Improving Taxes, Electricity Markets and Framework Conditions to Help Integrate Wind Power

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Abstract: This paper discusses the need to develop a dynamic energy system and focuses on low cost options like development of market design and traditional technologies like electric boilers, heat pumps, and turbine by-pass. It is concluded that there is large potential in these areas – enough to balance the expected expansion of wind power for the next ten years.

I. Introduction

The integration of large scale wind power in the energy system is a huge challenge – not only for the electrical transmission and distribution system, but for the whole energy system.

The variable production from wind power combined with limited predictability in the time scale of the day-ahead market makes it relevant to study if new dynamic responses to variable power production can be introduced in all parts of the energy system. This paper describes different relevant technologies in the heat and power system that can increase the dynamic behaviour of the systems. Potential developments of relevant market systems are also analysed.

Large scale expansion with wind power challenges many procedures and routines in the electricity system and the energy market. The variable nature of wind power production requires a dynamic response from the rest of the electricity system. This study analyses how framework conditions can be improved to help integrate more wind power using Denmark as a full scale laboratory. Special focus is on how the framework can motivate to improve the dynamics of the energy system. The framework is described and analysed with respect to market design, such as the timeframe for allocation of transmission capacities, financial regulations in the tax system and technical options, such as heat production based on electricity.

The higher level of dynamic behaviour can be facilitated by the potential to communicate prices and power system requirements in real-time. Furthermore, the paper includes an evaluation of a temporal reduction of taxes paid for electricity used for heating purposes in Denmark.

II. Problem Outline

A. Wind power dynamics

The variability of wind power generation is a challenge. When wind power generation is high electricity production must be reduced elsewhere. At the same time export capacities are often used to their limits in order to balance the wind power. Interaction between Danish wind power generation and Norwegian and Swedish hydro power units acts as an efficient energy storage in order to address this challenge. This interaction takes place based on standard bids in the Nord Pool spot market.

Hours with zero prices in the spot market indicate too little dynamism in the market, since power plants and other generation units should stop generation when the electricity price is below the marginal production costs. Today, the zero-hours are quite rare and in 2008 28 hours in the Elspot area DK1 had zero-price, corresponding to 0.3 % of the hours in the year. In such hours traditional power generation is relatively high, as seen on table I.

TABLE I
ELECTRICITY GENERATION AND EXPORT DURING HOURS WITH ZERO-PRICE. AVERAGE FOR 28 HOURS, WESTERN DENMARK, 2008

	Relative to demand
Central power units	53%
Decentral CHP	21%
Wind Power	86%
Export	-61%
Total	100 %

Also, periods without wind power generation are a challenge for the energy system, because the power generation needs to be substituted by other power plants. Since wind power may reduce the generation from traditional plants thereby reducing their revenues, a development can be foreseen where more peaking power plants are needed in the Danish system.

In some situations wind power is difficult to predict and this makes e.g. the day-ahead market less suitable for wind power. It is often said in general terms that wind power is difficult to predict. However, as illustrated in Fig 1, the uncertainty of prediction is highly related to the level of expected wind. When high or low wind is expected the predictability is relatively good, while at medium expected wind speed the predictability is poor. This is an important observation, because the electricity system is scarcer of capacity in the situations with high or low wind power generation. In these situations import or export capacities are often used to its capacity limits.

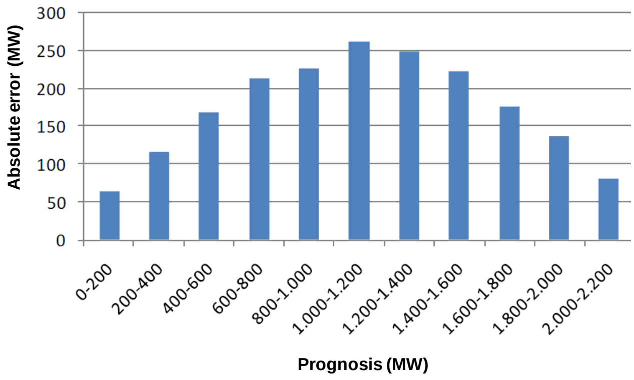

Fig. 1. Average absolute prognosis error as function as expected wind power generation. Data provided by Energinet.dk. Hourly data for Western Denmark, 2006. Prognosis is from the morning on the day before operating day.

