The Electricity Journal 31 (2018) 51–55

Contents lists available at ScienceDirect

The Electricity Journal

journal homepage: www.elsevier.com/locate/tej

The economics of electricity adequacy

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ARTICLE INFO

Keywords:
Economic adequacy
Value of lost load
Capacity benefit
Expected unserved energy
Contingent value surveys
Interruption costs
Loss of load probabilities

ABSTRACT

Control areas around the world use a variety of methods to ensure that resources added to meet future electricity loads create an adequate supply. This work describes a particular method for determining adequacy based on economic costs and benefits that applies equally well to dispatchable and nondispatchable resources. Analysis of the Northwest power supply indicates that energy efficiency and demand response may be the most cost-effective capacity resources for achieving an economic adequacy standard.

1. Introduction

Ensuring the continuity of electricity service is a key objective for preserving the well being of residential customers and protecting the viability of businesses. Historically, many different approaches have been used by power planners to ensure a particular level of electricity adequacy, some of which include setting targets for reserve margins, for loss-of-load probabilities, or for loss-of-load expectations. But as the world incorporates increasing amounts of renewable energy, the task of determining electricity adequacy has become more challenging. This work explores one general method for setting an adequacy standard based on economics that is suitable for both dispatchable resources, such as gas plants, and for nondispatchable resources such as energy efficiency, wind, and solar.

Any power planning exercise involves decisions about whether to purchase a generating resource or a demand-side resource such as energy efficiency or demand response. It makes economic sense to purchase resources only if the benefit of doing so outweighs the costs. Many costs and benefits need to be considered in this calculation including the value of reducing expected load loss. This approach provides a framework for achieving economic adequacy in an electric power system.

2. A general model

While the economic criteria for electricity adequacy is no more complicated than costs and benefits, the model is complicated by definitions and terms that are unique to the power industry. One of the key variables is the value of lost load (VoLL), which measures the impact of electricity curtailment on businesses and households. The magnitude of these impacts, measured in dollars per megawatt-hour, is defined as the VoLL. The VoLL is technically the *cost* per megawatt hour of interrupting electrical service but in the decision to acquire a resource it represents the *benefit* of *avoiding* a curtailment. A resource with any amount of capacity value will reduce curtailments and thus contribute a capacity benefit. These and other benefits can be compared to the levelized annual costs of the resource to determine if the resource is cost-effective and if so, how much should be acquired.

For any complex power system there may be episodes when loads exceed generation, resulting in load loss. The total energy (megawatt-hours) associated with these loss-of-load events summed over an entire year represents expected unserved energy (EUE). Adding a unit of a new resource with some capacity value, whether it is a power plant or energy efficiency, will reduce the EUE.

Therefore, the capacity benefit (in dollars) represents the value of energy that is no longer curtailed when a resource is added to the system, equal to the product of VoLL and the reduction in EUE.

$$\text{Capacity Benefit} = \text{VoLL} \times \Delta\text{EUE} \tag{1}$$

Other benefits and costs of a new resource must also be considered. In addition to reducing load loss, a resource can also supply energy that is valued by the market price. The expected annual revenue from energy is a second and distinct benefit, defined as the energy value (E),

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https://doi.org/10.1016/j.tej.2018.05.003

also measured in dollars. Two important costs include the annualized capital cost (C) and the annual operating cost (OC).[1]

In principle, a unit of a resource will be economical as long as the lifetime benefits exceed the lifetime costs or, when calculated on an annualized basis,

$$[\text{VoLL} \times \Delta\text{EUE}] + \text{E} > \text{C} + \text{OC} \tag{2}$$

Defining the net capital cost (NCC) as the annualized capital cost (C) less the net operating profit (E-OC) results in a new condition. The unit of the resource is economical as long as the capacity benefit is greater than the net capital cost.

$$\text{VoLL} \times \Delta\text{EUE} > \text{NCC} \tag{3}$$

where NCC = C – (E-OC)

An optimum strategy is to purchase units of the resource up to the point where the capacity benefit equals the net capital cost. Acquiring any more units of the resource would not be cost-effective since the costs for the incremental unit outweigh the benefits. In this case, the demand for a capacity resource is represented by the capacity benefit and the supply is represented by the net capital cost.

$$\begin{array}{ll} \text{VoLL} \times \Delta\text{EUE} & = \text{NCC} \\ \text{Demand} & = \text{Supply} \end{array} \tag{4}$$

3. Supply and demand for a capacity resource

A key variable in the demand for a capacity resource is the change in expected unserved energy (ΔEUE) resulting from an additional unit of resource. EUE can be assessed using a Monte Carlo computer program that simulates the operation of the power supply under thousands of different possible future conditions. The model records all simulated curtailment events, which can then be ranked by magnitude (megawatts) from highest to lowest, as shown in Fig. 1.

