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How do demand response and electrical energy storage affect (the need for) a capacity market?

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HIGHLIGHTS

- Impact of demand response-DR & electrical energy storage-EES in energy-only market.
- Analysing the impact of limited DR and medium-term EES on a capacity market-CM.
- Hybrid electricity market model allows realistic generation capacity investments.
- DR reduces the peak load which implicitly reduces requirements for the CM.
- Limited DR & medium-term EES lessens the case for a centralized CM.

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ABSTRACT

To ensure security of supply and incentivize reliable investment in generation capacity, capacity markets (CMs) have been implemented or are being considered. However, demand response (DR) and electrical energy storage (EES) also contribute to system adequacy. In this paper, we analyse the change in the need for a CM if DR and EES are available, in the presence of a growing portfolio share of intermittent renewable energy sources electricity (RES-E). We present a novel hybrid electricity market model of the transition to a low-carbon electricity system which uses optimization for short-term market operations and agent-based simulation of long-term decisions.

DR and EES may significantly reduce the risk of shortages in an energy-only market, even if investment decisions are myopic, like in our model, as compared to an energy-only market without flexibility options. We also present a novel mechanism for contribution of EES to the CM. This reduces the cost of the CM and improves the business case for EES. In our model, DR and EES achieve almost the same improvement of security of supply as a CM, but they do so at a lower cost. Therefore, the case for a centralized CM is weakened in a system with even a limited share of DR and medium-term EES, as presented in our model. These results depend on the duration of scarcity events and the cost of EES and DR. Refinement of the model representation will be required to extrapolate these conclusions to real markets with other types of DR, EES and CMs.

1. Introduction

1.1. Motivation & research objective

Transitioning electricity systems with a growing share of intermittent RES-E in the supply mix[1] increase the need for flexibility options like DR and EES in order to contribute to system adequacy. The European Commission [1] recommends that flexibility options like DR and EES should be considered to contribute to system adequacy. Capacity remuneration mechanisms (CRMs) ensure adequate level of generation capacity, provide adequate price signals for investment in generation capacity and facilitate the development of RES-E. Concerns that CRMs such as CMs [2–3] may be inefficient and distort trade between member states [1], gave rise to the question that to what extent flexibility options like DR and EES can reduce the need for a capacity mechanism such as CM. This question is addressed in this paper, together with a second question that emerged as part of this research, namely whether and how DR and EES should be remunerated by a CM.

We use EMLab-Generation, a hybrid agent-based – optimization model with agents making investment decisions to maximize future

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[1] Supply mix is the group of different energy sources from which electricity is produced.

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profits in an isolated uncongested electricity market (based on the Netherlands), including an endogenous CO_2 market and EES investment [4–7]. As our objective is to present a novel method for understanding the policy implications of DR and EES in an electricity system with a CM, we need to be able to model intertemporal constraints required for DR and EES. The existing version of model used in this paper and in past research did not have this functionality, as it used a load duration curve to clear the electricity market. Furthermore, we required a mechanism that enables EES to receive capacity credits in the CM. So we modified and extended EMLab-Generation, in order to improve the representation of short-term market dynamics, particularly intertemporal dependencies.

The core of the model, the electricity market clearing algorithm, has been changed entirely. The current model utilizes hourly demand data (time-series) instead of the previous load-duration curve and minimizes the cost of generation, carbon credits, EES and DR over the year. This enabled us to add intertemporal effects to the model, which are needed to assess the impact of intermittent renewables better and implement DR, EES and CO_2 market endogenously. Various modules of the model, including the power plant dismantlement, investment, the CM, bidding and annual payments (for electricity, capacity credits, carbon emissions credits, fuel) were modified/extended in order to respond to the detailed inputs/outputs from the hourly market clearing. An EES investment module was also added in order to better understand the business case for EES in the long term. Furthermore, we also present a mechanism for enabling the participation of EES in the CM to study its impact. We analysed six experiments with different combinations of policy instruments. Stochastic electricity demand growth and fuel prices trends were used in all experiments. Using this novel approach, we analyse an electricity market (with and without flexibility options), CM (with and without EES), and an investment market to study the transition of the power system with optimization and agent based modelling.

In the following sub-section, we review relevant literature and summarize how this paper contributes to the literature. Section 2 describes the methodology & modified hybrid version of EMLab-Generation, implementation of DR, EES, CM, generation capacity & EES investment along with input data and data analysis. Section 3 describes the experiments design. In Section 4, we discuss the model limitations and assumptions. In Section 5, we discuss and analyse the results along with sensitivity analysis and policy recommendations. The conclusions are discussed in Section 6.