To sum up, the challenges in connection with wind power are especially related to the difficulties involved with storing electricity. The challenges can briefly be grouped after:

- Unpredictability. Wind power is difficult to predict for at time horizon beyond 3-6 hours. This is expected to increase the need for regulation in the power system and poses challenges with respect to operation and markets.
- Changing production. Wind power takes operating hours from other electricity producers but when there is no wind there is still a need for alternative production.
- Large changes in the production. The need for dynamics in the power system increases.

B. *Lack of dynamic response in the energy system – taxes and tariffs as a barrier*

The electricity demand is to a large extent independent of the cost of providing electricity. Demand response can be demand that is adjusted according to hourly prices or it can be fuel switching, e.g. where electricity is used instead of fuel. This could introduce a valuable dynamic behaviour, but this potential is only utilised marginally in Denmark.

Taxes are hindering an efficient use of electricity for heating in Denmark. The energy tax system in Denmark is complicated with different levels of taxation for different end-uses. In general, households and the public sector pay a high tax (in the order of 100% of the energy price) – and this is also the case for energy used for comfort heating in all sectors. Energy used in trade and industry is generally taxed at much lower levels. This is still the case after the most recent energy tax reform in 2009, although a step has been take to increase the lowest taxes the most.

The high taxes can only partly be explained as an instrument to reach environmental goals and goals about increased security of supply. Instead, the high taxes are also an instrument to create tax revenue.

In general energy is taxed when buying the fuel. However, for electricity the tax is placed on electricity consumption to avoid a negative influence on the international competitiveness of electricity producers in terms of import and export of electricity. The taxation of electricity is in the order of three times the fuel tax, corresponding to the efficiency of a traditional fossil fuel based condensing power plant.

However, with large scale wind power in the system, the marginal power plant may occasionally not be a condensing power plant – but may be wind power. This can be the case in a situation with high winds and fully utilised transmission lines for export.

As shown in table II electricity cannot compete with natural gas – even when the spot price is zero. This is due to the taxes and tariffs. A spot price of zero indicates that all generation that can be stopped should stop. For central power plants start/stop costs may require several hours of negative prices before it is profitable to stop production, while the marginal production cost of wind power does not support electricity production when the value is zero. This problem illustrates that the influence of taxes and tariffs is distorting the use of energy. When the spot price is zero it would be better to use electricity for heating, if this would reduce consumption of e.g. oil or natural gas.

In order to enable the utilisation of electricity during zero price hours the tax on electricity used for heat in district heating system has been reduced in Denmark for a period of four years (2008-2011). In addition, exemption from the PSO-tariff (Public Service Obligation) is made for the test period.

There are only practical reasons behind the fact that the reduced taxes and tariffs can be applied to district heating systems only. It would be too costly to implement the general reduction for all electricity end-users.

TABLE II
EXAMPLES OF ENERGY COST. FOR ELECTRICITY IS SHOWN STANDARD TAXES AND TARIFFS AND AN ALTERNATIVE CORRESPONDING TO THE 4 YEARS TEST WITH REDUCED TAXES AND TARIFFS. FURTHERMORE AVERAGE (A) AND ZERO ELECTRICITY SPOT PRICES (Z) ARE SHOWN.

€/MWh	Spot price	Tariffs	Taxes	Total
Natural gas	23	13	23	72
Electricity (a)	40	36	74	150
Electricity (z)	0	36	74	110
Electricity Alternative (a)	40	17	24	82
Electricity Alternative (z)	0	17	24	42

III. STEPS THAT WILL INCREASE ENERGY SYSTEM DYNAMIC

Several decisions have already been taken, and these have or will increase the dynamics of the electricity system.

A. *Electric boilers*

In four district heating systems in Western Denmark investments in electric boilers have been made from 2005 to 2008. Today 54 MW are available as down regulation in the regulating power market. These investments have been motivated by the reservation price that could be obtained for down regulation. In January 2008 reservation prices peaked at more than 7,000 €/MW per month. However, recently the reservation price has collapsed, and currently no or a low reservation price is paid. In the first eight month of 2009 the average reservation price has been 140 €/MW per month.