The energy lost during each event is equal to the megawatts (MW) multiplied by the number of hours (h), which is equal to the area of each rectangle in Fig. 1. In Fig. 2 the curtailment events are represented as a continuous function and the area below the curve is the expected unserved energy (EUE) measured in MWh.

The next step is to add one unit of a resource such as a gas turbine generator or a portfolio of energy efficiency and measure the change in expected unserved energy, as represented in Fig. 3.

Each unit of a resource added should reduce the expected unserved energy. Furthermore, it is expected that as each unit is added, the benefit in reducing unserved energy will be smaller. This is because each unit reduces the number of curtailment hours and events, leaving less potential benefit for the next unit. The relationship should look something like Fig. 4.

Two steps remain to derive the demand curve. That is, multiply the change in expected unserved energy (ΔEUE) by the value of lost load (VoLL) and convert to a continuous function. The result in Fig. 5 is the demand for a capacity resource.

The supply of capacity is represented in Eq. (4) as the net capital cost. Although annual capital costs should be constant it is possible that energy sales will decline with additional units, which would tend to increase net capital cost.[2] Therefore the expectation is that the supply curve is relatively flat or upward sloping as represented in Fig. 6. In this figure the optimum number of units is U*. To invest in more units than U* would result in costs greater than benefits and would not be economical.

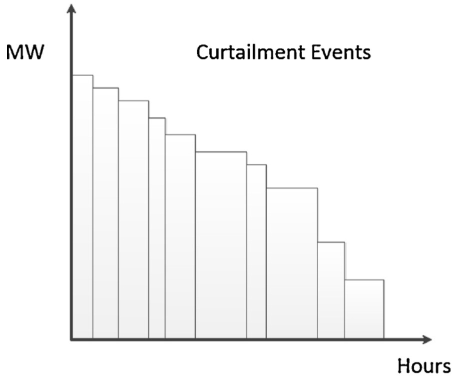

Fig. 1. Curtailment events.

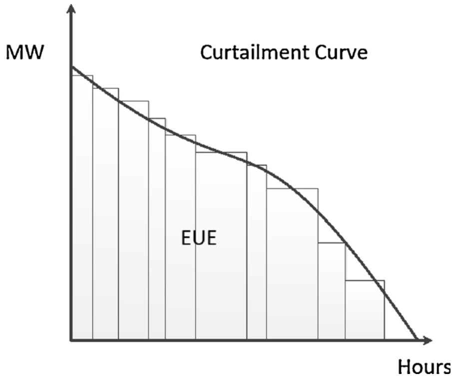

Fig. 2. Curtailment curve and EUE.

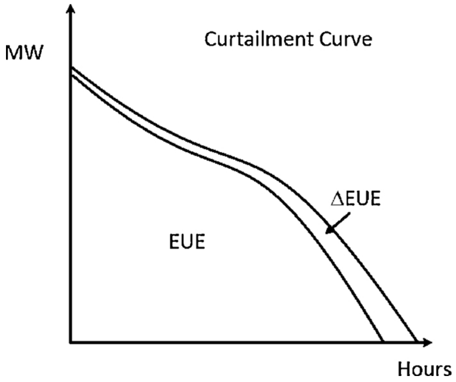

Fig. 3. Curtailment curve and the change in expected unserved energy.

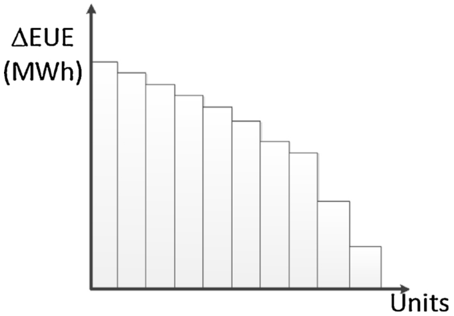

Fig. 4. Change in expected unserved energy per unit of a new resource.

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[1] Operating costs include the cost of producing output for both energy and capacity. Capital and related fixed costs are discounted and summed to a present value, which is then annualized for comparison to annual benefits over the life of the resource.

[2] When the market is particularly large relative to the size of resource units, the NCC curve will be flatter since energy sales are likely to fall off more gradually with the addition of more units.