Coherency of the European resource adequacy framework

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***Abstract*—It is widely accepted that the marginal costs of additional capacity should be balanced by the marginal benefits of increased reliability or adequacy. This is the core principle of the resource adequacy framework mandated by the EU. In this framework, three pillars, namely the reliability standard calculation, adequacy assessments and capacity remuneration mechanisms, should conspire to deliver a realised adequacy in liberalised markets which is close to that which would be delivered by a central planner minimising total system costs. However, this framework is vulnerable to inconsistencies in the parameters used in each of the three pillars, making the framework internally incoherent. More importantly, these inconsistencies may lead to deviations from the optimal level of adequacy and hence significant increases in costs.**

We illustrate and discuss such inconsistencies using a simple, single scarcity event model. In particular, we show how an inconsistent choice of storage operation can lead to a sub-optimal level of adequacy. However, a consistent storage operation challenges the stated purpose of adequacy assessments in the EU which is to predict adequacy resulting from market operations.

***Index Terms*—resource adequacy, reliability standard, adequacy assessments, capacity remuneration mechanisms, electricity storage, electricity regulation**

I. Introduction

The resource adequacy of an electric power system is crudely defined as the ability of a power system to meet electrical load. The Expected Energy Not Served (EENS) and the Loss of Load Expectation (LOLE) are the two dominant metrics used to quantify resource adequacy, defined as the expected volume in MWh of load not served or shed and the expected number of hours per year in which load shedding or scarcity occurs. In this paper we will focus on the resource adequacy framework in the European Union (EU), however the insights we provide may prove useful for other power systems with an economic justification for LOLE.

We employ three related though different terms throughout this paper: correctness, consistency and coherence.

We define an exercise such as an adequacy assessment as <u>correct</u> if it does what we expect it to do. Most literature on the subject of resource adequacy focuses on correctness, e.g. correct capacity credit definitions [4] or economically efficient reliability standard calculations [10].

<u>Consistency</u> means using the same parameters across exercises within the resource adequacy framework. For example, it seems natural to consistently use the same forced outage rate for a generator type when conducting an adequacy assessment and calculating capacity credits. This subject has recieved little to no attention in academic literature, though we know of at least one instance where it is mentioned in a regulatory note by the Belgian energy regulator, the CREG, with regards to the investment cost of new entry [5].

The focus of this paper is on <u>coherency</u> - the resource adequacy framework is internally coherent if it's parts work together as a whole to yield a power system with the same level of adequacy as that which a central planner would (at least in theory). While coherency implies correctness of the individual parts it does not necessarily imply consistency. To the best of our knowledge coherency has only been discussed before by [3] in relation to national reliability standard calculations in interconnected systems.

The key contribution of this paper is to illustrate how <u>a seemingly logical choice of parameters used within the resource adequacy framework may make it incoherent</u> and an inadequate power system. Specifically we show that the storage operation assumed within the framework must be consistent with operation assumed when calculating the reliability standard and not with that which would occur under market conditions. This is at odds with the current understanding of adequacy assessments in the EU, which is that they simulate scarcity during market conditions.

The rest of this paper is organised as follows. Section II describes the resource adequacy framework in the EU, its ultimate goal and how it is supposed to achieve it. Section III explains the single scarcity event model used in Section IV to illustrate how using an estimated instead of theoretically coherent storage operation may lead to an incoherent resource adequacy framework. Section V concludes.

II. The resource adequacy framework in the EU

The resource adequacy framework in the EU can be thought of as consisting of three pillars, parts or exercises: reliability

