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Capacity value estimation of a load-shifting resource using a coupled building and power system model

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HIGHLIGHTS

- The load-shifting resource examined provides a generation adequacy contribution.
- Load shifting resources may have user constraints that impact CV.
- The resource's capacity value could be 26% for the given year but is usually lower.
- The capacity value is impacted by operational constraints and occupancy profiles.
- Results indicate the need for more analysis to identify valuable DR resources.

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ABSTRACT

Understanding the contribution a resource can make to the power system could indicate where its value lies. This paper estimates the capacity value of a load-shifting resource which is capable of providing multiple services. The capacity value represents the contribution of a resource to generation adequacy and an understanding of this contribution is important to compare how different power system resources can assist power system operators and planners. Additionally, policy-makers and market operators need an appreciation of the capacity value of different resources in order to design capacity remuneration mechanisms. A building energy model coupled with a power system model, co-optimizing the supply-side and the demand-side, is employed in this paper to estimate the capacity value of a specific load-shifting resource. The resource examined is electric thermal storage heating devices for space and water heating. Ireland is used as a test case. It was found that these load-shifting devices can provide an adequacy contribution to the power system and thus have a capacity value. The capacity value, for the Irish case, can be up to 26% for the DR resource in question for the given year but the values are typically much lower due to operational constraints (reserve provision) and due to occupancy profile impacts. The results highlight the need for holistic modeling of demand response resources, as well as the need for additional work for different load-shifting resources and more data.

1. Introduction

Interest in demand response (DR) has been increasing in recent years and a large number of programs are being developed and deployed. This interest stems from the ability of DR to change the energy usage of customers from normal consumption in response to events on the power system or to varying electricity prices over time [1]. DR can thus potentially reduce system operating costs by load shifting or by reducing load at peak hours and can postpone investment in new generation [2]. DR is also in a position to provide ancillary services [3–5] and by providing ancillary services, DR could be capable of assisting with the integration of large penetrations of variable renewable energy [6,7].

In addition to providing energy and ancillary services, DR has been shown to be capable of providing capacity. Indeed, according to [8], in PJM Interconnection, over 90% of the revenue earned by DR is from the capacity market, highlighting the potential importance of the capacity market for attracting DR investors. While the provision of capacity is just one of the value streams attributable to DR, it could be key for DR participants.

There is a trend in the research community, the literature and within the energy industry to describe DR as a very valuable resource and therefore a lucrative business proposition [9–12]. Indeed, according to [13], peak-shifting in the US in 2019 could be worth $16 billion, annually. However, there has been a lack of

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Nomenclature

Indices

arch	building archetype
elec	electrical output
g	conventional generators
h	hydro generators
heat	heat output
REQ	requirements
space	refers to space heating devices
t	timesteps
water	refers to water heating devices

Parameters

η	efficiency
$COST$	marginal cost of operating generator
DEM_{BASE}	system demand minus heating requirements
E_{MAX}	installed energy capacity of DR resource
P^{MAX}	installed capacity of generator
$P^{space,t}_{heat,REQ,arch}$	space heating requirement in archetype arch at time t
$RATING$	power rating of DR resource
$VOIR$	Value of Insufficient Reserve
$VOLL$	Value of Lost Load

Variables

dem_{lost}	load shed
$dres$	downward reserve
e	energy storage
$LOLH$	Loss of Load Hours
$LOLM$	Loss of Load Magnitude
$losses$	losses from the DR resource energy component
p	power
$por^{t}_{dr,max}$	max POR available from the DR resource
por^{t}_{REQ}	POR requirement in hour *t*
por^{t}_{unmet}	POR unmet in hour *t*
U	binary variable for availability of generator

holistic analysis, across the system from demand and supply side, quantifying how valuable DR could be for both DR investors and for the end-user who is engaged in a DR program. This paper seeks to contribute to the discussion regarding the value of DR by determining one specific value, CV of a load shifting resource. While the results presented in this paper are for a single specific load shifting resource on a particular power system, it is a resource which is representative of many load shifting resources in that it has an element of storage associated with it, as well as user requirements to satisfy. An understanding of the capacity value would be of interest to potential DR aggregators and investors because, as noted by [14], a resource with a low capacity value also has reduced economic value.

Capacity Value (CV) represents the contribution a resource can make to generation adequacy [15]. Generation adequacy is the existence of sufficient resources on the power system to meet system peak load. CV (often also referred to as capacity credit) can be used as a means of comparing different generating resources in a transparent manner [16], ensuring they are compared on an equal footing. An understanding of the CV of DR is important because it can give an indication of the contribution of DR to the power system relative to other resources on the system. This would assist power system operators and planners equipping them with knowledge of the extent to which DR can be relied upon, now and in future generation portfolios.

It has been shown in previous work [17–20] that DR is successful in contributing to power system generation adequacy (by reducing system adequacy metrics) and thus must, by definition, have a CV. Consequently, on the assertion that DR has a CV and given that other power system technologies are often remunerated for the contribution based on their CVs [21], policy makers and market operators need an appreciation of the CV of DR in order to design technology neutral capacity remuneration mechanisms.

However, the CV of load-shifting resources cannot be assessed in a manner similar to the CV of thermal generation. This is because of the unique characteristics of load-shifting resources. Typically, load-shifting resources have an energy use constraint and their operational availability in one time period is contingent on previous and subsequent hours, which is similar to storage plants. Furthermore, while DR is very different from renewable generation, they do share some common characteristics. For example, like wind and solar generation, which are highly reliant on an uncontrollable meteorological phenomenon, load-shifting is dependent on an underlying resource which is largely driven by consumer demand behavior, and variable, although largely predictable if aggregated. Consequently, it is worth examining methodologies for estimating the CV of renewable resources in more detail. This is presented in Section 2, which reviews the literature and identifies the key contributions of this paper. Section 3 outlines the methodology employed in this paper while Section 4 details the test system and the specific case study examined in this paper. Section 5 presents the results of the study, with emphasis on the contribution of DR resource to generation adequacy and the effect the operation of DR resource can have on the aforementioned contribution. Section 6 summarizes and concludes the paper.

2. Literature review

A methodology for calculating the CV of wind is proposed in [15] which involves subtracting a time series for the wind power output from the system load giving a net system load profile. The method then follows the standard approach for determining the CV, using the net system load profile instead of the total system load. A very similar approach is employed to determine the CV of wave power [22]. Tidal barrage [23] and Concentrating Solar Power [24] are similar to wind and wave resources but also have an element of storage associated with them. In order to incorporate the operational issues associated with the storage component, explicit modeling of the resource operation is required. A time series of the device operation is generated and incorporated with the approach in [25] as negative demand, similar to the approach used for wind power in [15].

DR is in a position to provide multiple services and the intrinsic relationship between these services necessitates that they be analyzed holistically. This concept refers to the need to analyze DR services simultaneously and in the context of the wider power system. It is evident that, in order to assess the CV of load-shifting resources, an approach incorporating the operational and time-dependent characteristics of the resources, as well as the end-user requirements and the physical characteristics of the resource, should be employed. Additionally, in order to determine the impact the interactions of the DR resource with power system can have on the CV of such a resource, a model of power system operations is paramount.

Despite the fact that there have been significant contributions to the literature in the area of demand-side contribution to generation adequacy [17,18,20], all of these fail to incorporate supply-