1.2. Literature review

Past research has highlighted the importance of CRMs in light of social welfare loss, the missing money problem and decrease in resource adequacy, due to structural weaknesses in liberalized electricity markets. For example, generation adequacy challenges posed by the liberalization of electricity markets [8]; market failures and market barriers that prevent reduction in consumer costs [9]; the advantages and disadvantages of different CRMs [10]; a lack of adequate investment in generation capacity in liberalized markets [11]; the impact of market power abuse [12]; failure of reformed competitive electricity markets to reduce consumer costs and provide reliable supply [13]; challenges and alternatives for achieving long term security of supply in competitive wholesale electricity markets [14]; challenges for competitive wholesale and retail electricity markets to maximize social welfare and ensure adequate generation capacity investment programs [15]. Considering these issues, designs for optimal power/energy markets [16] and dynamic approaches to CRMs in competitive electricity markets [17] have been proposed.

Many countries have already implemented CRMs, including Spain [18–19], Germany [20], France [21–23], the UK [24] and the USA [25] or are planning to implement them. The performance of various CRMs has been studied and analysed. The Regulatory Assistance Project [26] discusses the compatibility challenges between market coupling and CMs. Rodilla and Batlle [27–28] discuss the failure of energy-only markets to ensure security of supply, making a case for implementation of CRMs. Finon [29–30], Newbery and Grubb [31–32] discuss the challenges in implementing an integrated European electricity market and coordinating CRMs. CMs and issues of generation adequacy are discussed and analysed by: Batlle and Rodilla [33], Cepeda and Finon [34], Cramton and Stoft [35], Genoese et al. [36], Vazquez et al. [37], Bhagwat et al. [38], Bothwell and Hobbs [39], Bushnell et al. [40], Höschle et al. [41], Fraunholz et al. [42], Zimmermann et al. [43].

The participation and the potential of DR in electricity markets has been discussed by many [44–48]. DR significantly contributes to US electricity markets through wholesale and retail DR programs by curtailing/shifting load [49–50]. PJM power system allows for DR participation in the wholesale day-head spot market trading [51]. Walawalkar et al. [52] give detailed insights on the impact of DR participation in PJM and NYISO electric power systems and the opportunities present for optimal DSM. DR has been included in CMs in PJM, ISO-NE and NYISO in the US through various programs [49,52–53]. Consumers are incentivized to curtail/shift consumption during summer (e.g. PJM) or winter (e.g. NYISO) peak load hours [3,54]. Genc [55] analyses the impact of DR on hourly electricity prices in the Ontario electricity market. Aalami et al. [56] summarize the participation of DR through load shifting/curtailing in various CM programs in the US and its impact on reducing consumer costs.

The potential of DR in Europe has been assessed by, among others, Finn and Fitzpatrick [57], Gils [58] and Warren [59]. Torriti et al. [60] discuss the experiences of UK, Italy and Spain with understanding the constraints as well as initiatives and policies for DR. A demand-based electricity distribution tariff in the residential sector has been introduced for increased DR in order to fully exploit the Swedish power system in intra-day market [61]. The Electricity Balance Adjustment Service or Elbas market has also allowed for DR trading in the intra-day market in Scandinavia [62]. The NEBEF mechanism in the French power system also allows trading of DR in the day-ahead market [23]. Eid et al. [63] summarize the participation of DR for electric flexibility trading. The impact of participation of DR in the German balancing mechanism has also been quantified by Koliou et al. [64]. The French power market is foreseeing DR trading in CMs in 2018 [65]. While the western countries are racing towards increased DR, Asia and the middle east represent the new frontiers for DR programs [66–68].

The participation and the potential of EES in electricity markets has also been discussed by many, focusing on two aspects: its importance in market economics and the value of EES to the power system [69]. Zakeri and Syri [70] present a comprehensive study on the comparative life cycle costs of various EES. The results show that the costs of deploying large-scale EES systems in electricity markets is too high and the business case of EES on utility scale is weak. However, vigorous research to bring these costs to a feasible level are underway, which leaves room for optimism for inclusion of utility-scale EES in future. Dunn et al. [71] discuss the available choices of batteries, suitable for storing electricity. Lithium is the material of choice for making efficient batteries [72–73]. Nevertheless, in order to realize a flexible and efficient liberalized electricity market, the importance of EES is widely recognized [70]. EES can charge during off-peak hours and discharge during peak hours to benefit from the price arbitrage in the intra-day and day-head market [74–76]. With integration of increased amount of intermittent RES-E, the spot market prices will become more volatile. This gives an opportunity for price arbitrage, adding to the profitability of EES [76–77]. The need for EES has been emphasized, even in the presence of a perfect transmission and distribution grid [78].

Various methods have been presented for analysing hybrid power systems, leading to a better understanding of participation of EES [79–82]. The potential of deploying large-scale EES in the PJM has been estimated and the results predict high revenues from spot market price arbitrage [83]. EES minimizes the effects of ramping, leading to more