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A system operator's utility function for the frequency response market

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HIGHLIGHTS

- Modelling the preference/utility function of a system operator in the market for electricity ancillary services.
- The utility function is combined of exchange rates in monetary values between different frequency response services.
- The exchanges rates are used in an auction mechanism to sell frequency response services.
- The mechanism delivers the welfare optimal mix of speed of frequency response and quantity to procure.
- We show that this mechanism is the efficient way to support new faster sources of frequency response.

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ABSTRACT

How can the electricity system operator determine the optimal quantity and quality of electricity ancillary services (such as frequency response) to procure in a market increasingly characterized by intermittent renewable electricity generation? The paper presents a system operator's utility function to calculate the exchange rates in monetary values between different frequency response products in the electricity system. We then use the utility function in a two-sided Vickrey-Clarke-Groves (VCG) mechanism combined of two frequency response products – enhanced and primary – in the context of the system in Great Britain. This mechanism would allow the market to reveal to the system operator the welfare optimal mix of speed of frequency response and quantity to procure. We show that this mechanism is the efficient way to support new faster sources of frequency response, such as could be provided by grid scale batteries.

1. Introduction

The electricity system is facing a significant challenge of renewables integration. Current EU28 targets for decarbonisation by 2030 would seem to imply renewable electricity shares of 50%+ by 2030, with massive reductions in the share of fossil fuels on the electricity system (to below 20%).[1] Ambitious reductions in carbon emissions will result in a large scale deployment of wind and solar generation in particular. The integration of a large share of renewable generation will increase the system requirements for non-energy electricity products (so called 'ancillary services'), such as reserve capacity, frequency response and reactive power, to maintain the stability of the electricity system.

The rise of renewables, combined with the decline of conventional fossil fuel generation, on the electricity system increases the requirement for new sources of ancillary services, such as frequency response, to maintain the reliability and security of the grid (by matching of supply and demand in real time at appropriate levels of power quality). Such ancillary services provide 'flexibility' to the system to respond to the intermittent weather conditions affecting the amount of renewable energy that is instanteously available (see [2]). Electrical energy storage facilities, such as lithium ion batteries or compressed air storage (hereafter denoted as suppliers), can provide the necessary ancillary services.

National Grid (NG) is the system operator (SO) in Great Britain (GB) and therefore, it is responsible for the reliability and security of the grid. It procures ancillary services for use in the everyday operation of the grid, such as reserve and frequency response, to avoid blackouts, interruptions and to manage peak demand. For instance, to deal with sudden generation loss, NG uses services like primary frequency response (PFR), which requires a supplier to deliver response in 10 seconds (10 s), and the newly designed enhanced frequency response (EFR), which is a service to deliver in 1 second (1 s). Each service is

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[1] See [1].

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designed to meet the different technologies in the market, e.g. batteries and interconnectors can deliver electricity in milliseconds, pumped storage in seconds, gas turbines in minutes and longer for coal-fired plants [3].

To ensure the reliability and efficiency of the system, the SO needs the right services to be delivered. However, what are the right services? A SO might have chosen to work with a 1 s service, 10 s service and/or 1 h service. Why not a 0.5 s service or a guaranteed delivery in 13 s? Current services may have been of interest to the majority of suppliers, but maybe these were the bigger ones or maybe they were the right services some years ago. As we are in a world of asymmetric information between the SO and the market, the selling mechanism needs to be able to test the market for the right services at each allocation procedure.

Just as the suppliers want to maximise their own outcomes, a SO wants to balance the system. The current market design does not allow the SO to express complex and consistent preferences to balance the system. What the SO needs is an opportunity to express its preference/willingness to pay (WTP). One way is to allow it to submit a utility function for the market to react to.

This paper presents a utility function of a SO. The function was created with GB in mind, but the idea can be applied to all countries. It connects two frequency response services (PFR and EFR) into one function and places monetary values on each of the services. It is built up in different scenarios, including different levels of demand and inertia. To simplify the analysis, we show (based on modelling discussed in the next section) that the exchange rate between PFR and EFR is 1.3 if demand is 60 GW, inertia is 4 s and we expect to have 500 MW of EFR available in the system. In other words, if the value of 1 MW/h of PFR is £8.2, then the price of 1 MW/h of EFR is 1.3 times greater than £8.2, hence, £10.7. In another case if demand is 40 GW, inertia is 3 s and we expect to have 500 MW of EFR available, the exchange rate is 3.5.

