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Value of flexible consumption in the electricity markets

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ABSTRACT

A transition from an oil and coal based energy system to a systems based on renewable and sustainable energy sources has begun in many countries throughout the developed world. As a pioneer, Denmark currently has a wind energy penetration of 30% in the electricity sector and an end goal of 100% renewables in all energy sectors by 2050. The main elements in this transition are an increase in the wind energy production and electrification of main energy sectors such as transport and heating. Activation of flexible consumption in the electricity markets is believed to be one of the means to compensate for the growth of fluctuating renewables and the decrease of conventional power plants providing system-stabilizing services. In this work, we examine the requirements for flexible consumption to be active in the spot market and the regulating power market in the Nordic system and estimate the costs of entering these markets; further, we briefly describe the debated and planned changes in the electricity market to better accommodate flexible consumers. Based on recent market data, we estimate the revenue that flexible consumers can generate by market entry depending on the capacity of the consumers. The results show that consumers should have an energy capacity in the magnitude of 20–70 kWh to break-even in the spot market, while a capacity of 70–230 kWh is required in the regulating power market under current regulations. Upon implementation of the debated and planned market changes, the break-even capacity will decrease significantly, possibly to an energy capacity as low as 1 kWh.

1. Introduction

Many actions have been taken from a political point of view to increase the penetration of renewables throughout the world. A few examples are: renewable portfolio standards or goals that ensure a certain percentage of renewables in almost all states in the US [1], an energy target of 20% renewables by 2020 in the European Union [2], and an increase in wind power capacity in China from 1260 MW in 2005 to 62,000 MW in 2011 [3]. The Danish electric power system, which is the focus of this work, is a particularly interesting case with a wind energy penetration of 30% in 2012 and an expected 2020 penetration of 49.5% [4,5]. The end goal in Denmark is to phase coal out by 2030 and become 100% renewable in *all energy sectors* by 2050 [4].

The implementation of the Danish 100% renewable goal requires actions from the entire energy supply system [6–8]. One of the necessary steps is electrification of consumption from other energy forms [9]. This electrification has already begun: in recent years, 27,000 heat pumps have been installed in Danish homes [10], and additionally 205,000 households have the potential to benefit from replacing their oil-fired boilers with a heat pump [11]. Further, the Danish Government decided in 2012 to lower the taxes on electric heating to expedite electrification of the heating sector [12]. Similarly, electrification of the transport sector is planned: the Danish Department of Transport decided in 2012 on electrification of the railroad in Denmark [13] and a report from 2013 by the Danish Energy Association projects that electrical vehicles will become an attractive alternative to combustion engine vehicles in the following decades leading to an electric vehicle population of 47,000 in 2020 and 221,000 in 2030 [14].

This planned electrification and replacement of conventional power plants with renewables are crucial elements in the future 100% renewable energy system in Denmark. However, when conventional power plants are replaced with renewables such as wind turbines and photovoltaics, the ability to provide power balancing services in the classical sense disappears: the renewable energy sources will often fully utilize the available power and thus not be able to provide balancing ancillary services. Furthermore, conventional fossil fuel power plant generators are synchronous with the

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grid and therefore provide rotating inertia that supports the system frequency against changes [15]. As renewable energy sources typically interface with the grid via power electronics, they do not directly provide inertia to the grid as the conventional synchronous generators [16], which further increase the balancing challenges. Although recent works suggest that wind turbines can provide artificial inertia by regulating the active power output of the generator according to the system frequency [17,18], this type of control is generally not implemented in the wind power plants of today. Moreover, many renewable sources are characterized by highly fluctuating power generation: they can suddenly increase or decrease production depending on weather conditions. These rapid production changes are not always predictable and can therefore imply severe consequences for grid stability [19].

It is therefore evident that the transition towards a Danish 100% renewable energy system will lead to challenges of balancing the electricity supply and demand [7]. Already now, indications of balancing issues are seen in Denmark as evident from the following examples. Negative spot prices occurred in 24 h in 2012 at the electricity day-ahead spot market [20] even reaching the minimum limit of −200 €/MWh. Notice that the negative spot prices occurred in spite of Denmark being well interconnected with Germany (950 + 600 MW), Norway (1040 MW), and Sweden (1900 + 740 MW) [21]. Also, several wind turbines were requested to derate production for several hours on one occasion in December 2012 due to a combination of circumstances where high wind and CHP (combined heat and power) production collided with a holiday with low consumption.[1] These instances are indicators of the increasing balancing issues due to the growth in renewables. As a pioneer in utilizing fluctuating renewables such as wind power, Denmark is among the first places to experience these challenges; however, the rest of Europe can expect similar issues in the coming years [22].

