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A review of demand side flexibility potential in Northern Europe☆

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ABSTRACT

The number of regional and national power systems with a high share of wind and solar power in the world is quickly increasing. The background for this development is improved technology, decreasing costs, and increased concern regarding environmental problems of competing technologies such as fossil fuels. For the future there are large possibilities for increasing the renewable electricity share. However, variable renewable power production has to be balanced. Demand side flexibility offers an interesting approach to the balancing issues. The aim of this paper is to compare flexibility potentials and how they were estimated in seven Northern European countries in order to compare general challenges and results as well as the connection between used method and results. The total flexibility is estimated to 12–23 GW in a system with a total peak load of 77 GW.

1. Introduction

The world's total electric consumption is currently (2016) around 24,800 TWh per year [1] of which around 5.2% [1] is provided by Variable Renewable Energy (VRE), such as, wind and solar power. The increase in the 5 year period 2009–2014 is for solar power + 41% per year and for wind power + 17% per year [1]. In 2014 Spain covered 24% [2] of its electric energy demand with wind plus solar power. The corresponding figures were 21% for Ireland 25% for Portugal, and 45% for Denmark [2]. The impacts and integration efforts are, however, quite different for Ireland, an isolated system, and Portugal, Spain and Denmark which are part of larger electricity systems. For example Portugal, Spain and Denmark west are a part of the European continental synchronous region that has 10% wind and PV while Ireland is only asynchronously connected to UK.

For the future there is a high expectation for a continuous increase of variable renewable power. One example is the European decisions for 2020 and 2030, which means an increased target from 20% renewable energy sources (RES) for 2020 up to 27% for 2030 [3] with 29% RES in the electricity generation, potentially up to 35% [4]. With a high share of wind and solar power there will be situations with both very low availability of wind and solar as well as situations with high availability. A more detailed analysis of the challenges with a high share of wind power, including impact on adequacy, is available from [5] and its references.

The flexibility handled in this paper mainly considers the possibility to decrease demand in high load situations. This is one solution to the "adequacy" challenge. The Nordic Transmission System Operators (TSO) [6] have identified that "The share of wind power … is expected to triple in the period 2010–2025". Concerning "Generation adequacy" it is stated: "At the moment, low market prices represent one of the main challenges for the Nordic power system. Reduced profitability of conventional power generation will lead to lower capacity of thermal and nuclear power plants." And further: "Measures to address adequacy should be identified from a Nordic perspective". A preliminary estimation of the Loss of Load Probability (LOLP) in the Nordic system, c.f.

Abbreviations: RES, Renewable Energy Sources; LOLP, Loss of Load Probability; DSR, Demand Side Response; OCGT, Open Cycle Gas Turbines; DR, Demand Response; SFD, Single Family Dwellings; COP, Coefficient of Performance; CHP, Combined Heat and Power; VRE, Variable Renewable Energy; TSO, Transmission System Operator; AMR, Automatic Meter Reading; DH, District Heating; AC, Alternating Current; DC, Direct Current; FCR, Frequency-controlled operational reserve; DSO, Distribution System Operator; IPS/UPS, The Coordinated Power System consisting of Russia and 9 other countries

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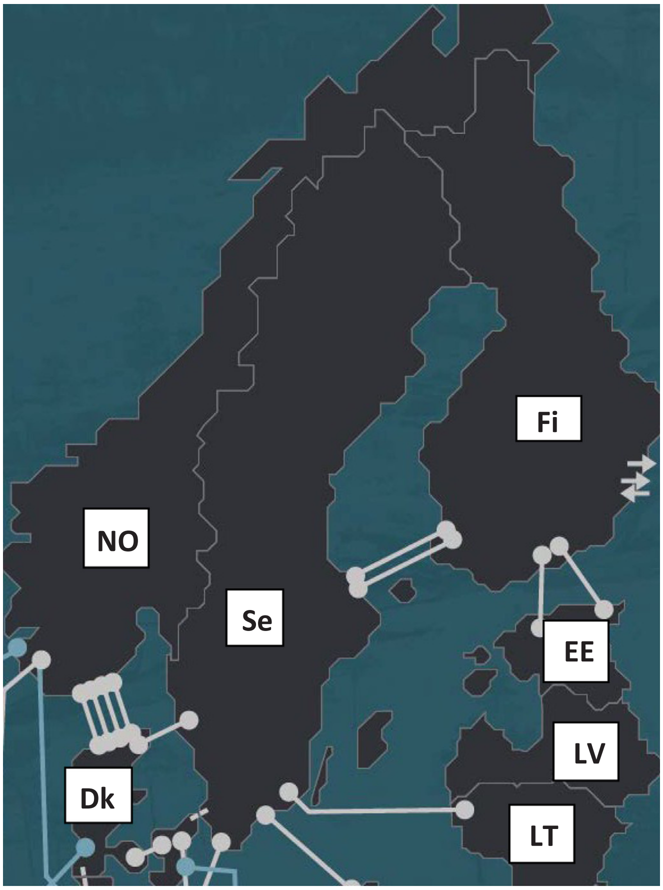

Fig. 1. Nordic power system with interconnections [6].