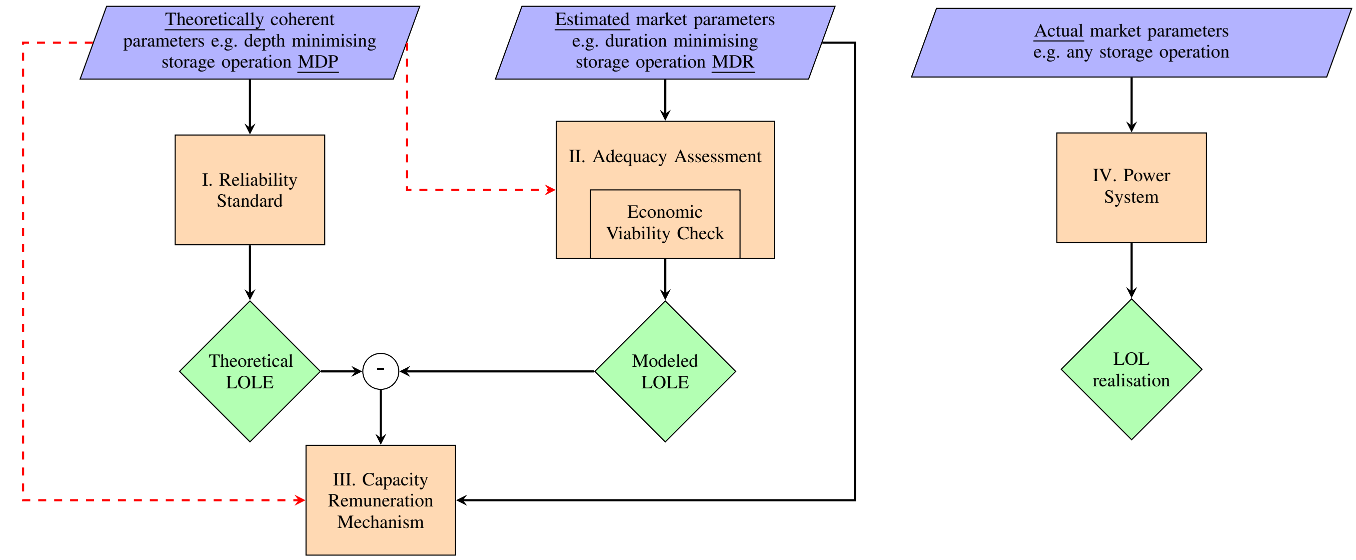


Fig. 1: Illustration of the three pillars (rectangles) of the resource adequacy framework in the European Union (EU), the types of parameters (trapezoids) they use, the Loss of Load Expectations (LOLEs) (diamonds) which result from and how the constituent parts interact with each other (arrows). The realised adequacy of the power system is also illustrated on the right hand side. The red, dashed arrows illustrate parameter useage which runs counter to what is currently understood, in this case storage operation (see Section III) which deviates from what may be expected to occur under market conditions. This consistency is necessary for the whole framework to be coherent.

target setting; adequacy assessments, which also involve a projection of the future capacity mix, economic viability checks; and capacity remuneration mechanisms. These parts, the types of parameters they use as input (which we will discuss in due course) and their major interactions are illustrated in Figure 1[1].

The principal interaction between these parts is that of comparing the ideal, social welfare maximising LOLE and the predicted or modeled LOLE. If the former is greater than the latter, a capacity remuneration mechanism may be required to ensure sufficient capacity to make up the difference. The methodology for calculating the theoretically optimal LOLE is described in [1] and in it's simplest form it can be expressed as:

$$LOLE = \frac{CONE}{VOLL} \tag{1}$$

where $CONE$ is the cost of new entry, i.e. the net cost of an additional or marginal MW of resource and $VOLL$ is the mean Value of Lost Load (VOLL).

The types of inputs to the parts of the resource adequacy framework are listed in Table I. We identify three main types: actual parameter values, which are ultimately unknowable; their estimated values; and their theoretically coherent values. Consider the risk averseness of investors as an example. In theory, there exists a correct parametrisation of this risk averseness, though we cannot determine it with complete accuracy. Hence we have to resort to an estimation of it, both in how it's modeled (e.g. using the conditional value at risk or a hurdle rate) and the model's parameter values. The risk averseness of investors is however undesirable, as the lack of hedging instruments is a market imperfection which prevents reaching the optimal level of adequacy [9]. Its theoretically coherent value then is that investors should be risk neutral.

As illustrated in Figure 1, the theoretically coherent parameters (which we will refer to as simply ‘theoretical’ from now on) are used when calculating the reliability standard as might be expected. The principal contribution of this paper is to show that theoretical parameters, namely storage operation, should also be used in the rest of resource adequacy framework, namely in the adequacy assessment.

It is useful to further differentiate parameters by their source: behavioural parameters such as storage operation can be influenced while physical ones cannot (anthropocene notwithstanding). Furthermore, behavioural parameters can be separated into those coming from market participants and stakeholders. The former are principally influenced by decisions made or parameters chosen by stakeholders such as policy makers.

In this paper we will analyse the coherency of the resource adequacy framework through storage operation. It is a behavioural parameter determined by market participants and influenced by stakeholders. Theoretically coherent operation prescribes a depth minimising behaviour MDP (see Figure 3a) as we have shown in a working paper [6]. This is equivalent

[1]The alert reader will note that there is no interaction between the realised adequacy of the power system and the resource adequacy framework. To the best of our knowledge this is the case and there is no formal feedback process such as backcasting adequacy asssessments.

to the-interpretation of the LOLE by [10] as the LOLE which would occur ignoring the "set of stores which ... are empty at the end of the shortfall period."

