clingendael international energy programme

briefing papers

Demand Reduction During Low Wind Periods

Why demand response has only limited potential to reduce the necessary long-term back-up capacity for wind power

Nora Méray

May 2012

The Clingendael paper "Wind and Gas: Back-up or Back-out, that is the question" (further referred to as the "Wind and Gas" study) has addressed the necessity of back-up generation capacity for wind energy and the effects of wind power on the Northwest European power generation mix in different market conditions. It concluded that installed wind capacity needs substantial additional back-up capacity in order to provide a sufficient amount of power generation capacity in times of low wind supply. The back-up capacity amounts to some 70-80% of installed wind capacity in Northwest Europe. In addition, the study showed that the efficiency of wind power to reduce CO_2 emissions is strongly affected by market conditions, especially by the CO_2 price.

Demand response is often mentioned as one of the means for reducing the necessary back-up capacity of wind power. This briefing paper examines in more detail demand response's potential to reduce the amount of fossil-fuel-based back-up capacity of wind. The aim of this briefing paper is to place some of the findings of other studies into perspective and in this way to contribute to the discussions around different Roadmap scenarios.

The conclusion of this paper is that demand response has the potential to reduce the *total* peak generation capacity, independent of the share of wind energy in the power generation mix. However, demand response only becomes a meaningful option to reduce long-term back-up capacity of wind power if demand can be consistently reduced over entire periods of low wind supply, which may last up to several days. It is most unlikely that this can be achieved. Therefore demand response will not significantly reduce the necessary long-term back-up capacity for wind power. At the same time, wind power introduces a higher volatility of the electricity price. As the literature study shows, a higher peak to off-peak electricity price ratio improves the economics of introducing demand response. Therefore in a power mix with a high share of wind power, more demand response can be expected, resulting in lower peak generation capacity.

Balancing reserve capacity and long-term back-up in power generation

Any kind of power generation technique needs a certain amount of back-up capacity, as no generation capacity in existence has 100% availability. The power generation mix has to have enough reserve capacity for periods of reduced power supply (planned or unplanned), both for short-term variations and for long periods of supply interruption. In this paper *short term* refers to a time period of up to one hour, while *long term* is a time period of more than one hour. Back-up capacity for the short term with the purpose of balancing the power system is referred to in this paper as *balancing reserve capacity*. Back-up capacity for periods of longer than one hour is referred to in this paper as *long-term back-up capacity*.

Effect of wind on the balancing reserve capacity and long-term back-up capacity

Balancing reserve capacity in a power system is needed in order to deal with short-term fluctuations between planned or expected and actual supply and demand. Without wind the balancing reserve capacity is generally in the order of 5% of the total power generation capacity. Wind has more short-term variability and uncertainty. Adding wind power to the fuel mix increases the necessary balancing reserve capacity: at a wind energy penetration level[1] of 10%, the short-term balancing reserves in the power grid will increase by about 1-4% of the installed wind power capacity. Doubling the wind penetration level leads to an increase of the necessary short-term balancing capacity by 4-8% of the installed wind capacity.

A different type of back-up capacity is necessary to provide a sufficient amount of power generation capacity for long periods (possibly up to several days) of low wind supply. In the “Wind and Gas” paper it was concluded that the necessary long-term back-up capacity of wind power would be approximately 70-80% of the installed wind capacity.

Balancing reserve capacity and back-up capacity can overlap slightly, although balancing instruments are usually not efficient means to offer backup support for more than a few hours. The balancing reserve capacity has to deal with the variability of supply or demand within one hour and therefore has to be able to start and stop quickly. These flexible peak generation capacities, like open cycle gas turbines (OCGT), usually have low energy efficiency and high variable costs compared to mid- and baseload power generation techniques[2]. Therefore, balancing reserve capacities are less efficient in providing back-up generation for long periods of low wind supply. While for short-term balancing capacity flexibility is essential, for long-term back-up capacity it is instead the cost that determines the best option for partnering wind energy. Therefore only a small part of the balancing reserve capacity of wind is suitable to contribute to the necessary 70-80% long-term back-up generation of wind[3].

[1] *Wind energy penetration level* refers to the percentage of the total annual electricity consumption (in kWh/ MWh) that is produced by wind.

[2] The efficiency of an open cycle gas turbine is around 35%, while a combined cycle gas turbine has an efficiency of around 60% (under ideal conditions).