The 54 MW are activated when the regulating power price is low, but the activation price depends also on the value of the heat produced. These units will reduce the hours with very low prices in the regulating power marked, but could also be activated in the spot market.

B. Negative spot prices

Negative prices have often occurred in the regulating power market and from October 2009 negative prices will also be possible in the spot market, which will motivate a higher dynamic response. This could motivate investment in turbine by-pass so electricity output can be reduced temporally from central coal plants.

C. Great Belt connection

In 2010 Western and Eastern Denmark will be connected directly with an electric transmission line for the first time. The 600 MW DC Great Belt cable will have significant impact on the integration of wind power and will e.g. reduce the amount of zero prices. Differences in wind power penetration in the two areas and access to more transmission lines to neighbouring countries will clearly impact the price formation.

D. Market integration Denmark – Germany

Also, better market integration between Denmark and Germany will help establish robust pricing. Market based integration with indirect auctions is announced to start in the third quarter of 2009. Without the indirect auctions the power flow is inaccurate with cases where electricity flows in the wrong direction, from high price areas to low price areas.

E. Upgrading Swedish transmission lines

Finally, the planned strengthening of the internal Swedish transmission lines will have a significant impact on the exchange of power between Denmark and Sweden. Today both import and export are often limited below the technical capacity of the lines on the national borders. This is expected to stop when upgrading of the Swedish transmission lines is completed in six years.

To sum up, a number of initiatives have been taken to develop the power system and the framework. These initiatives will help integrate more wind power in the Danish power system. However, more steps will need to be taken in order to cope with new wind power in the system. The analysed steps regarding technology are described in IV and proposed steps for changing the framework conditions are described in V.

IV. Technologies for Increased Dynamic Response of the Energy System

Several options are available for improving the technical dynamism of the energy system – both with existing and future technologies. The aim of the technology descriptions in this paper is not to prepare an extensive list of technological options, but to describe principal options, with a focus on existing technologies and the integration of the heat and power market. Sørensen, et al have developed a more extensive list of options [2], which forms the background for the following descriptions. The potential for the different options is described in terms of achievable up and down regulating power in the electricity system. Depending on the market design, the up- and down regulation abilities can be activated in the regulating power market or in the day-ahead market.

A. Integration of heat and power markets

An important measure to increase the dynamics of the energy system is to improve the integration of the heat and power market. As opposed to the power market, the heat market has a greater flexibility with respect to production patterns due to the presence of both heat storage systems and natural heat capacities in e.g. buildings.

In district heating systems, both heat pumps and electric boilers offer the possibility to react to both high and low electricity prices. However, their primary potential is different. Electric boilers offer relatively low investment cost, and can be used to replace heat production on e.g. natural gas boilers when the electricity price is low. Heat pumps on the other hand, have higher investment cost, and will therefore require more operational hours, in order to be profitable. As a consequence, heat pumps are more likely to offer up regulation power, by stopping heat production during hours with high electricity prices. Missing heat production can be substituted by e.g. natural gas fired boilers or heat storage during those hours.

In principal both electrical heating and heat pumps are also relevant for individual heating systems, and could also be utilized for improving the dynamics of the energy system. In this case both technologies would be used as the primary (and probably only) heat source, and therefore, individual heating systems are most relevant for up regulation in the power system.

B. Dynamics on central power stations

As shown in table I, central power stations produce a significant amount of power during hours with low electricity prices. This is partly due to technical restrictions on the plants themselves, but also due to power system requirements. The dynamic abilities of the power plants could be improved by introducing steam turbine bypasses, which offer the possibility to switch between combined heat and power production to heat production only. Thereby, fuel consumption can be reduced, while the necessary heat production can be maintained. At the same time there is no need to shut down the entire plant, which makes this process faster and eligible for improving the response of central power plants to low electricity prices. Furthermore, the option to switch the power plant to condensing mode, thereby increasing the electricity production, could be used on a more dynamic basis than it is today. Today, this option is used to optimize the operation of the central power plants in relation to the day-ahead market, but the usage of this option as regulating power can be improved.

