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Integration of flexible consumers in the ancillary service markets

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Flexible consumption devices are often able to quickly adjust the power consumption making these devices very well suited as providers of fast ancillary services such as primary and secondary reserves. As these reserves are among the most well-paid ancillary services, it is an interesting idea to let an aggregator control a portfolio of flexible consumption devices and sell the accumulated flexibility in the primary and secondary reserve markets. However, two issues make it difficult for a portfolio of consumption devices to provide ancillary services: First, flexible consumption devices only have a limited energy capacity and are therefore not able to provide actual energy deliveries. Second, it is often difficult to make an accurate consumption baseline estimate for a portfolio of flexible consumption devices. These two issues do not fit the current regulations for providing ancillary services. In this work we present a simple method based on the existing ancillary service markets that resolves these issues via increased information and communication technology. The method allows an aggregator to continuously utilize the markets for slower ancillary service to ensure that its portfolio is not driven towards the energy limitations resolving both the baseline issue and the energy limitation issue.

1. Introduction

The renewable energy sector is the fastest growing power generation sector and is expected to keep growing over the coming years [1,2]: the global share of non-hydro renewables has grown from 2% in 2006 to 4% in 2011 and is predicted to reach 8% in 2018 [2]. Many actions have been taken all over the world to increase the penetration of renewables: in the US, almost all states have renewable portfolio standards or goals that ensure a certain percentage of renewables [3]; similarly, the commission of the European Community has set a target of 20% renewables by 2020 [4].

A number of challenges arise as the penetration of renewables increases. Many renewable sources are characterized by highly fluctuating power generation and can suddenly increase or decrease production depending on weather conditions. A recent example of this phenomenon took place Denmark on October 28, 2013 where a large number of wind turbines were shut down because of a storm. This caused a decrease from a level where more than 100% of the Danish electricity consumption was covered by wind to a level less than 45% in just 2 h,[1] see Fig. 1. Such rapid production changes can imply severe consequences for grid stability due to the difficulty of accurately predicting the timing of the events [6].

Further, as more renewables are installed, the conventional generators are phased out: in Denmark, the increase of renewables during the last years has caused a petition for shutting down 8 central power plants [7]. This, however, causes another major challenge because the central power plants currently are the providers of system stabilizing ancillary services. As the conventional power plants are replaced with renewables, the ability to provide ancillary services in the classical sense is lost as the renewables usually do not possess the ability to provide such system stabilizing reserves: First of all, keeping renewables in reserve will entail that free energy is wasted making this a very expensive solution. Second, the highly fluctuating nature of the renewables caused by

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[1] Data taken from the website of the Danish transmission system operator: Ref. [5].

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0360-5442/

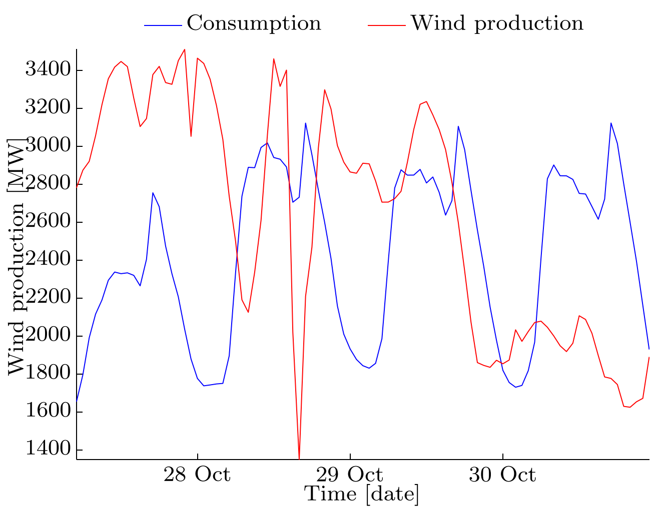

Fig. 1. Hourly consumption and wind production during 4 days in Denmark in end October, 2013. A storm hits Denmark in the afternoon on the 29th causing a large number of wind turbines to shut down resulting in a production drop of more than 2,000 MW in just 2 h.