[3] During off-peak periods, the short-term back-up capacity of wind can be provided by a pool of mid-merit generation capacity (like CCGT plants, instead of peak power generation), by simultaneously increasing or decreasing the output of several plants in small steps. In this way mid-merit power generation capacity can contribute to the short-term balancing of the power grid.

The impact of wind on the short-term balancing reserve was neither part of the "Wind and Gas" study nor part of this briefing paper and therefore will not be discussed further.

How often does wind need long-term back-up capacity?

As long as no alternatives —such as demand response, interconnection or electricity storages— are available, wind power does need a significant amount of fossil-fired long-term back-up generation capacity. The question of how often this back-up generation capacity will be called upon to produce electricity (i.e., the expected load factor of the back-up power plant), becomes relevant for determining the economic viability of new investments in back-up capacity.

Analysis of the wind supply for the combined area of Germany, Denmark and Ireland (representing Northwest Europe) for the period 2006 – 2010 shows that periods of low wind power supply (less than 10% of the maximum design capacity) regularly exceed 24 hours. Annually this happens on 30-40 occasions in this combined area (in total 1300 – 2200 hours per year). On average, in the summer the chance of there being low wind supply for more than 24 hours is higher than in the winter. However, extra long (> 48 hours) periods of low wind supply occur regularly even during winter (cold temperature, high pressure meteorological fronts), when electricity demand in Northwest Europe is high.

Wind power not only needs back-up capacity, but also "back-up volume". Onshore wind power in Northwest Europe produces around 2500 full load hours, offshore wind around 3500 hours. As the electricity demand in this region has a load factor of approximately 7000 hours, wind supply will have to be supplemented by another generation technique for 3500-4500 hours. In the "Wind and Gas" paper it was assumed that wind power supply will at any time be at or below market demand. Back-up generation capacity will need to meet the remainder of the 7000 hours of electricity demand (i.e., a back-up capacity with a load factor of 40 – 50%). This is a simplification which would work in the case of a relatively low penetration of wind energy. With a high contribution of wind energy in the fuel mix, power may become available when it is not needed[4].

Demand response as an alternative to fossil-fired back-up capacity

Without other alternatives, wind power would need about 70-80% of its nameplate capacity to be present in the (conventional) power generation mix in order to be able to offer reliable back-up capacity during calm periods. The three main alternative techniques that are considered in the literature to reduce the necessary back-up capacity (both short-term and long-term) of wind are:

- Demand response
- Electricity storage
- Interconnectors

In the "Wind and Gas" paper it was suggested that none of these options could offer significant reduction of the long-term back-up capacity for Northwest Europe. However, some have indicated that the effect of demand response was underestimated. Therefore, in this paper, the

[4]This excess power could then be stored and released later if large-scale electricity storage is available.

potential of demand response to reduce the necessary long-term back-up capacity of wind is examined in more detail.

Demand response

In the power grid, supply and demand must be constantly in balance. This balance can be obtained either by varying the electricity supply according to the demand, or by adjusting the power demand to reflect the supply. Currently electricity demand is highly inelastic, therefore the power grid is mainly balanced by continuously adjusting the output of the power generation plants, both for the short term and the long term.

Demand Response is a term used for programmes designed to encourage end users to bring energy demand in line with available supply on a cost-efficient basis. The power demand reacts either in response to a price signal from the electricity hourly market, or to a trigger initiated by the electricity grid operator[5]. There are two ways of changing the shape of a customer's energy load profile by dynamic pricing:

1. The first is by shifting the demand within a certain time period. In this form of demand response the total electricity demand will not change, but the peak demand is reduced. An often mentioned example is using household appliances (like dishwashers or washing machines) during off-peak periods.
2. The second is by conserving energy through behavioural changes triggered by electricity prices. In this case both the demand peak and the total demand is reduced. An example is temporarily accepting a lower comfort level (for example, turning off air conditioners during periods of high prices due to low power supply, without the appliance of "cold storages", and therefore accepting a temporarily increase of the ambiant air temperature).

The current inelasticity of demand is partly due to the fact that consumers are not incentivised to increase/decrease their electricity consumption according to the actual electricity costs of that moment. For the time being, the lack of wide-scale integration of smart meters and intelligent (smart) grids makes response to the demand for supply technically impossible.

The challenges to introduce demand response by means of dynamic pricing through smart grids on a large scale are expected to be solved in the future. Demand response is therefore an often mentioned option for decreasing the challenges of integrating wind energy.

