159	136.6	159.7
IPR8	25	0	16.5	16.8	16.6
IPR9	200	0	197	198	193.2
IPR10	50	0	45.5	45.3	44.2
IPR11	800	0.7962	12.9	15.1	23.6
ES1	600	1200	570	515.2	224.0
ES2	1500	12000	1500	1500	1437.2
Perfect	*21576.3*	*0*	*21576.3*	*21576.3*	*21576.3*
Total	32916.3	-	28911.9	28415.2	28334.9

To test the additivity of different accreditation methods, consider IPRs 1-8 as a single group. The group's accredited values under different accreditations are calculated and listed in Table 2, along with the sum of individual accreditation values in Table 1. It can be seen from Table 2 that the group AELCC of 903 MW is 56.7 MW more than the sum of individual resource AELCCs (i.e., 846.3 MW), consistent with the non-additive feature of AELCC method. The MRIC of the group, whether calculated as a single group or the sum of individual unit MRICs, yields almost identical results with the small 0.3 MW difference attributing to numerical tolerance, which is consistent with the additive feature of MRIC. The MELCC accreditation, although additive in theory with assuming differentiability of LOLE, shows sizable gap (25.7 MW) between the group MELCC (756.6 MW) and the sum of individual MELCCs (730.9), verifying the numerical challenges of MELCC calculation.

Table 2: Group accreditation and total individual accreditations.

IPR Group	ICAP	AELCC	MELCC	MRIC
Group Accreditation	3975	903	756.6	902.8
$\sum$ Individual Accred.	3975	846.3	730.9	902.5

To test reference independence, consider TH4 as the new reference. Then resource accreditation values under the new reference can be calculated and compared with the values under the perfect capacity reference. Table 3 lists accreditation values of TH1 and TH4 as examples under the new reference TH4. All accreditation values of unit TH4 equal its ICAP since the unit becomes the reference. The accreditation values of unit TH1 measured in the new reference capacity in Table 3 have increased from those values measured in perfect capacity (listed in Table 1), since the new reference capacity is less perfect. The percentage increases of accreditation values due to the reference shift are also listed in Table 3. Note that marginal methods (i.e., MELCC and MRIC) impose a uniform percentage increase to the accreditation values of both units, without affecting the *relative* capacity values between the two units, and thus are considered reference independent. AELCC, however, results in accreditation increases of 12.2% for TH1 and 18.9% for TH4, respectively, altering the relative values of the two units, i.e., TH4 gained an advantage over TH1 due to the reference shift. Therefore, AELCC is reference dependent.

Table 3: Accreditation values with TH4 as reference.

Unit	ICAP	AELCC	MELCC	MRIC
TH1	150	166 (+12.2%)	198.65 (+33.8%)	183.8 (+23.9%)
TH4	750	750 (+18.9%)	750 (+33.8%)	750 (+23.9%)

V. Conclusion

An MRI-based accreditation framework is introduced for capacity markets. The framework is analyzed for its features and compared with other accreditation methods. With the MRI-based resource accreditation and capacity demand, the capacity market of MRIC product is better aligned with the system adequacy need, allowing more efficient market outcomes.

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