Fig. 1, with higher share of wind power replacing thermal production is presented in [7]. The estimation is based on a theory presented in [8]. It showed significantly higher LOLP values than today and it is stated that "possible solutions include more flexible demand". However, the key question here is the potential of flexible demand.

International Energy Agency (IEA) in its recent World Energy Outlook (2017) [9] highlights the importance of digitalization to provide better demand-side flexibility. IEA estimates that nearly 185 GW of demand-side flexibility could be reached cost effectively by 2040. IEA also recognizes the importance of demand-side response (DSR) as a source of flexibility for the integration of variable renewable electricity (WEO 2017). Globally IEA estimates a DSR potential of nearly 4000 TWh/yr, or 15% of total electricity demand. In [4] different approaches, technologies, and strategies to manage large-scale schemes of variable renewable electricity such as solar and wind power are reviewed. A specific focus in [4] was the potentials on the consumer side.

However, an important question is how large these potentials are. In general, large amounts of solar and wind power is mainly a challenge for the future, so flexible consumers are not realized to a large extent in current systems. This means that in order to design a rational future power system one has also to estimate the potential of consumer flexibility. This can be done for different consumer sectors, with different methods [10,11] and for different areas, e.g. [12–14]. Here, in this paper, the results for seven different countries will be summarized concerning available flexibility in different consumer sectors.

Our study focuses on seven countries in Northern Europe to review the potential of demand side response across the different energy use sectors to better understand which factors could contribute to this potential, but also to understand the magnitude of this potential for the energy transition to clean energy. Northern Europe as a case is interesting as this region has pioneered deregulation of the electricity markets in the 1990s and has a highly resilient common power market, and could also show the way on demand-side flexibility for managing large shares of variable renewable power. In addition to this, the ambitions for the future concerning renewable energy is significant. Denmark had in 2016 47% of its electric energy production from wind power, and Sweden had 40% of its yearly production from nuclear power, Table 1. But the Swedish parliament has decided: "goal in 2040 is 100% renewable electricity production" [18]. Demand Response is then seen as one of the possible solutions for an efficient way to keep the balance in the power system.

Table 1
Consumption and production during 2016 in TWh from different sources in the studied countries [2].

Source	Dk	EE	Fi	LT	LV	NO	Se	Tot
Nucl.	–	–	22,3	–	–	–	60,5	83
Fossil	10,8	9,0	13,4	1,1	2,9	3,1	3,3	44
Hydro	–	–	15,6	0,4	2,5	143	61,2	223
VRE	13,5	0,6	3,1	1,2	0,1	2,1	15,4	36
Bio	4,4	0,8	10,8	0,4	0,8	–	10,2	27
Prod:	28,7	10,4	66,0	4,0	6,3	149	152	416
Cons.	34,5	8,4	85,0	11,4	7,3	133	140	419

The main aim here is to study the possibility to reduce the peak in situations with high demand and lower amounts of solar and wind power. This means that the need for peak units, e.g. Open Cycle Gas Turbines (OCGT), can be reduced. These units normally use fossil fuels; so in this way the Demand Side Flexibility can reduce the CO_2 emissions. In Section 2 the different studies are presented. Section 3 summarizes the different results and Section 4 provides an analysis and comparison of different results. A summary and conclusions are presented in Section 5.

2. Performed studies for available flexibility

This study reviews available flexibility for Sweden, Denmark, Norway, Finland, Estonia, Latvia and Lithuania. The systems are of different size, c.f. Table 1, and there are different types of demands in the different countries, e.g. different amounts of electric heating and different types of industries. This has a significant impact on the flexibility. All areas have a winter peak, and comparatively low amount of air-conditioning. Below these studies will be shortly explained. All studies use the same set-up with the following nomenclature:

S: System data and Sectors for which the flexibility has been estimated including metrics of how the level is defined.

R: Results from the study

2.1. Sweden

S: Sweden currently gets around 40% of its power production from nuclear power. These power plants started in the period 1972–1986. During 2015 decisions were taken to close the 4 oldest stations constructed in the 1970s. In a political agreement from May 2016, Sweden will move to a 100% renewable power system. This then means that the amount of wind and solar power will significantly increase which has led to a discussion on consumer flexibility. The total Swedish energy consumption [19] was in 2015 136 TWh, divided into industry (50 TWh), households (40 TWh including 30 TWh for heating), service (36 TWh) and losses (10 TWh). The peak consumption in Sweden is around 27,000 MW.

R: The flexibility potential has been estimated in several reports for different sectors. The largest potentials in Sweden are in industry and electric heating. The results are summarized in Table 2.

2.1.1. Industry

This sector was divided into two subsectors:

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