For assessing the future potential impact of demand side management, two dimensions must be taken into account:

- the available demand *capacity* that can be shifted/reduced/increased (MW), and
- the *time scale* during which this capacity can be shifted/reduced/increased (hours).

The available flexible capacity (MW) and the time period (hours) during which this capacity can be reduced or shifted gives the total amount of flexible demand energy (MWh).

---

[5] http://www.energyadvantage.com/blog/2010/02/demand-response-demand-side-management-what%E2%80%99s-difference/

Demand response is generally expected to stimulate customers to use electricity more efficiently, and by doing so, to reduce the total cost of electricity. The focus of the following sections is on the available demand capacity that can be *decreased* or *shifted* for a period of longer than one hour, possibly days. Demand response potential for capacity that can be *increased* during high supply/low demand is not part of this paper, as it will not directly reduce the necessary long-term back-up capacity.

Demand Response – literature overview on its ability to reduce total power generation capacity requirement

Most existing demand response initiatives consist of interruptible programmes[6]. Demand that is contracted under interruptible conditions can be shut down for a certain period (depending on the contractual terms), contributing to the reduction of peak demand and in this way reducing the necessary short-term balancing reserve capacity of the power system. The advantage of interruptible contracts is that they do not require the introduction of smart grids and intelligent nets.

One example of interruptible demand is the bid system for reserve and regulation power of the Dutch TSO (Tennet). In this system, consumers (mostly large-scale industry) can bid to consume less electricity for a certain period for a certain compensation. In Italy interruptible programmes represent 6.5% of the peak power, again, mostly involving large-scale industrial consumers. In Denmark demand response for the residential sector was estimated to reduce the necessary peak generation capacity by about 6%[7], using the optimistic scenario that 50% of the households with electric heating would accept demand response. The total demand response potential of the Finnish industry has been estimated in another study[8] to be 9% of the total Finnish power demand peak.

Demand response in combination with smart grids has not been applied in practice on a large scale yet, therefore analysis of its technical and economic potential is usually based on extensive models. The Union for the Co-ordination of Transmission of Electricity (UECT) has analysed the potential of demand response per European country. The average potential of demand response to reduce peak load in Europe was 2.9%[9]. Capgemini[10] has estimated the total potentially avoided peak generation capacity by demand response to be around 28 GW - 72 GW by 2020 in Europe (EU-15). This is up to 6% of the expected production capacity requirement in 2020.

Other studies often concern one specific country. The German Energy Agency, Dena, has analysed the potential flexibility of the demand side in Germany[11]. In their reference case, "only" the household and industrial sectors were taken into account, with a total capacity requirement

---

[6] Torriti J. et al. "Demand Response Experience in Europe: Policies, programmes and implementation". Energy (2009), doi: 10.1016/j.energy.2009.05.021.
[7] Ea Energy Analysis: Analysis of Demand Response in Denmark (2006).
[8] VTT: Demand Response Activities in Finland (2006).
[9] Survey of regulatory and technical development concerning smart metering in the European Union electricity market (2008).
[10] Capgemini: Demand Response: A decisive breakthrough for Europe.
[11] Dena Grid Study II: Integration of Renewable Energy Sources in the German Power Supply System from 2015 – 2020 With an Outlook to 2025 (2010).

for these sectors of 60-70% of total peak demand capacity. An average *technical*[12] demand response potential of 35.3 GW reducible capacity was found for the household sector, while for the industrial sector the technical potential was 2.7 GW reducible capacity. Remarkably, when analysing the demand response potential that could be made accessible by 2020 in *economic* terms, only a very small amount of demand response potential will have opened up in the household sector (up to around 50 MW by 2020), while a large potential in the industrial sector will remain (around 2500 MW by 2020). This, in total slightly more than 2.5 GW reducible demand response potential, would result in a total reduction of the necessary peak power generation capacity in Germany by just 800 MW. A more optimistic scenario considering all sectors and significantly lower costs for the implementation of demand response (i.e., higher learning rates) resulted in a much higher demand response potential: by 2020 the total peak load and mid-load generation capacity could be reduced by 8.5 GW in Germany according to this sensitivity scenario. To put these numbers in perspective: by 2020 a total amount of 160 GW power generation capacity is expected to be in place in Germany, of which about 50 GW wind capacity.