Finally, the power system imposes requirements on the operation of central power due to frequency and voltage regulation. By improving the abilities of other parts of the power system to provide these ancillary services, the need for the operation of central power stations could be reduced. This could for example be achieved by demand as frequency controlled reserve which introduces the ability to respond to frequency changes to certain electrical appliances such as refrigerators [ref 8]. Voltage regulation can also be achieved by other technologies, such as Flexible AC Transmission Systems (FACTS).

C. *Other options*

Other options for increasing the dynamic abilities of the power system lie within the introduction of flexible demand, such as in electric cars [7]. On the production side a number of diesel based regulating power stations have recently been build in Denmark in order to support the electricity systems during the few hours with very high prices. Similarly, it is possible to use existing backup power systems at hospitals, computer centres and airports in order to support the electricity system [5-6]. Another option to use existing technologies, is to equip de-central combined heat and power stations with cooling towers, in order to enable electricity production independent of the actual heat demand. Finally transmission capacities to neighbouring countries have traditionally been utilized in order to balance the power system, and increasing transmission capacities will also help to ensure the flexibility of the power system in the future.

D. *Technology Potentials*

The potential for the different options described above has been estimated and quantized in terms of achievable up and down regulating power in the electricity system. Table III describes the potentials estimated in this paper. The mentioned potentials are meant to illustrate practical potentials, but will depend on the current operation status of the different technologies. Similarly, the investment costs shown can vary depending on the actual site. Especially for future investments, such as electric cars and large heat pumps, the estimates of the investment cost contain great uncertainties. For further descriptions on the technical potentials and economical differences, the reader is referred to appendix two in [1].

An important factor for the investment cost of the different technologies is whether the whole installation is carried out due to the power system. For some of the heating technologies this is not realistic, and therefore the shown cost for the individual heating technologies only include investment cost for control, communication and metering systems, and not the heat installation itself.

Apart from the investment cost, the operating cost, fuel prices and electricity prices have a great effect on the actual price of the regulating power. Therefore, the expected number of operating hours is an important factor when considering the different options.

It is not only a question of choosing the cheapest alternative for increasing the flexibility of the power system, but it is also important to use different technologies, in order to minimize the dependence on one specific solution, and in order to be able to react on different operating situations of the power system.

TABLE IIII

POTENTIALS FOR UP AND DOWN REGULATING POWER FOR DIFFERENT TECHNOLOGIES. THE POTENTIALS ARE ROUGH ESTIMATES IN ORDER TO ILLUSTRATE THE OPTIONS. THE INVESTMENT COST FOR THE INDIVIDUAL HEAT TECHNOLOGIES AND ELECTRIC CARS DO ONLY INCLUDE THE NECESSARY INVESTMENTS IN CONTROL AND COMMUNICATION SYSTEMS IN ORDER TO MAKE THE REGULATION SERVICE AVAILABLE TO THE POWER SYSTEM.

	Up regulation potential	Down regulation potential	Investment cost
Electric boilers for district heating	1,000	1,000	0.13
Heat pumps for district heating (prices for 2020)	286	286	2.09
Individual electric boilers	190	190	0.31
Individual heat pumps	170	170	0.28
Switch to condensing mode on central power plants	100-500		
Steam turbines bypass	>2,000		0.013
Cooling towers on decentral power stations	750		0.012
Electrical interconnectors			0.17-0.67
Regulating power stations (gas turbine)			0.36
Existing backup power	400		0.04
Electric cars	200	200	0.17
	MW	MW	Million €/$MW_{elec.}$

V. RECOMMENDATION FOR THE DEVELOPMENT OF THE FRAMEWORK CONDITIONS IN DENMARK

A. *A new regulating power market*

Increased dynamism can be achieved in many ways. One promising possibility is to redesign the market for regulating power. The current market system and the requirements are well-justified in relation to large and medium scale generation. However, demand and micro-generation could also potentially deliver regulating power. Demand and micro-generation can be controlled at very short notice and represents a valuable source for regulating power, e.g. demand such as electric heating, heat pumps and charging of electric vehicle can be stopped in fractions of a second. Also, the cost of such control can be low. Demand can be increased at a later time often without any discomfort for the end-user.

In [1-3] the following extension to the current regulating power market is suggested. The market that should attract new, small resources could be a price-only market, e.g. with broadcasting of prices each five-minutes. There should be no bids, no on-line measurement of demand and furthermore reaction should be voluntarily. The five-minutes price should be equal to the most costly regulating power that has been activated in the traditional marked. In practise this would be the spot price adjusted with an *adder* to reflect the need for up or down regulation.