TABLE I: Categorisation of parameters used by processes in the resource adequacy framework.

Type	Example(s)
Categorisation by value	
Theoretically coherent	Investors are assumed to be risk neutral
Estimated	Best estimate of investor risk aversion
Actual	The actual investor risk aversion
Categorisation by source	
Behavioural	Storage operation, price cap
Physical	Weather, technical limits of power plants
Sub-categorisation of behavioural	
Market participants	Storage operation, investor risk aversion
Stakeholders	Policies and regulations e.g. price cap

Paul Joskow states that "the goal of a well functioning market should be to reproduce the ideal central planning results" [8]. This is the position implicitly adopted by ACER in its methodology [1] and the vision which has guided the building of this resource adequacy framework. It implies that the framework is internally coherent if it achieves this goal. The framework is considered necessary because of market imperfections which would lead to deviations from the central planner solution, such as investor risk aversion coupled with the inability to effectively hedge investment risks and inflexible electricity demand [9].

III. Single scarcity event model description

The single scarcity event model we will use is illustrated in Figure 3. The LOLE depends on the resources added, firm capacity (k) and storage (ec); whether depth (MDP) or duration minimising (MDR) storage operation is chosen; and

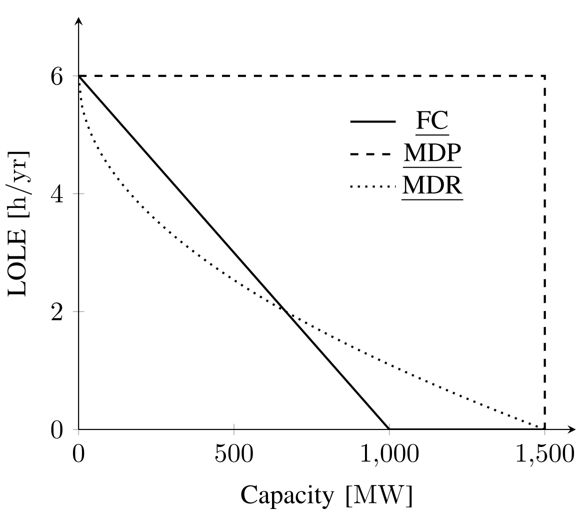


Fig. 2: Plot of LOLE as a function of firm capacity (FC) or storage capacity (MDR and MDP).

the characteristics of the scarcity event in the absence of additional resources, namely the duration D and the depth P. The expressions for LOLE are then:

$$LOLE_{\underline{FC}} = \begin{cases} D \cdot (1 - \frac{k}{P}) & \text{if } k < P \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$LOLE_{\underline{MDR}} = \begin{cases} D - \sqrt{\frac{2 \cdot D \cdot ec}{P}} & \text{if } ec < D \cdot P/2 \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

$$LOLE_{\underline{MDP}} = \begin{cases} 1 & \text{if } ec < D \cdot P/2 \\ 0 & \text{otherwise} \end{cases} \tag{4}$$

The resulting LOLE for differing amounts of resource added is plotted in Figure 2 assuming a 2 h duration of storage.

The expressions for Expected Energy Not Served (EENS) are shown below with no distinction between storage operation:

$$EENS_{\underline{FC}} = \max(LOLE_{\underline{FC}} \cdot (P - k), 0) \tag{5}$$

$$EENS_{\underline{MDP,MDR}} = \max(D \cdot P/2 - ec, 0) \tag{6}$$

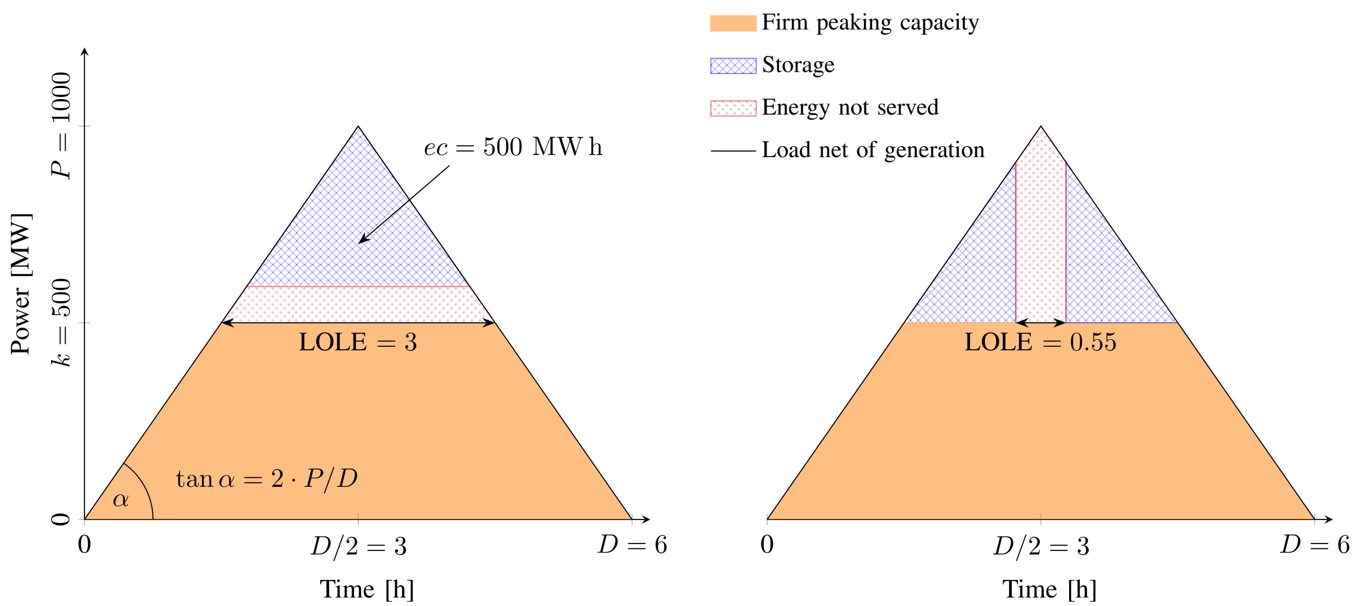
IV. Illustrative example

In this section we will describe a 'runthrough' of the resource adequacy framework described in Figure 1 in which we make two different assumptions on storage operation during the adequacy assessment. We will see how one leads to a coherent solution and the other not.

Consider the following scenario. The baseload, renewable and storage capacity of our power system are optimal and all that remains is to determine the amount of firm peaking capacity that is required.We will analyse the coherency of the EU's resource adequacy framework using the single scarcity event model from Section III, assuming a duration of 6 h, a peak load net of generation of 1 GW and 500 $\mathrm{MW\,h}$ of 2 h duration storage. We will further assume that market conditions are estimated to dictate a duration minimising storage behaviour, MDR. The actual storage behaviour is unknown and so we provide the range of possible LOLE realisations.

In the absence of peaking capacity, the LOLE is 6 $\mathrm{h/yr}$. The cost of peaking capacity is 60 $€/\mathrm{kW/yr}$ and the VOLL is 20 $€/\mathrm{kWh}$, giving a reliability standard or optimal LOLE of 3 $\mathrm{h/yr}$as calculated according to Eq. (1) (recall that a a depth minimising strategy MDP should be assumed for the reliability standard calculation [6]). The operation of the optimal system during scarcity is illustrated in Figure 3a.

In our example it is easy to see that 3 $\mathrm{h/yr}$ of LOLE requires 500 MW of firm peaking capacity assuming a depth minimising storage behaviour. If we assume a duration minimising behaviour we would incorrectly deduce that we need 91 MW of peaking capacity from our adequacy assessment. This is less than the 333 MW which our economic viability check says would be invested in anyway, so no adequacy issue would be detected.



(a) Load shedding depth minimising storage strategy MDP

(b) Duration or LOLE minimising storage strategy MDR

Fig. 3: Single scarcity event model used to illustrate the issue of coherency. The numerical values are the same as those in the ideal case described in Section IV.

The above conclusion is at odds with the European perspective on adequacy assessments, which is that they simulate market behaviour [2]. This is because we had to assume a different storage operation in our adequacy assessment than that which would happen in a market situation to be consistent with our reliability standard calculation. To ensure coherency, it appears that the stated purpose of a European adequacy assessment is therefore incorrect.

The examples above are summarised in Table II. What is striking is that in the coherent example the realised LOLE would be at most equal to the ideal LOLE.