In addition to theoretical studies, several pilot projects have been carried out to analyse the possible effects of demand response, mostly in the residential sector. Two economists of the Brattle Group analysed the results of 126 pricing experiments with dynamic pricing and time-of-use pricing of electricity[13]. The amount of peak generation capacity reduction due to demand response varied considerably in the different studies, but in general, the amount of demand response rose with the price ratio. The results showed that if the peak to off-peak price ratio were to get as high as 16, the peak reduction made by demand response would be slightly more than 20 percent[14]. To put these results in perspective: the current electricity price at APX-ENDEX of around €50/MWh would need to reach peaks as high as €800/MWh[15] before there would be an economic incentive to introduce demand response that is capable of reducing peak demand capacity by 20%. The potential of demand response to reduce generation capacity in pilot studies was thus higher than shown by the simulation studies. A possible explanation is that in pilot studies demand response is already a 'given', the economic decision to introduce it did not need to take place. The Dena study showed that the *technical* potential of demand response in the household sector was significantly higher than what became accessible on *economic* terms.

[12] In this paper *technical potential* refers to the amount of demand that can be reduced taking into account only practical constrains, without economic or social considerations. It is the upper limit of demand response potential.

[13] Faruqui A. & J. Palmer. "The Discovery of Price Responsiveness: A survey of experiments involving dynamic pricing of electricity". EDI Quarterly, *Volume 4, No. 1, April 2012.*

[14] If enabling technologies were present, a peak to off-peak ratio of 16 would be expected to result in a peak reduction of over 30 percent.

[15] Alternatively this ratio would be achieved if the electricity price dropped regularly to €3/MWh, which seems unrealistic in the light of the current and expected share of wind and solar power in the power mix and the current and expected fuel prices.

The conclusion based on the above studies is that demand response can reduce the necessary total *peak* generation capacity. However, a significant price differential is necessary before it is possible to reach a reasonable peak reduction effect, with high peak to off-peak electricity price ratios.

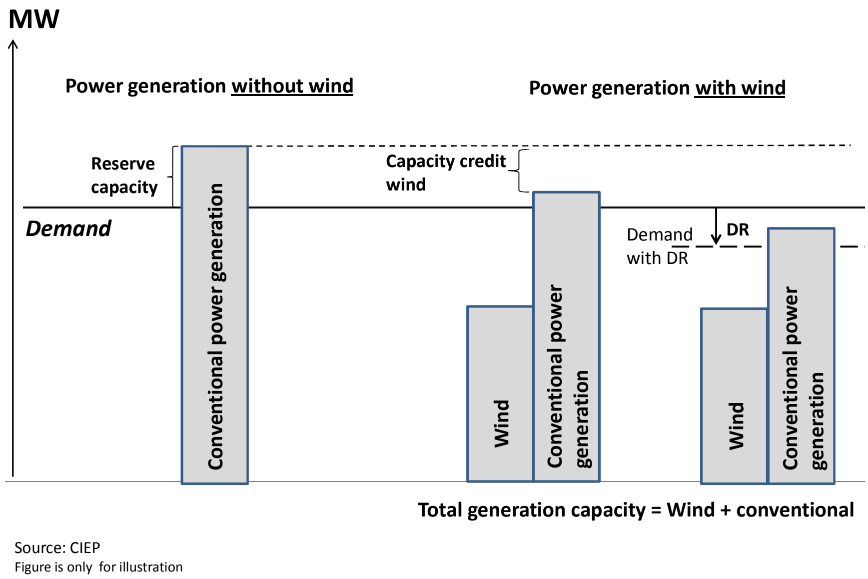

Figure 1: Illustration of the effect of demand response on the necessary total power generation capacity (here the capacity of wind is unchanged, based on the assumption that wind is the preferred generation source due to its zero-carbon emissions).

Demand Response – the future potential of electric vehicles

Shifting electricity demand by demand response for a time period can in fact also be seen as virtual means of electricity storage. One of the comments on the “Wind and Gas” study was that the effect of electric vehicles, as a potential future demand response technique to offer significant balancing potential for wind energy, was not taken into account. In general, in the case of a large-scale introduction of electric vehicles, their batteries could feed power into the grid during peak demand hours by charging at night, storing power in their batteries and feeding the stored power back during peak hours. Apart from the technical challenges that probably will be solved in the near future, and the societal challenge (financial incentives should be introduced to car owners to ‘offer’ the battery of their cars as back-up capacity during peak hours, instead of driving the car themselves), there is also a scale limit to using electric vehicles for balancing the electric grid. To obtain 5% peak demand capacity reduction on a European level, arounde 4-6 million electric cars would need to be available to feed the power grid during peak demand hours[16]. As it is not realistic to assume that all existing electric cars will be available to give power back to the grid during peak hours, significantly more than the 4-6 million electric cars would have to be present to gain the 5% peak generation capacity reduction. Electric cars could,

[16] Calculating with a battery of 24 kWh (Nissan Leaf) and a 1-hour charging time.

however, be of importance when dealing with periods of high wind and low demand by charging their batteries at off-peak periods, especially at night.