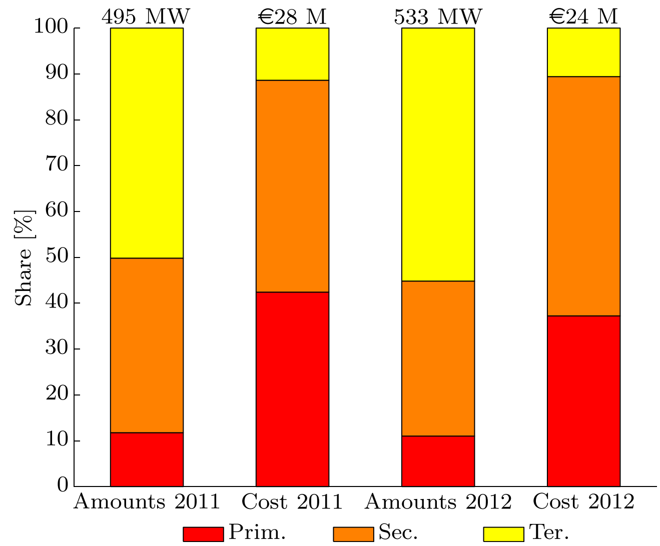

Fig. 2. Amounts and prices of traded primary, secondary, and tertiary reserves in Western Denmark in 2011 and 2012.

weather conditions can make it difficult to deliver a well-defined power response.

It is therefore evident that alternative sources of ancillary services must be established as renewables replace conventional generation. One approach to obtain ancillary services is to purchase reserves in neighboring countries; however, this requires that transmission line capacity is reserved for the reserve markets which will limit the capacity in the day-ahead spot markets and thereby possibly cause higher electricity prices [7]. Further, the ENTSO-E (European network of transmission system operators for electricity) grid code sets limits on the amount of reserves it is allowed to exchange internationally [8].

An alternative approach to obtain alternative ancillary services is the *smart grid* concept, where local generation and demand-side devices with flexible power consumption take part in the balancing effort [9,10]. The basic idea is to let an aggregator control a portfolio of flexible devices such as thermal devices, batteries, pumping systems etc. Hereby, the aggregator can utilize the accumulated flexibility in the unbundled electricity markets for primary, secondary, and tertiary reserves, on equal terms with conventional generators [11,12].

In this work, we identify the difficulties of including flexible consumption devices in the existing ancillary service markets and propose a method for better integration of this type of devices.

2. Scope and structure of the article

The increase of renewables and shutdown of central power plants call for alternative sources of primary, secondary, and tertiary reserves. This work proposes a method for making better conditions for flexible consumption devices to deliver these services. The method is valid for both the primary and secondary reserve, but not for the tertiary reserve, as will be come evident later. For the following reasons, we still believe the method is most relevant.

The first reason is that flexible consumption devices and storage systems are well suited for fast reserves but less suited for slower reserves where large amounts of energy must be delivered. Many consumption devices are able to deliver a response fast enough even for primary reserve [13,14]; however, they are not able to provide actual energy deliveries as they only have a limited energy capacity. A battery system will for example only be able to deliver/consume a limited amount of energy before reaching the energy limitations; similarly, a consumption devices with a given thermal mass will only be able to shift a limited amount of energy before reaching the thermal comfort limits [12].

The second reason is that although the amounts of required tertiary reserves is significantly higher than the required amount of primary and secondary reserves, the expenditure on primary and secondary reserve exceeds that of tertiary reserve by far. This is illustrated in Fig. 2 where 2011 and 2012 data for Western Denmark is analyzed.[2] The figure shows that the amount of tertiary reserve in 2011 and 2012 indeed is the highest of the tree comprising more than 50% and 55%, respectively, of the combined primary, secondary and tertiary reserve those years. However, as illustrated in the same figure, the expenditure for the tertiary reserve in these two years accounted for below 12% and 11%, respectively. The reason is the fast delivery requirements for primary and secondary reserves making it more difficult, and thus more costly, to provide these reserves.

Based on the observation that flexible consumers are well suited for fast reserves and because the value of these services is far greater than of tertiary reserve, it is chosen to limit the scope exclusively to primary and secondary reserves.

A portfolio of flexible consumption devices generally has two significant differences from conventional power generators when providing ancillary services. The first is that the portfolio will have a *limited energy capacity* whereas the conventional generator simply will be able to use more or less fuel. A heating system will for example have flexibility due to its thermal capacity; however, only a limited amount of energy can be stored depending on the temperature bounds that must be satisfied. Similarly, a factory may be able to expedite or postpone a batch production, but will in the long run have the same average consumption. This significantly limits the possibilities for flexible consumption devices to provide ancillary services. The second difference is that a portfolio of flexible

[2] Data for primary and tertiary reserve taken from Ref. [5] while data for secondary reserve is from Ref. [15,16]. Only the reservation prices are included, not the activation prices which only apply for secondary and tertiary reserves.