We will briefly comment on the role of the economic viability check and CRMs. Regarding the former, the goal of this is to make a best estimate at the amount of capacity that would be invested in under market conditions. Here we've represented market imperfections through a price cap which is below the VOLL of 15 €/kWh. This gives 4 h/yr in which the price cap is reached and therefore 333 MW of peaking capacity. We've made the distinction between the LOLE and the number of hours in which the price cap is reached since the former is affected by storage operation while the latter is not necessarily. Concretely, we assume that energy limited storage will always set the price at the price cap if it is fully discharged by the end of what would otherwise be a moment of scarcity.

In our example we assumed that our CRM works perfectly and makes exactly the right amount of additional peaking capacity viable. In practice, storage operation affects its own capacity credit if this is calculated not based on EENS [7]. If the capacity target is the equivalent firm capacity required to reach the target LOLE and storage can participate in the CRM then the assumed storage operation should be depth minimising to be consistent with the reliability standard calculation. If the capacity target is based on EENS (which is not an output of the reliability standard calculation) then the capacity credit of storage is insensitive to storage operation and this problem is resolved.

V. Concluding Remarks

In this paper we showed how the European resource adequacy framework may be incoherent if taken at face value. Specifically we gave an example of adequacy assessments emulating market conditions (as they are meant to do [2]) and the resulting storage operation meant that an adequacy issue was missed.

This issue arose because the reliability standard calculation implies a certain type of storage operation or at least a different interpretation of the LOLE. A similar reasoning is made in [3] for the case of interconnectors, where to ensure coherency "hours where additional domestic capacity could have decreased lost load in the neighbor country should also be counted as lost load hours." Here too there is a disconnect between the LOLE that arises from the reliability standard calculation and the realised loss of load hours. This issue therefore relates to interconnectors as well as storage or energy limited resources more generally.

The question remains how to heal this disconnect. Our coherent example would require changing the definition of what an adequacy assessment does to accomodate the 'ideal', depth minimising storage behaviour. It is unclear what a clear and concise definition of an adequacy assessment should be in

TABLE II: Examples of (in)coherent parameter choices when running through the resource adequacy framework described in Figure 1. Recall that a parameter choice is coherent if it results in the same power system, in terms of peaking capacity, LOLE and EENS, as in the ideal case given by the reliability standard calculation. Assuming a storage operation other than MDP in the adequacy assessment stage would be incoherent, as it is inconsistent with the reliability standard calculation. The actual storage operation is unknown so we provide the range of possible LOLE.

Part	Output	Coherent	Incoherent
I. Reliability Standard (RS)	Storage operation	MDP	
	Ideal peaking capacity [MW]	500	
	Ideal LOLE [h/yr]	3	
	Ideal EENS [MW h/yr]	250	
II. Economic Viability Check (EVC)	Storage operation	Not applicable	
	# of hours in which price cap is reached	4	
	Viable peaking capacity	333	
II. Adequacy Assessment (AA)	Storage operation	MDP	MDR
	Modeled LOLE [h/yr]	4	1.5
	Modeled EENS [MW h/yr]	833	833
III. Capacity Remuneration Mechanism (CRM)	Storage operation	MDP	
	Additional peaking capacity made viable [MW]	167	0
IV. Power System	Storage operation	Unknown	
	Total peaking capacity [MW]	500	333
	Range of possible realised LOLE [h/yr]	0.55 - 3	3.55 - 6
	Realised EENS [MW h/yr]	250	2,500

this case. Another possibility is to adapt market incentives to match the assumptions in the reliability standard calculations, in other words ensure that storage operators choose a depth minimisation approach.

A more drastic approach would be to exogeneously impose the LOLE, thereby scrapping the reliability standard calculation as well as the need for consistency with it. However, there are numerous benefits to the reliability standard calculation as it is now done in the EU such as transparency, a consistent approach across highly interconnected member states and an (imperfect) attempt at maximising economic efficiency.

While we illustrated how a careless choice of storage operation could lead to an incoherent framework, we did not make an attempt to quantify the magnitude of the effect of storage operation. This was the subject of a previous work [7] in which we showed that storage operation could vary the LOLE betweenn 6 and 2 h/yrfor a stylised Belgian power system. The numerical values we obtained in our toy example, in which the LOLE could vary by approximately 3 h/yr, are not therefore unreasonable. This suggests that regulators and policy makers should take note of this issue. As a very first step they should ask for transparency on how energy limited resources (such as short-term storage) are operated within adequacy assessments such as the European Resource Adequacy Assessment (ERAA) [2]. A sensitivity analysis on the LOLE for two or more types of energy limited resource operation could then be used to determine whether the issue of incoherency discussed here is worth addressing and how.

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