We then go on to show how the utility function can be applied in a two-sided Vickrey-Clarke-Groves (VCG) mechanism to sell ancillary services. The VCG has two important properties relevant to the market for ancillary services. First, the most convincing part of the literature defines the security and reliability of the electricity grid as a public good (e.g. see [4,5]). The selling mechanisms for ancillary services used today are not based on social welfare. Second, a step forward to ensuring the welfare optimum is allocatively efficient (hereafter efficiency), i.e. licencees to deliver electricity end up in the hands of those who value them the most. Current designs do not by themselves deliver efficiency. Without these two properties, the desired welfare optimum may not be achieved. The design in this paper also determines the optimal speed of frequency response by allowing the SO to express complex and consistent preferences over the different frequency response services it is simultaneously procuring (following [6]). This is the truly novel part of our design and involves the SO defining its utility function with respect to ancillary services products.

In a recently published consultation report, NG outlines its approach to a new design that can meet the challenges of the ancillary services markets [7]. The aim is for more flexible, but efficient markets. Firstly, NG wants the values of the inertia to be part of the frequency response market ([7], p. 10). Since the SO controls the size of the inertia, one may interpret this as NG's desire to work with a utility function. Secondly, NG states that new frequency response services are needed and these should be valued against existing responses ([7], p. 14). We interpret this as our vector of services. Lastly, NG questions the current auction design that is used to procure services. Designs that can optimise the use of technologies across markets are said to be of interest ([7], p. 36). The design presented in this paper is one such mechanism, which is emphasised with our vector.

There is a large literature on energy storage and how to integrate storage into the system, e.g. see [3,8,9]. With the increasing amount of new technologies, grid management has become more important than ever for a SO. One approach is to develop efficient algorithms to optimize the operation of enery storage, e.g. see [10,11]. Another approach is portfolio theory that allocates energy storage capacity in different markets, as used in [12]. If one transfers this to a vector made up of different markets, their design is similar to ours. However, they do not use auctions to optimize the grid and therefore, they do not use price signals to allocate the storage capacity.

Auctions have become massively popular in recent years, especially in energy markets and now in the balancing markets. The designs of auctions (as procurement mechanisms) in classic markets (such as for wholesale energy and capacity) are well studied. Ref. [13] study the VCG mechanism with the purpose of ensuring truth-telling, efficiency and maximum social welfare. They use the capacity market as an application for their mechanism. Ref. [14] have the same agenda as [13], but they focus on the spot market (for similar papers, see [15,16]).

The next step is to ensure an optimal outcome for the new balancing market. Ref. [17] analyse the use of double auctions for demand response (DR). They are *per se* not interested in an optimal method of controlling the DR, but to demonstrate the complexity of analysing the use of auctions and smart grid technologies. Among other things, they emphasise the importance of price signals from demand when managing the grid. Ref. [18] study bidding strategies for maximizing profits when bidding in both energy and balancing markets. The bidders are not given the opportunity to submit one bid that covers all markets. Ref. [19] study the optimal bidding strategy in the balancing market alone. However, they have their focus on ramping products and aim to maximizing the revenues from the energy and reserve markets. Compared to [18,19], our mechanism can cope with all balancing services in one design (it allows the bidders to submit one bid that covers all markets) and it has its focus on maximizing social welfare. It is a modified VCG mechanism built up to test the market for different responses, where a SO is part of the bidding process. The exiting literature does not allow the bidders and the SO to submit bids on different responses in one bid. Our framework allows us to test the market for the optimal responses, defined as where social value is maximised. The papers closest to ours are [6,20].[2] [20] present a methodology to connect the different types of frequency responses. The function they present is developed for the GB power system. However, a similarly calibrated function can work in other systems.

The contributions of this paper are as follows:

(1) We extend the methodology of [20] to create a function that delivers both the exchange rates in monetary values on PFR and EFR and the implied quantities. The methodology can, in theory, be extended to include all frequency response services.[3]
(2) The function gives a SO's values of at least two services, which we apply using the VCG mechanism presented by [6]. The mechanism of [6] is extended from the area of energy to create a market for ancillary services products that can be supplied by electrical energy storage.[4]

The rest of the paper is organised as follows: Section 2 discusses the need for further flexibility with the increased use of renewables. Section 3 presents a SO's utility function. Section 4 applies the utility function

[2] Our framework works for the sale of a single unit, multi-objects and packages, see [6] for single unit sale and [21] for multi-objects and package bidding. Package bidding could potentially deliver significant economies of scope for suppliers of balancing services if it is to be part of a future auction. A supplier should be able to reduce its cost with a package bid if winning to deliver. In today's design, a supplier can submit bids on more than one service, but it could also end up being asked to deliver only one of the service, hence, losing the chance of gaining from cost synergies. Several papers are interested in package bidding, e.g. see [22], [23], [24]. However, only the papers of [6] have a bidding framework that is similar to ours.

[3] In GB this would also include Secondary Frequency Response.

[4] [21] proves that the presented VCG mechanism maximises social welfare.