Crucial for the success of such a design is the ability to predict the impact of the five-minute price based on historical data for demand. With thousands of participants it is expected to be possible to develop models that accurately can predict the impact – based on calendar information, temperature and the most recent prices. With each user having different preferences, different restrictions and different profile of electricity consumption, the overall impact is expected to be smooth and predictable.

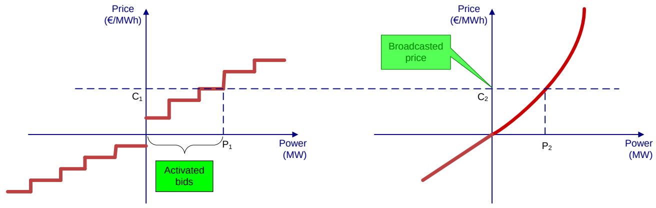

Fig. 2. The current market for regulating power (left) and the proposed additional market developed for electricity and micro-generation (right). The total activated regulating power is the sum of the two markets (P_1+P_2). The curve for the predicted impact from demand can be developed by the balance responsible based on historical demand.

B. *Dynamic taxes*

The use of dump loads in district heating was evaluated to improve the dynamic properties of the energy system. It has therefore been recommended to make the reduced taxes and tariffs for electricity used for heating in district heating permanent, which may lead to investment in more electric boilers. However, the reduced taxes in their current form encourage the usage of electricity not only during hours with very low prices, but also have an effect during hours with higher electricity prices. Therefore, it is also recommended to develop dynamic taxes that can be applied to all electricity use. In the long term there are no reasons to restrict electric heating to district heating systems. An electric boiler can be implemented in houses heated by oil and activated only when electricity prices are very low. From October 2009 negative prices can occur in the spot market, and this would increase the incentive for such an arrangement. 1.3 million Danish households have or will soon have an interval meter which is needed to implement dynamic taxes and tariffs.

C. *Dynamic tariffs*

The losses in the electricity system are in the order of 7% of the total consumption. Tariffs from the Transmission System Operator and the Distribution System Operators cover the costs of these losses. The tariffs used are all with a fixed value per kWh. Value of electricity is typically 40 €/MWh, but is in some hours 0 and in others more than 200 €/MWh. This dynamic is not shown in the tariffs. A simple improvement could be to require all users to pay 7% of their electricity consumption as a spot price.

A further development could be to introduce dynamic in the level of losses. The losses are heavily dependent of the flow in the network so a time-of-use tariff could be developed based on the expected flow. This could be announced the day before operating day.

In many other electricity markets losses in the transmission system are included in the day-ahead price. This is the case in system with nodal pricing, e.g. New Zealand and large US systems like New England, PJM and Northwest.

D. *Dynamic subsidies for renewable energy power production*

Often the subsidies for power production for renewable energy are given as a fixed feed-in-tariff. This can reduce the dynamics of the electricity system as the wind power or other renewable production will not have the motivation to stop the production when the electricity price is lower than the short run marginal costs of the production unit.

An example of dynamic subsidies can be found in the tender for the next Danish large off-shore wind park – the Anholt Park [4]. For this park subsidy is not paid for electricity if the price is zero or negative. When zero or negative prices occur the subsidy is set to zero but the subsidy period is extended with the same period. This is similar to the suggested tax system for electricity for all end-users.

VI. Conclusions

Integration of 20% wind power in the Danish electricity system is a success. Commercial transactions though Nord Pool create an efficient and dynamic integration e.g. between Danish wind power and Nordic hydro power.

However, during the next year an additional 800 MW wind power come online in the Danish electricity system and new measures are needed to maintain the good results.

This analysis indicates that there is a significant potential in well-known technologies related to improving the dynamic between the electricity system and the heating system, including both district heating and individual heating.

The use of these technologies can be motivated by developing a market design e.g. developing a regulating power market specially designed to attract new, small resources like demand and micro-generation.

In the coming 10 years solutions like energy storage (batteries, compressed energy storage and hydrogen) appear much too expensive compared to the technologies described here.

Acknowledgment

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