2. Scope and structure of the article

As the wind penetration from fluctuating renewables increases, the need for balancing services will consequently also increase [23,24]. Alternative sources of balancing services must therefore be established as the conventional power plants are pushed out. One of the approaches to obtaining alternative balancing services is the *smart grid* concept, where flexible consumption takes part in the balancing effort [25,26]. This approach is supported by the ENTSO-E (European Network of Transmission System Operators for Electricity), who in a resent paper stated that demand side response is acknowledged as “a main contributor to more effective markets and to system security with a high penetration of fluctuating generation” [27]. Therefore, demand side response is included in the 2012 ENTSO-E network code [28]. In Denmark, the smart grid approach is supported by the Danish TSO (the Danish transmission system operator) and the Danish Energy Association, who have concluded that it is economically attractive to implement the smart grid concept in Denmark as a means to reach the 100% renewable goal. The main stakeholders have recommended a smart grid roadmap with the ultimate goal of having flexible consumption traded on a market place on equal terms with conventional production according to the deliberated electricity market setup in Denmark [29,30].

Control of flexible consumers to support grid stability has been discussed as early as the 1980s [31]. Since, the topic of demand-side management has received much attention from a research perspective [32–34]. Within the deliberated electricity markets, the *aggregator* or *VPP* (*virtual power plant*) concept has likewise been much discussed. The functionality of the aggregator or VPP is to aggregate and control flexible consumption devices whereby the accumulated flexibility can be sold in the electricity markets, as described e.g. in Refs. [35–38]. Examples of flexible consumption devices examined as power balancing resources are: domestic heat pumps [22,39–42], supermarket cooling systems [43–46], domestic refrigerators [47,48], electrical heating elements at CHPs [49,50], and electrical vehicles [51–54]. These existing works describe the effects of including flexible consumers in electric power balancing. Some of the works describe how utilizing flexible consumers will allow larger penetration of renewables, while the focus of other works are the possible electricity savings that can be achieved by selling balancing services. The works do, however, not discuss the requirements for such devices to enter the electricity markets, which is a crucial element in the Nordic liberalized system. Further, these works do not consider the costs associated with being active in the electricity markets.

In this work, we take the aggregator’s point of view and examine the Nordic electricity markets and describe the requirements for market participation of flexible consumption. In particular, we describe the requirements and identify the barriers for participation in the two largest markets: the day-ahead spot market and the regulating power market. Moreover, we estimate the costs of making devices able to participate in these markets. The main contribution of this part of the work is a short overview intended for potential aggregators and smart grid researchers in the Nordic countries, describing the core regulations that apply for market participation of flexible consumers. The background for this market overview is the existing regulations, technical documents, reports, and interviews with the Danish TSO.

Following, we describe how an aggregator can generate revenue via the flexibility of consumers by participating in the two examined markets, namely the spot market and the regulating power market. We present concrete methods for utilizing flexibility in the markets and estimate the revenue that can be generated depending on the power and energy capacities of the consumers. This revenue is compared to the previously found costs of enabling devices to be active in the markets. Hereby we are able to examine the capacity of a consumer required to make market participation attractive. To complete the conceptualization, we briefly describe the potential of some specific flexible devices: domestic heat pumps, supermarket refrigeration systems, and water purifying plants.

Notice, that this paper does not analyze the social benefit of utilizing demand response or examine how flexibility is best utilized. This while social benefit analysis is a most important topic [55–58], we instead take the aggregator’s point of view and examine the costs and potential benefits an aggregator can expect when entering the main electricity markets. This aspect gives an indicator of the state of the current markets with regards to the ability to accommodate aggregated flexible consumers. Also, it provides an easy overview to potential aggregators of the barriers and costs that can be expected upon market entry.

The structure of this work is as follows. First, in Sec. 3, a brief overview of the considered markets is presented; following in Sec. 4 and Sec. 5, we describe the requirements for participating in the day-ahead spot market and the regulating power market, respectively. In Sec. 6, we describe the main barriers for market entry and show the estimated costs of market participation. Following, in Sec. 7, we estimate the revenue flexible devices can obtain by being active in the spot market and the regulating power market and complete the comparison between expenses and revenue of market participation. Finally in Sec. 8, we conclude the work.

[1] Information based on e-mail correspondence with the Danish transmission system operator (TSO), Energinet.dk on March 22, 2013.