Demand Response – its ability to reduce the long term back-up capacity of wind

The above studies have shown that demand response can reduce demand for a short period and thus reduce the necessary peak generation capacity in the power system. This effect is true for a power mix with any kind of generation capacity, be it wind or conventional. However, as wind power introduces more short-term variability in the power supply, the benefits of demand response to reduce the short-term balancing reserve capacity is especially important for power systems with a large share of wind.

While there is a clear potential that demand peak capacity can be reduced by demand response, the time scale for which this demand can be reduced will determine the potential of demand response to reduce the necessary long-term back-up capacity of wind. Typically, demand response actions would be in the range of 1 to 4 hours. The German Research Center for Energy Economics (FfE) has analysed the demand response potential of the German industrial sector. The demand response potential was as high as 9 GW for a period of 5 minutes, decreasing to less than 2.5 GW for a period of 1 hour. Less than 1 GW of the German industrial power demand could be shifted during a period of 4 hours[17]. It is questionable how representative these results are for all power sectors for the total European market. However, it does show the importance of the time frame during which demand can be shifted.

From the above-mentioned study it would seem that power demand cannot be materially shifted or reduced for long periods, especially not for several days, as periods of low wind will sometimes be, as this would imply that a certain part of the demand can do without —or with less— electricity for possibly a number of days, which is an unlikely situation. Therefore, the question remains as to whether demand response can reduce the necessary *long-term* back-up capacity of wind and to what extent.

To analyse the potential of demand response to reduce the long-term back-up capacity of wind (for periods up to several days), we need to understand whether more demand can be reduced by demand response in a power system including wind energy than in a power system without wind energy. Wind power is more variable than conventional power generation and therefore would create a higher price differential, resulting in an increased volatility of electricity prices, particularly with a high wind capacity share in the energy mix. Adding wind power to an existing system would generate "negative" price peaks, because at moments of a large-scale availability of wind power, electricity prices would drop. An increased peak to off-peak electricity price ratio would, as the Faruqui&Palmer study[18] has shown, make the economic incentives to introduce demand response more attractive, resulting in there being a larger share of potentially economic technical demand response. More introduction of demand response would further reduce the *peak* demand capacity, but would not considerably reduce the long-term back-up capacity of wind for long periods (up to several days) of low wind supply.

---

[17] FfE: Demand Response in der Industry – Status un Potenziale in Deutschland.

[18] Faruqui A. & J. Palmer. "The Discovery of Price Responsiveness: A survey of experiments involving dynamic pricing of electricity". EDI Quarterly, Volume 4, No. 1, April 2012.

If the available power generation capacity in a system is not sufficient to meet demand during long periods with low wind supply (i.e. there is not enough long-term back-up capacity of wind power), electricity prices would be likely to rise significantly in these periods. Very high prices over such a period could lead to cutting back industrial production and to very high electricity bills for households. The economic and social effects of this type of power supply seems undesirable. Therefore, the working assumption for assessment of back-up capacity in the "Wind and Gas study" has been that the introduction of wind should not lead to shortages of power at any time.

Conclusions

Different studies show that demand response has the technical potential to reduce peak demand and thus the total peak generation capacity. What has been discussed to a lesser extent is the *time scale* during which demand can be reduced. The time scale during which demand can be reduced is an essential parameter in determining the potential of demand response to reduce the *long-term* back-up capacity of wind. Wind power introduces a higher volatility of the electricity price. As the literature study shows, a higher peak to off-peak electricity price ratio would improve the economics of introducing demand response. Therefore in a power mix with a high share of wind power, more demand response can be expected. However, demand cannot be reduced materially for long periods of up to several days, yet calm periods with low wind supply will sometimes be this long. Therefore we conclude that demand response will not significantly reduce the necessary *long-term* back-up capacity.